FINAL REPORT

Human Health and Environmental Risk Assessment

Orica Villawood

Prepared for

Orica Australia Pty Ltd

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Melbourne VIC 3001

9 February 2011

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Glossary of Terms

Absorption - The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.

Acceptable Daily Intake (ADI) - The amount of a chemical a person can be exposed to on a daily basis over an extended period of time (usually a lifetime) without suffering deleterious effects.

Acute exposure - Contact with a substance that occurs once or for only a short time (up to 14 days) [compare with intermediate duration exposure and chronic exposure].

Additive effect - A biologic response to exposure to multiple substances that equals the sum of responses of all the individual substances added together [compare with antagonistic effect and synergistic effect].

Adverse health effect - A change in body function or cell structure that might lead to disease or health problems

Antagonistic effect - A biologic response to exposure to multiple substances that is less than would be expected if the known effects of the individual substances were added together [compare with additive effect and synergistic effect].

ANZECC - Australia and New Zealand Environment and Conservation Council

Background level - An average or expected amount of a substance or material in a specific environment, or typical amounts of substances that occur naturally in an environment.

Biodegradation - Decomposition or breakdown of a substance through the action of micro-organisms (such as bacteria or fungi) or other natural physical processes (such as sunlight).

Body burden - The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.

Carcinogen - A substance that causes cancer.

Chemical of Potential Concern (COPC) – Chemical present in environmental media at a concentration sufficiently high or there is a sufficiently high degree of uncertainty to warrant further assessment in relation to risks.

Chronic exposure - Contact with a substance that occurs over a long time (more than 1 year) [compare with acute exposure and intermediate duration exposure]

Dermal contact - Contact with (touching) the skin [see route of exposure].

Detection limit - The lowest concentration of a chemical that can reliably be distinguished from a zero concentration.

Dose - The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An "exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.

Exposure - Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure could be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].

Exposure assessment - The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.

Exposure pathway - The route a substance takes from its source (where it began) to its end point (where it ends), and how people can come into contact with (or get exposed to) it. An exposure pathway has five parts: a source of contamination (such as chemical leakage into the subsurface); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching); and a receptor population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.

Groundwater - Water beneath the earth's surface in the spaces between soil particles and between rock surfaces [compare with surface water].

Guideline Value - Guideline value is a concentration in soil, sediment, water, biota, or air (established by relevant regulatory authorities, such as the DEC or institutions such as the NHMRC, ANZECC and WHO), that is used to identify conditions below which no adverse effects or nuisance or indirect health effects are expected. The derivation of a guideline value utilises relevant studies on animals or humans and relevant factors to account for inter- and intra-species variations and uncertainty factors. Separate guidelines may be identified for protection of human health and the environment. Depending on the source, guidelines will have different names such as investigation level, trigger value, ambient guideline, etc.

Hazard Index and Hazard Quotient – Hazard quotient is the ratio of daily chemical calculated for a specific receptor and exposure pathway, to the acceptable or safe dose (ADI, TDI, RfD, etc.) for that chemical. A value less than 1 indicates that the intake is less than the safe intake. A hazard index is the sum of the hazard quotients for all exposure pathways for a receptor.

Ingestion - The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way [see route of exposure].

Inhalation - The act of breathing. A hazardous substance can enter the body this way [see route of exposure].

Intermediate duration exposure - Contact with a substance that occurs for more than 14 days and less than a year [compare with acute exposure and chronic exposure].

Lowest-observed-adverse-effect level (LOAEL) - The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.

MRL – The Maximum Residue Limit (MRL) is the maximum residue concentration from the legal use of an agricultural or veterinary chemical that is recommended as the acceptable maximum concentration in a food.

Metabolism - The conversion or breakdown of a substance from one form to another by a living organism.

NHMRC - National Health and Medical Research Council.

No-observed-adverse-effect level (NOAEL) - The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.

Plume - A volume of a substance that moves from its source to places farther away from the source. Plumes can be described by the volume of air or water they occupy and the direction they move. For example, a plume can be a column of smoke from a chimney or the envelope of a contaminant moving with groundwater.

Point of exposure - The place where someone can come into contact with a substance present in the environment [see exposure pathway].

Population - A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).

Receptor population - People who could come into contact with hazardous substances [see exposure pathway].

Glossary of Terms

Reference dose (RfD) – Specifically refers to a toxicity value identified by the USEPA. The RfD is similar to an ADI or TDI and incorporates uncertainty or safety factors to identify a safe dose assuming daily lifetime exposure to a substance that is unlikely to cause harm in humans.

Reasonable Maximum Exposure (RME) - The RME represents an exposure scenario based on a set of exposure parameters that is representative of expected maximum exposure for that receptor and activity. The RME would not be expected to be exceeded except under highly specific and exceptional circumstances.

Reference concentration (RfC) - The concentration of a specific chemical in air to which a human population might be exposed to without appreciable risk to their health. RfC's are identified by the USEPA.

Risk - The probability that something will cause injury or harm.

Risk reduction - Actions that can decrease the likelihood that individuals, groups, or communities will experience disease or other health conditions.

Route of exposure - The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].

Surface water - Water on the surface of the earth, such as in lakes, rivers, streams, ponds, and springs [compare with groundwater].

Synergistic effect - A biologic response to multiple substances where one substance worsens the effect of another substance. The combined effect of the substances acting together is greater than the sum of the effects of the substances acting by themselves [see additive effect and antagonistic effect].

Tolerable Concentration (TC) - A TC (established by WHO) is an airborne concentration to which it is believed that a person can be exposed continuously over a lifetime without deleterious effects. The TC is based on non-carcinogenic effects and is usually calculated by applying uncertainty factors to a NOAEL or LOAEL. As such, the TC is similar to the USEPA reference concentration for inhalation exposures and ADI, TDI or RfD for oral exposures.

Tolerable Daily Intake (TDI) - The term tolerable daily intake (TDI) is used by the International Program on Chemical Safety (IPCS) to describe exposure limits of toxic chemicals and the term acceptable daily intake (ADI) is used by the World Health Organization (WHO) and other national and international health authorities and institutes.

Toxicological profile - An assessment that examines, summarizes, and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.

Toxicology - The study of the harmful effects of substances on humans or animals.

Uncertainty factor - Mathematical adjustments for reasons of safety when knowledge is incomplete. For example, factors used in the calculation of doses that are not harmful (adverse) to people. These factors are applied to the lowest-observed-adverse-effect-level (LOAEL) or the no-observed-adverse-effect-level (NOAEL) to derive a minimal risk level (MRL). Uncertainty factors are used to account for variations in people's sensitivity, for differences between animals and humans, and for differences between a LOAEL and a NOAEL. Scientists use uncertainty factors when they have some, but not all, the information from animal or human studies to decide whether an exposure will cause harm to people [also sometimes called a safety factor].

WHO – World Health Organisation

Executive Summary

URS Australia Pty Ltd (URS) has been engaged by Orica Australia Pty Ltd (Orica) to complete a Human Health and Environmental Risk Assessment (HHERA) for the Orica Site located at 2 Christina Road, Villawood NSW.

An HHERA has been undertaken to assess potential health risks associated with identified contaminants on site and off site in soils, groundwater and air. It is understood that on 29 July 2004, Orica notified the NSW EPA (now part of the Department of Environment and Climate Change and Water, DECCW) under section 60 of the *Contaminated Land Management Act 1997* ("CLM Act") that the site is contaminated in such a way as to present a potential significant risk of harm (SRoH) as defined by the CLM Act. The site was declared to be a remediation site on 22 April 2005 and the EPA issued a remediation order (RO) on 11 July 2005.

The human health risk assessment has been undertaken in accordance with guidelines established by the Commonwealth Government (enHealth and the National Environment Protection Council) which are recognised by the DECCW. The relevant toxicity data, exposure scenarios, exposure assumptions and models agreed with DECCW and NSW Health have been incorporated into this assessment. The risk assessment has used worse case exposure assumptions for workers on and off site.

The aims and objectives of the HHERA were:

- Provide a quantitative assessment of potential risks to human health associated with the presence of site related chemicals in soil and groundwater beneath the site and in off-site areas;
- Provide a qualitative assessment of potential risks to the environment associated with the presence of site-related chemicals in soils and groundwater, particularly within off-site areas; and
- Develop risk-based soil, groundwater and/or vapour concentrations that can be used at a screening level for further investigation or as remediation end-points (if required).

The risks associated with these exposures have been quantified using assumptions which relate to how people could be exposed (assumed to represent reasonable maximum exposure) and the data collected from the site that is representative of concentrations in air, soil and groundwater relevant to the assessment of human exposure. The assessment has focused on Impacted Soil Zones (ISZ) on the site and inferred groundwater plumes that are present on the site and extend downgradient beneath off-site areas.

Human Health

Human health risks are the combination of the toxicity or hazard of a chemical substance and the amount of exposure by people. The higher the exposure or dose the higher the risk. Under some circumstances where there is no exposure then there is no associated risk. The risks to human health have been calculated following methodology that is representative of best industry practice in accordance with both Australian and international guidance.

The risk assessment has identified the potential for soil contaminants to be present at sufficiently high concentrations in some areas of the Orica Villawood site (associated with ISZ 1a/1b, 4, 5, 7, 8, 9, and 10 [if the Pharmaceuticals Building is removed]) to present an unacceptable risk to human health under a commercial/industrial land use. The prime exposure pathways for concern are ingestion and dermal contact with soil.

Inhalation generally presents a minor contribution to the risk with the calculated risk associated with inhalation exposures less than the adopted target for all areas with the exception of ISZ 5 where the presence of 1,2,3-trichloropropane dominates the calculated risk. The presence of this chemical in this area requires further assessment.

Assessment of exposure to volatile chemicals of potential concern (COPC) via inhalation in areas located above groundwater plumes in areas on the site (where no source zones are present) and off site indicates risks to be low and essentially negligible. This assessment is based on measured data and further data should be collected to assist in the assessment of variability, particularly in off-site areas. Nevertheless, on the basis of the assessment of inhalation risks, risk-based vapour concentrations have not been derived.

Total petroleum hydrocarbons (TPH) were not identified as a COPC, however the characterisation of TPH has been limited to a small number of samples. Additional assessment of the nature of the TPH, which can be undertaken by reviewing relevant chromatograms, would be warranted to ensure that the COPC list adequately addresses health risks.

Environment

The environmental risks are assessed as being negligible given the commercial land use and the hydrogeological conditions. It is noted that contaminated perched groundwater is expected to be removed and surface water managed under the proposed remediation of the site to ensure contaminant discharge via surface water and buried stormwater lines does not occur. Consequently, risk-based groundwater concentrations that are based on the protection of the environment have not been derived.

Risk-Based Soil Concentrations (RBSC)

The RBSC have been calculated for ISZ on the site where risks were identified to be of concern and have been derived to be protective of human health under commercial/industrial land use. In addition Risk-Based Site-Wide Criteria (RBSWC) have been derived to assist in remediation of the larger site. The values are applicable only to the Orica Villawood site and have been developed assuming the mixture of COPC identified in each key ISZ identified. The RBSC may be used for the following purposes:

- Screening of data collected as part of ongoing investigations and delineation of areas of concern; and/or
- Remediation criteria for the site. However, the final selection of remediation criteria could be determined by issues other than risk to human health. In addition criteria relevant to scheduled chemicals, as outlined in the Scheduled Chemical Wastes Chemical Control Order 2004 (EPA NSW 2004) might need to be considered in the use of RBSC as remediation criteria. The scheduled chemicals are covered under the Stockholm Convention on Persistent Organic Pollutants and have been identified based on their persistence, tendency for bioaccumulation and toxicity. Also, concentrations may be varied to reflect different proportions of COPC in the event that non health-based criteria are used for selected COPC.

The RBSC have not considered leaching to groundwater, however, groundwater has not been identified as presenting unacceptable risks to human health or the environment, therefore there are no risk-based requirements to consider this further.

Risk-Based Groundwater Concentrations (RBSC)

Based on the available data and the assessment presented in this report there are currently no unacceptable risks to human health or the environment associated with the presence of impacted groundwater beneath existing (slab-on-grade construction) down-gradient off-site areas. However to assist in the evaluation of further monitoring data RBGCs have been calculated for impacted groundwater beneath existing off-site areas. The RBGCs have been derived for COPC identified in off-site groundwater and are based on the protection of human health, in particular exposures by long-term workers within existing (slab-on-grade construction) buildings and intrusive workers. The derived RBGCs are considered trigger levels, where exceedance of these levels should prompt the need to conduct further sampling (such as soil gas or indoor air) and assessment.

Section 1

Introduction

1.1 General

URS Australia Pty Ltd (URS) has been engaged by Orica Australia Pty Ltd (Orica) to complete a Human Health and Environmental Risk Assessment (HHERA) for the Orica Site located at 2 Christina Road, Villawood NSW (**Figure 1**).

The Orica Villawood site was initially part of a larger chemical complex owned by the Commonwealth of Australia and used for the manufacturing of munitions, including TNT, in 1941. The site was purchased by Taubmans Pty Limited in 1946, who manufactured a range of chemicals including chlorobenzene and DDT. The southern portion (the site) was purchased by ICIANZ Pty Limited (now Orica) in 1953. Orica continued to manufacture a wide range of agricultural and pharmaceutical chemicals on the site until the site was closed in 2000.

A number of investigations have been undertaken on the site (and surrounding areas) that indicate the presence of contamination in on-site soil and in groundwater beneath the site and off site to the south and south-southwest.

It is understood that on 29 July 2004, Orica notified the NSW EPA (now part of the Department of Environment and Climate Change and Water, DECCW) under section 60 of the *Contaminated Land Management Act 1997* (“CLM Act”) that the site is contaminated in such a way as to present a potential significant risk of harm (SRoH) as defined by the CLM Act. The site was declared to be a remediation site on 22 April 2005 and the EPA issued a remediation order (RO) on 11 July 2005. The RO specifically identified the following substances at the site:

- Total Petroleum Hydrocarbons (TPH);
- Benzene;
- DDT (and its degradation products DDD and DDE);
- 1,2-Dichloroethane (1,2-DCA);
- Trichloroethene (TCE);
- Chlorobenzene (MCB);
- 1,4-Dichlorobenzene (1,4-DCB);
- Hexachlorobenzene (HCB);
- Lindane (a-BHC);
- Polycyclic Aromatic Hydrocarbons (PAHs), including Benzo(a)pyrene; and
- Cyanide.

To assist in the completion of the HHERA, URS prepared the following document:

> Work Plan. Human Health and Environmental Risk Assessment, Orica Villawood Site. Prepared for Orica Australia Pty Ltd. Dated 14 June 2006. (referred to herein as the Work Plan).

The Work Plan has been reviewed and discussed with the then NSW Department of Environment and Conservation (DEC; now DECCW), NSW Health (Health) and the Site Auditor (Mr Chris Jewell). It is noted that the Work Plan provided a review of the available data in relation to on-site areas A to I. Since review of the Work Plan, site data and the assessment of risk on the site has been presented in relation to Impacted Soil Zones (ISZ) defined by HLA Envirosciences Pty Ltd (HLA 2006) (HLA is now AECOM Pty Ltd) to assist in the development of an appropriate Remediation Action Plan (RAP) for the site (being prepared by HLA). In general these ISZ relate to key soil source areas in each Area previously considered in the Work Plan; however there is some ISZ overlap with some of the Areas. Where relevant the location of ISZ presented in this report is described in relation to the Areas previously defined within the Work Plan.

1.2 Objectives and Scope

The overall objectives of the HHERA are to:

- Provide a quantitative assessment of potential risks to human health associated with the presence of site related chemicals in soil and groundwater beneath the site and in off-site areas;
- Provide a qualitative assessment of potential risks to the environment associated with the presence of site-related chemicals in soils and groundwater, particularly within off-site areas; and
- Develop risk-based soil, groundwater and/or vapour concentrations that can be used at a screening level for further investigation or as remediation end-points (if required).

It is not the purpose of the HHERA to present and discuss risk management activities; rather the HHERA aims to provide technical information and assessments to enable appropriate risk management decisions to be made.

1.3 Approach to Human Health Risk Assessment

The approach taken to the assessment of human health risks is generally in accordance with the protocols/ guidelines recommended by enHealth (Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards, June 2002). These guidelines draw on and are supplemented by those provided by ANZECC and NH&MRC and detailed in the documents:

- “The Health Risk Assessment and Management of Contaminated Sites” (CSMS 1991, 1993, 1996 and 1998 and enHealth 2002b);
- ANZECC/NH&MRC (1992); and
- The NEPM (Schedule B(4), Guideline on Health Risk Assessment Methodology, 1999).

ANZECC and NH&MRC currently provide only general guidance for the completion of these tasks and, as such, the more detailed protocols and guidelines developed by the US EPA (1989 and 2001) have been used to provide supplementary guidance.

In following this approach and in accordance with these types of risk assessments, the human health risk assessment presented is not an epidemiological study (which is a study of the distribution and causes of existing health related issues in the community), nor does this assessment provide a statistical analysis of the existing health status of the community. Rather, the assessment provides an evaluation of the potential impact of exposure to site related chemicals at the Orica Villawood site on risks to human health using guidance recommended and endorsed by Australian regulators in particular the DEC and NSW Health.

Human health risk assessment is divided into the following four prime tasks:

- Issue Identification/Data Evaluation
- Exposure Assessment
- Toxicity/Hazard Assessment
- Risk Characterisation.

The following diagram illustrates the key tasks required in the assessment of risk to human health.

HHRA Approach

Issue Identification - Data Evaluation

This involves a review of available data from the site and off site areas. The review aims to identify relevant concentrations that may be used to define potential exposure concentrations during activities relevant to the site and surrounding area and identifies chemicals of potential concern (COPC) and data gaps.

Exposure Assessment

This section identifies the human populations who could be exposed to the COPC associated with contamination identified for the Orica Villawood site, outlines the mechanisms (exposure pathways) by which these populations could be exposed and provides a quantitative estimate of reasonable maximum exposure and intake of the COPC. This follows the Work Plan presented to DEC and Health.

Hazard - Toxicity Assessment

This section identifies the most appropriate toxicity values for the COPC and intake pathways (such as ingestion or inhalation), which can be used to define and quantify potential hazards and associated risks to human health. This draws on the toxicity reviews and discussed with the DEC and NSW Health.

Risk Characterisation

Risk characterisation uses the toxicity values and quantitative estimates of chemical intake to provide a quantitative estimate of the potential health risks associated with exposure to the COPC.

The calculation of Risk-Based Soil Concentrations (RBSC) uses the quantitative health risk assessment to identify concentrations of individual COPC that meet defined risk targets.

1.4 Approach to Environmental Risk Assessment

There are currently no relevant Australian guidelines that are applicable to the completion of the environmental risk assessment for the site. The “Guideline on Ecological Risk Assessment” (NEPM, Schedule B(5), 1999) addresses only risks to terrestrial environments and has not been prepared to cover aquatic environments. The site is currently an industrial area and the proposed landuse will remain as commercial/industrial. Hence the focus of the environmental risk assessment should be on the off site environment, namely Byrnes Creek (and other concrete canals) located to the south, south-west and west of the site and associated ecosystems.

The environmental risk assessment (presented in **Section 8**) has been conducted as a qualitative assessment according to the following steps:

- Assessment of the potential for contaminant migration beyond the site boundaries and discharge into Byrnes Creek;
- Identification (where relevant) of ecologically sensitive receptors associated with Byrnes Creek; and
- Evaluation of the potential for contaminant migration to adversely affect the quality of the surrounding water and ecological systems.

1.5 Features of the Risk Assessment

As stated, the risk assessment has been carried out in accordance with international best practice and general principles and methodology accepted in Australia by groups such as ANZECC, NHMRC, NEPC and enHealth. However, there are certain features of risk assessment methodology that are fundamental to the assessment of the outputs and to drawing conclusions on the significance of the results. These are summarised below:

- The risk assessment is a mathematical procedure which addresses potential exposure pathways based on an understanding of the contamination status of the Orica Villawood site. The risk assessment is based on estimation of worst-case concentrations identified in relevant exposure media and hence is expected to overestimate the actual risks.
- Conclusions can only be drawn with respect to the contaminated media associated with the Orica Villawood site.
- The risk assessment does not present an evaluation of the health status of individuals who might be exposed to contaminants arising from the Orica Villawood site. Rather, it is a logical process of calculating the potential daily intake of chemicals associated with exposure to the Orica Villawood site contamination. This estimate is then compared to regulatory and published estimates of daily intakes that a person might be exposed to over a lifetime without unacceptable risks to their health.

The risk assessment reflects the current state of knowledge regarding the potential health effects of COPC identified at the Orica Villawood site. This knowledge base could change as more insight into biological processes is gained, further studies are undertaken and more detailed and critical review of information is conducted.

Section 2 Background

2.1 Previous Investigations

The HHERA has been prepared using data and assessments from the following sources:

- SHE Pacific Pty Limited (2000) Site Historic Review.
- URS (2001). Stage 1 Phase 2 Environmental Site Audit of the Orica Site Located at 2 Christina Road, Villawood NSW. 8 January 2001.
- CH2MHill (January 2004) Additional Stage 2 ESA.
- CH2MHill (2005a). Conceptual Site Model. Reference 32177, April 2005.
- CH2MHill (2005b). Preliminary Report (Draft Version) Voluntary Investigation - Part 1A – Groundwater and Soil. September 2005.
- HLA (2005). Phase 1 Remedial Investigation Orica Site, 2 Christina Road, Villawood. 22 December 2005.
- HLA (2006). Draft Phase 2 Remedial Investigation Orica Site, 2 Christina Road, Villawood, 7 July 2006.
- HLA (2007). Phase 3 Data Gap Investigation, 2 Christina Road, Villawood, NSW. 31 May 2007 (note soil data was not specifically included in this assessment as it was not available at the time of preparation).
- ENSR (2009). Remediation Action Plan Addendum, 2 Christina Road, Villawood, NSW. Final Draft, 27 April 2009.
- URS (2007) Soil Gas, Flux Emissions and Indoor Air Sampling, Orica Villawood, 30 August 2007.
- URS (2009) Additional Soil Gas and Indoor Ambient Air Sampling, 2 Christina Road, Villawood, Draft Report 21 May 2009.

The following presents a summary of key aspects of these reports that area relevant to the conduct of the HHERA. It is recommended that the above reports be read in conjunction with this assessment. These reports provide detailed evaluations of groundwater migration and the nature and extent of contamination. This detail has not been reproduced in this report. In this aspect the HHERA should not be viewed as a stand-alone report.

2.2 Description of Site and Surrounding Areas

The following description is summarised directly from information provided in URS (2001), CH2MHill (2004) and HLA (2005).

2.2.1 Site Identification

The Site is legally identified as Lot 1 on Deposited Plan (DP) 634604 at Leightonfield in the City of Bankstown, Parish of Liberty Plains and County of Cumberland.

2.2.2 Site Location

The Site is located at 2 Christina Road, Villawood and has a total area of 12.6 hectares (ha). **Figure 1** shows the Site location.

The Site is currently zoned Industrial 4(a) under the Bankstown City Council's Local Environmental Plan. It should be noted that under the description for this zoning includes child care centres and motels. For the purposes of this risk assessment these land uses have not been considered.

2.2.3 Site Layout

On the basis of previous manufacturing activities, the Site was divided into nine separate areas (Area A to I) to enable targeted investigations of each area. The site layout with Areas A to I is provided as **Figure 2**. Figure 1.2 included in **Appendix A** (Figures from HLA) presents these areas and includes the location of all former and existing site buildings. This figure (Figure 1.2 from HLA (2005)) indicates which buildings were present on the site at the time of preparation of this report.

2.2.4 Vegetation

CH2MHill (2005) notes that the majority of the Orica Villawood site is "*covered with former building foundation slabs, roadways and pavements.*" A portion of remnant bushland is located along the northern most section of the western boundary of Area B which is reported in CH2MHill (2005) as having been identified as a remnant stand of *"Cooks River/Castlereagh Iron Bark Forest, a community which is listed as 'endangered' by the NSW Threatened Species Conservation Act 1995."*

2.2.5 Surrounding Land Uses

Surrounding land use comprises commercial/industrial use. The Villawood Detention Centre is located approximately 500 m to the north-east of the site. The nearest residential areas are located more than 500 m to the east and west (beyond Woodville Road). There are no recreational areas within 500 m of the site. The following presents a summary of surrounding land use to the north, west, east and south of the site:

North

This area was originally part of the Commonwealth of Australia's Villawood Explosives factory and was later utilised as a formerly Taubmans paint and resins manufacturing facility.

Currently Barloworld (manufacture of paint) and Ansett Wridgeways (storage facility) are located to the north of the Site.

West

This area was part of the explosives factory but it is understood that it was not used for processing or storage. After World War II, it was occupied by Avery Scales (relatively heavy manufacturing).

Recently Plessey (manufacturer of electronic equipment) located to the west of the Site.

The Hui Hong building (picture framers and furniture manufacturers) is located directly to the west adjacent to the site (Area A **Figure 2**).

East

The land between the eastern boundary and Miller Road was open land until sold by ICIANZ in 1984. This area is currently owned by Macquarie Goodman and was previously occupied by Salmat (private mail centre) and is now occupied by P&N Beverages.

South

The Site boundary is Christina Road. Across the road are commercial/industrial areas with an open drainage channel and the Main Southern Railway located further south. The area south of the main railway line included the Leightonfield sidings.

2.2.6 Environmental Setting

Topography

The Site slopes gently towards Christina Road, with the majority of the Site covered by building slabs, roadways and pavements. An area of the Site to the north west is grassed and is believed to have been extensively filled in the past.

HLA Envirosciences (2005) reported that "*The highest natural elevation of the site at the north-east corner is approximately 36 m AHD and generally slopes towards the south-west corner of the site where the elevation is approximately 18.5 m AHD. The site has been progressively cleared and filled over the years and the highest relief at the site is the remnants of a blast mound (approximately 39 m AHD) located at the northern boundary of the site".*

Surface Water and Trade Waste

Historically all surface water runoff from the Site was collected in open earthen drains and discharged into an open surface water drain on the southern side of Christina Road. This practice ceased in 1990 when rainfall runoff from the Site was contained as 'clean' stormwater and potentially contaminated stormwater runoff from manufacturing areas was contained separately. Clean stormwater was managed by the use of a Site containment system using a first flush system with discharge to the south of the property and subsequent discharge into the Byrnes Creek concrete lined channel to the south. The open surface water drain on the southern side of Christina Road (Old No. 9 Branch Drain) has also been replaced with a buried concrete stormwater pipe in the same alignment.

Contaminated stormwater is treated on Site within the trade waste system. The Site trade waste system has always been separated from the stormwater and domestic sewage systems, with an extensive system of underground mains dating back to 1943. From the early 1980s, the Pharmaceutical plant and CropCare trade waste passed through a separate treatment plant in Area A. From 1991, CropCare trade waste passed through the effluent treatment plant in Area E, which was designed to remove any residual pesticide wastes. This system discharges via a separate sewer connection.

Surface water drainage is expected to be to Byrnes Creek which is located to the south of the rail line. Byrnes Creek is essentially a concrete lined drain and a tributary of Prospect Creek, which is located approximately 4.5 km downstream of the site. In the vicinity of the Site, Byrnes Creek receives stormwater discharge from several other open concrete lined drains including one located to the north of the Site and another located in the industrial area south of Christina Road. Byrnes Creek has no recreational or ecological value (refer to plates).

Geology

The Orica Villawood Site is located on the shales of the Mid-Triassic Wianamatta Group.

The soil and geological profile beneath the Site was observed to be as follows.

- **Residual Soil** comprising low to medium permeability clays resulting from weathering of the underlying shales. The clay is mottled orange/grey, moist with moderate to high plasticity. The depth of the residual soil varies across the Site and the clays might have been excavated in some areas during development and could be overlain with fill material in other areas;
- **Underlying bedrock** is characterised by shales with some sandstone lenses. The shales are identified as Shales of the Mid-Triassic Wianamatta Group. The shales are characterised by partings along bedding planes and fractures sets, which are oriented sub-vertically.

Off-site, clay material, that was identified south of the railway corridor, thickens significantly up to 6 metres. The clay material is likely to represent fine grained over bank alluvial deposits associated with the Byrnes Creek floodplain. Underlying the alluvial clay is Bringelly Shale.

Hydrogeology

The regional groundwater lies within the shale of the Mid-Triassic Wianamatta Group and is typically brackish and not used as a water resource. The regional groundwater flow is strongly influenced by catchment topography and surface water features. Groundwater flow in the upper Bringelly Shale is likely to be localised and discharge directly into Byrnes Creek and associated tributaries. Groundwater in the lower Ashfield Shale is likely to represent the broad regional groundwater flow system and discharge to Prospect Creek. The data collected and reviewed by ENSR (2009) indicates that the water table elevation reflects the regional and local topography and indicates that groundwater in the northern and western portion of the Site flows in a westerly direction. Groundwater from the southern and eastern portion of the Site generally flows in a south-westerly direction towards the Byrnes Creek concrete lined channel.

The groundwater depth beneath the site ranges from 2 m in the southern boundary and 10 m in the northern boundary (URS 2001) with the variation in the groundwater elevation at most locations is less than 1 m over the last 3 years (ENSR 2009).

Porosity within fractured groundwater aquifers are affected by the porosity of the rock mass (matrix porosity, expected to be heterogeneous) as well as the interconnected bedding plane partings and fractures (ENSR 2009). These porosities have been further considered within the assessment of groundwater and contaminant migration (ENSR 2009).

URS Australia (2001) accessed information from the Department of Land and Water Conservation (DLWC) for groundwater bores within 5 km of the Orica Site at Villawood. On the basis of this information, the closest bore identified as GW018740, and located approximately 3 km southwest of the Site, had a water bearing zone at 4.8 m and a standing water level at 1.5 m depth. The elevation of this well is similar to that of the Orica Site.

CH2MHill has reported the presence of a shallow water system present on site (0.3-2 m), however this is localised to areas of former building foundations and tanks (which have been removed). HLA also reported isolated seepage water in some test pits (HLA (2006)) *potentially from anthropogenic sources (i.e leaking water mains and or stormwater pipes*).

It is considered that the groundwater is not currently being used either on site or in the immediate vicinity of the site and it is not of a suitable quality for the extraction for drinking, irrigation or bathing. The regional groundwater in the Villawood area was reported by CH2MHill (2005) to lie within the shale sequences of the Bringelly Shale formation and is typically brackish to saline.

2.3 Site History

The following summary is taken directly from URS (2001).

The site history has been documented in the Site Historic Review (SHE Pacific, June 2000). A summary of the site history is documented below.

The site was formerly part of land acquired by the Commonwealth in 1941 for an explosives factory. This facility extended beyond current Site boundaries.

The Site was occupied by Taubmans Chemicals from late 1946 until June 1953, when occupancy was taken over by ICIANZ (Imperial Chemical Industries, Australia and New Zealand). Taubmans Chemicals manufactured a range of chemicals including monochlorobenzene and DDT.

During the occupancy by ICIANZ, a large portion of the Site was used for the formulation of agricultural chemicals rather than the synthesis of these chemicals.

In 1983 there was a fire in the former pharmaceutical plant with a new pharmaceutical plant constructed soon after.

In the late 1980s a Site containment system for stormwater including a first flush system was installed, which included the northern and southern reservoirs.

The property has been recently occupied by CropCare Australasia, located across the majority of the Site for the manufacture of agricultural and pool chemicals, and AstraZeneca located in the south western portion for the manufacture of pharmaceuticals.

The Site is currently closed, with all manufacturing and storage activities ceased by CropCare and AstraZeneca.

2.3.1 Areas of Potential Contamination from On-Site Activities

Areas of potential contamination have been assessed based on the Site Historic review (SHE Pacific, June 2000) and site inspections undertaken by URS personnel.

The areas of potential contamination have been identified as follows:

Area A

- *Presence of boiler ash, which possibly includes heavy metals and polycyclic aromatic hydrocarbons (PAHs);*
- *Effluent treatment plant; and*
- *Past activities by lease holders of the social club.*

Area B

- *Former empty drum storage area;*
- *Former equipment graveyard; and*
- *Presence of demolition waste as fill material.*

Area C

- *Storage area for empty drums in the northern area of the Pharmaceutical Store, which was observed in a brief aerial photograph review by URS Australia;*
- *Storage of chemicals at the Flammable Drum Store; and*
- *The potential for contamination from the Pharmaceutical Plant is minimal on the basis of Good Manufacturing practices (GMP) in this part of the Site.*

Area D

- *Chemicals stored in the Pharmaceutical Research and Development building;*
- *Location of the former Pharmaceutical Plant which was destroyed by fire;*
- *Chemicals stored in the CropCare Laboratory building;*
- *Interceptor pit on the eastern perimeter of the laboratory building, where wastes may have been discharged in the past; and*
- *An area between the Main Laboratory and Accounts Building, where grass has not grown and may have been used for waste disposal in the past*[1]*.*

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[1] Current observations at the site suggest grass cover has been observed to be good in this area.

Area E

- *CropCare Finished Goods warehouse where insecticide dusts were formulated in an old pan mill. DDT was handled in this building.*
- *Swampy area, west of the effluent treatment plant, where empty drums were stored;*
- *At the Effluent Treatment Plant, which removed pesticides;*
- *Store R14, which was used for the storage of flammable finished goods; and*
- *Laboratory Retention Store, where old samples were stored.*

Area F

- *Tetramisole plant where 1,2-dichloroethane (EDC) and ethylene imine were used. Other potentially contaminating chemicals used in this building included acetone, methanol, toluene, monoethanolamine, diol, thionyl chloride, tars, dimethyl amino pyridine and thiourea;*
- *Packaging Store (Building No. 308) where ethylene imine was handled.*
- *Tank farm where bulk chemicals were stored;*
- *Old dust laboratory store which was destroyed by fire;*
- *Effluent holding tank pit (also referred to as 'Black Tank'), which had possible EDC leaks;*
- *Engineering Huts on the northern boundary of Area F;*
- *Compressor house where diesel and oils would have been used. It is also reported that ethanol was used in the Compressor House;*
- *The scrubber, where acids and alkalis were used;*
- *The alkyl ketone building, where recovered ethanol that included tralkoxydim and tars were handled;*
- *Stripping plant which may have had possible leaks; and*
- *Store No. 30 (Store 315) also known as Boiler House, had the potential for contamination from water treatment chemicals, diesel and oils.*

Area G

- *CropCare No. 20, formerly known as the Waste Store which until recently had an earthen floor. Chemical odours have been observed from this building;*
- *Trade waste pit, which fed effluent to the treatment plant;*
- *Plant No.1 where trinitrotoluene (TNT) was manufactured and chemicals such as mononitrotoluene, acetic acid, PP321 (pyrethroids) and solvents were formulated;*
- *Bulk Touchdown area where chemicals were stored in tank, including cobalt and selenium based chemicals;*
- *Herbicide Plant No. 2, where solvents, simazine, urea, toluene, 2,4,5-T Butyl ester, 2,4-D (2,4-dichlorophenoxy acetic acid), cypermethrin, diquat dibromide, ethylene glycol, dimethylamine, cyclohexanone, n-butanol, octanol, n-methyl-2-pyrrolidone, vapam (herbicide), chloropropham (carbamate), pendimethylin (herbicide), bensulide (herbicide), monosodium methylarsenate, trifluralin and vernam (thiocarbamate) were handled;*
- *Tank Farm No.1 where weed killers were stored;*

- *Tank Farm No.2 where xylene, toluene, and solvesso were stored;*
- *Plant No.3 where cypermethrins, orchex 796 (thiocarbamates), herbicides and cotoran (urea) were handled;*
- *Scrubber area where caustic soda, sodium hypochlorite and phosphoric acid were used;*
- *Store No. 305 where Tandone (carbamate), simazine, and atrazine were used;*
- *Plant No. 4 formerly known as the Sorbies Plant, Chlorea Plant and Store No.305A which was used for the manufacture of herbicides;*
- *Bipyridyl tank farm where diquat dibromide and paraquat dichloride were stored;*
- *Filled area to the west of Store No. 17;*
- *Flammable Liquids Store No. 17 (formerly known as Store No. 279);*
- *Substation which has the potential to have contained transformer oils including PCBs;*
- *Bunded above ground diesel tank;*
- *Former Cobex Plant in the area of the above ground storage tank (AST). Chemicals such as dinitriamine, methyl iso amyl ketone, styrene monomer, atlac 382 N,N dimethyl amine, styrene, cobalt naphthalene and hydrocarbons were used; and*
- *Pilot laboratory where many different types of chemicals were used.*

Area H

- *Packaging Store No. 5 (formerly known as Store No. 205) which was used for the filling of insecticides and fungicides. Chemicals such as formaldehyde, malathion, lindane, imidan, hexachloroethane, EDC, ethylene dibromide, phenyl mercuric chloride, 2-phenylbenzimidazole, phenyl mercuric acetate, carbaryl, chloroform, diphenylamine, dieldrin, diazinon, cyhexatin and DDT were used;*
- *Buried malathion tank in the north eastern corner;*
- *Store No. 11 (formerly known as Flammable Solids Store No. 296) where weed killers were mixed on the floor;*
- *Scrubber where sodium hydroxide and sodium hypochlorite were used;*
- *Drum Store No. 7 (formerly known as Store 327) where ethanol and solvents were stored;*
- *Drum Store No. 8 (formerly known as T29) where ethanol and solvents were stored;*
- *Drum Store No. 9 (formerly known as Store 312) where chemicals such as triethanolamine, propylene glycol, thionly [sic]chloride, trifluarlin, DDT, diazinon, dinitriamine, cypermethrin, carbon tetrachloride, chloroform, paraquat dichloride, methylene chloride, monoethanolamine, perchloroethylene, permethrin, formothion, endosulfan, epichlorohydrin, ethylene glycol, malathion, hexylene glycol, and tetramisole salt were stored;*
- *Substation No. 2 which may have included polychlorinated biphenyls (PCBs) containing transformer oils;*
- *Plant No. 5 (formerly known as DPG Plant 311), which was the insecticide and fungicidal manufacture and filling plant. Chemicals such as diesel distillate, ethanol, n-butanol, isopropanol, butyl cellosolve (a hydrocarbon), propachlor (chloroacetanilide), Piromophos-methyl (insecticide), hexaconazole, dicofol (organochlorine (acaricide)), Tetradifon (organochlorine (acaricide)), methylene chloride, permethrin 25:75, Amitraz (Amidine (acaricide)), paraformaldehyde (Fungicide*

(acaracide)), Mancozeb (Dithiocarbamate), pirimophos ethyl, phenol, propachlor, octanol, propylene glycol, monochloroxylenol, malathion, methanol, methyl ethyl ketone, methylated spirits, permethrin, perchloroethylene, p-chloro-m-xylenol, toluene, xylene, triethanolamine, Shellsol 1687, solvents, diazinon, chloroform, dieldrin, dimethylformamide, diphenylamine, DDT, atrazine, bioresmethrin, carbon tetrachloride, EDC, acetone, acetic acid, cypermethrin, formaldehyde, hexachloroethane, kerosene, ethanol, epichlorohydrin, endrin, endosulfan, and ethylene dibromide were stored;

- *Lime Sulphur pit; and*
- *Sydney Williamson Hut, where weedkillers were used.*

Area I

- *Store No. 233 was the original mononitrotoluene plant and was later used for animal remedies filling and the manufacture of sheep dip. Chemicals such as TNT, mononitrotoluene, OCPs, chloral, propyl hydroxy benzoate, monochlorobenzene, methyl hydroxy benzoate, edicol tatrazine, toluene and DDT were used.*
- *Store No. 234 building was used to isolate DDT and was later used for the formulation of insecticides and fungicides. Chemicals such as n-butanol, trichlorofon, chloral, isopropanol, methanol, methyl hydroxy benzoate, Imidan, hexachloroethane, solvents, mononitrotoluene, methylated spirits, monomchloroxtlenol, chlorofenzon, malathion, dimethoate (OPP), n-methyl-2-pyrolidone, lindane, kerosene, methyl ethyl ketone, perchloroethylene, p-chloro-m-xylenol, solvents, formothion, propylene glycol, sodium benzoate, diazinon, DDT, cyclohexanone, cresylic acid, dieldrin, carbon tetrachloride, acetic acid, chloroform, ethanol, formaldehyde, ethylene glycol, ethylene dichloride, paraformaldehyde, epichlorohydrin, endrin, endosulfan, diphenylamine, tetramisole, ethylene dibromide, tolune, xylene, trichlorofon were used;*
- *Monochlorobenzene underground storage tank;*
- *Floor washings from monochlorobenzene production;*
- *Former Levamisole plant where toluene was used;*
- *Former tank farm where toluene, xylene, kerosene, methylated spirits, benzene, solvents, mineral oil, chloroform, endosulfan, ethanol, malathion were stored;*
- *Equipment washdown area, which recently included two 44 gallon petrol drums;*
- *Igloo Workshop where lubricating oils, oil, transformer oils (potentially containing PCBs), methylated spirits and diesel were used;*
- *Garage where cleaning solvents, lubricating oils and diesel distillate were used;*
- *Electrical Workshop where instrument liquids (potentially contain mercury) were handled;*
- *Cooling tower, where water treatment chemicals were handled;*
- *Two USTs, one located north west of the workshop and one south of the workshop; and*
- *HV substation No. 9, which has the potential to have oil contamination.*

Section 3 Issue Identification and Data Evaluation

3.1 General

As listed in **Section 2**, a number of studies have been undertaken on and surrounding the Orica Villawood site. The following sections present a review of available data for media relevant to the HHERA. Data is currently available for soil, groundwater and vapours (soil gas, surface flux emissions and ambient). The prime objective of the review of available data is to identify chemicals that warrant further quantification as part of the health risk assessment i.e. chemicals of potential concern.

Chemicals of potential concern (COPC) are those chemicals, which are known or suspected to be present at concentrations high enough to warrant inclusion in the assessment of risks to human health or the environment, or to pose a nuisance (eg. odours). The prime objective of identifying COPC is to focus the risk assessment on assessing chemicals that have the potential to significantly contribute to risks to human health.

3.2 Conceptual Model

Impacts have been identified in soil and groundwater beneath the site. Impacted groundwater has also been identified beneath off site areas down-gradient (south and south-southwest) of the site.

A detailed Conceptual Site Model (CSM) that addresses the nature and extent of contamination, mechanism for migration off-site and potential for further migration and discharge to Byrnes Creek is presented in the AECOM Addendum to the Remediation Action Plan (2009). The following presents a summary of the key aspects of the CSM, in particular issues that are of concern with respect to the potential for exposure:

- The geology on-site and off-site comprises fill materials, residual clay on-site, alluvial clay off-site and basal Bringelly Shale. This material is considered to be relatively impermeable;
- That the contamination is likely to be distributed in the clay (shallow) and in the deep shale matrix;
- Contamination has been identified in soil materials on the site due to historical operations at the site. Based on the available information, the most significant soil impacts have been identified as Impacted Soil Zones (ISZs) which are located across the Site and characterised by a range of contaminants consistent with historical operations in different areas of the Site;
- DNAPL has been identified on Site adjacent to former storage tanks and infrastructure. In addition, DNAPL was likely to have migrated off-site via former open surface water drains on the southern side of Christina Road, particularly near MWOS10 as indicated by the high concentrations of dissolved phase contamination. Geometry of the groundwater plumes, flow direction and groundwater modelling suggests rapid migration via surface flow in a southwest direction on site then a more westerly direction off site, aligning with the former No. 9 branch drain (refer to Figures F2 and F3 in **Appendix A**). Rapid migration in the subsurface through unidentified preferential pathways (e.g. fractures, bedding planes, etc) is not supported by the available data;
- Shallow vertical ingress of contamination is the predominant migration pathway, with deeper DNAPL migration controlled by vertical fractures and lateral diffusion into the bedrock matrix;
- Historically five dissolved phase groundwater plumes have been identified and delineated. Three plumes extend off-site. The distribution of plumes 1 and 2 was predominantly formed by the flow of dissolved and separate-phase source material over the surface of the land in drains and swales, followed by downward migration from the drains' bases into the underlying clay and weathered shale matrix. Plume 3 has migrated from the former Effluent Treatment Plant area (refer to Figure F35 in **Appendix A**). Off-site monitoring points within and south of Christina Road indicate no contamination has reached the Byrnes Creek concrete lined channel and the groundwater plumes are stable; and

- Contaminant transport modelling (Laase 2007) supports the observation that the groundwater contaminant plumes are stable due to matrix diffusion and to some extent biodegradation. Hence, even though groundwater could reach the Byrnes Creek concrete lined channel, the contaminants will not.

The following sections provide a review of available data with respect to the ISZs, groundwater plumes and vapour emissions on and off the site.

3.3 Soil

3.3.1 Chemicals of Potential Concern – On-Site

Exposure pathways associated with the presence of contamination in soil (refer to **Section 5**) include incidental ingestion and dermal contact as well as inhalation of vapours associated with volatile contaminants. HLA Figure 3.1 is located in **Appendix A** which presents an indication of the potential extent of soil contamination present on site. The available data indicates soil impacts are limited to on-site areas and as such the assessment of soil impacts has focused on on-site areas only.

Table 3-1 presents a listing of the maximum concentrations reported from previous investigations (2000 to 2006) undertaken and listed in **Section 2.1**. The maximum concentrations of chemicals reported on the site from data collected from 2000 to 2006 have been screened against the following guidelines to identify chemicals of potential concern for evaluation in the HHERA:

- **National Environment Protection Measure (NEPM),** Assessment of Site Contamination, 1999, Schedule B1, Health Based Soil Investigation Levels, Level F - Industrial Sites (Table 5A); and

- **NSW EPA Guidelines for Assessing Service Station Sites**, 1994, Table 3 - Human Health Levels for BTEX and TPH compounds in soils (no HILs defined in NEPM, 1999).

Where guidelines are not available from the above sources for specific chemicals, screening levels have been obtained from the following sources. These sources are from the United States and while not recognised in Australia, the values provide a screening level for a wide range of chemicals in soils for the purpose of identifying COPC:

- **USEPA Regional Screening Levels (RSL), 2008**. The USEPA RSLs, which replace the Region IX Preliminary Remediation Goals (PRGs), Region VI Screening Levels and Region III Risk Based Concentrations (RBC), present risk-based values for soil (residential and industrial use), tap water and air (residential and industrial exposure). The values presented for industrial soil (considering exposure via ingestion, dermal contact, inhalation of particulates and inhalation of volatiles, based on target risk levels of 10^{-6} for carcinogenic effects and 1 for non-carcinogenic effects) have been considered within this assessment. It is noted that the list of chemicals presented in the RSLs tables is not as comprehensive as previously provided by the US Region IX PRGs. Hence where no guideline is available from the RSLs, the previously derived US Region IX PRG (2004) has been adopted.

For some individual polynuclear aromatic hydrocarbon (PAH) compounds, no guidelines are available and hence soil screening levels have been adopted on the basis of considering other PAH compounds as surrogates. The surrogate compounds have been selected based on consideration of toxicity equivalent factors (TEFs) discussed and presented by Fitzgerald (1998). These are noted in **Table 3-1** where considered. Some other chemicals also have no data available and hence surrogate compounds have also been identified based on the similarity of the compounds and likelihood that the surrogate selected is more toxic than the chemical for which no data is available.

It is noted that the adopted screening levels are relevant for commercial/industrial use of the site, consistent with the current and expected land use of the site. In addition there are no sensitive environmental receptors identified on the site and hence the selection of the screening levels has focused on the protection of human health.

Only chemicals detected above the laboratory limit of reporting (LOR) in at least one sample have been included in **Table 3-1**. The concentrations presented in the table reflect maximum concentrations reported in soil regardless of location or depth.

Table 3-1 Review of Soil Data and Identification of Chemicals of Potential Concern

Chemicals Detected in Soils	Maximum Concentration Reported (mg/kg)	Screening Criteria (mg/kg)	Reference and notes
3,3-dichlorobenzidine	0.6	3.8	RSL
dibenzofuran	4.4	1563	Region IX PRG
carbazole	7.2	86	Region IX PRG
1,2,4-trichlorobenzene	158	400	RSL
1,2,3-trichlorobenzene	19	400 (S)	No data available, adopt data for 1,2,4-trichlorobenzene as surrogate
1,2-dichlorobenzene	41.9	10000	RSL
1,3-dichlorobenzene	18.7	10000 (S)	No data available, adopt data for 1,2-dichlorobenzene as surrogate
1,4-dichlorobenzene	165	13	RSL
pentachlorobenzene	12	490	RSL
1,2,3-trichloropropane	0.5	0.41	RSL
bis(2-chloroethyl)ether	0.7	0.9	RSL
dichloromethane (methylene chloride)	0.5	54	RSL
1,1,2-trichloroethane	9.2	5.5	RSL
1,1-dichloroethane	0.861	17	RSL
1,1-dichloroethene	2.725	1100	RSL
1,2-dichloroethane (EDC)	860.13	2.2	RSL
cis-1,2-dichloroethene	99.5	10000	RSL
trans-1,2-dichloroethene	1	500	RSL
trichloroethene (TCE)	385	14	RSL
tetrachloroethene (PCE)	608	2.7	RSL
chlorobenzene	3040	1500	RSL
vinyl chloride	823.91	1.7	RSL
carbon tetrachloride	5.8	1.3	RSL
4-chlorotoluene (p-chlorotoluene)	0.6	72000	RSL
chloroform	77	1.5	RSL
1,2,4-trimethylbenzene	101	280	RSL
1,3,5-trimethylbenzene	38	200	RSL
benzene	21.4	1	NSW Service Station Guidelines
toluene	177	130	NSW Service Station Guidelines
ethylbenzene	127	50	NSW Service Station Guidelines
m- & p-xylene	354	25	NSW Service Station Guidelines for total xylenes
o-xylene	241		
isopropylbenzene (cumene)	13.9	11000	RSL
n-butylbenzene	3.6	240	Region IX PRG
n-propylbenzene	23.4	240	Region IX PRG
p-isopropyltoluene (p-cymene)	2.5	11000 (S)	No data available – adopt data for isopropylbenzene as surrogate
styrene	1.2	38000	RSL
sec-butylbenzene	1.4	220	Region IX PRG
tert-butylbenzene	0.9	390	Region IX PRG
acetophenone	0.6	100000	RSL
N-nitrosodiphenyl & diphenylamine	250	350	RSL
α-BHC (α-HCH)	17400	0.27	RSL
aldrin	6.13	50	NEPM HIL for Aldrin + Dieldrin
dieldrin	562	50	NEPM HIL for Aldrin + Dieldrin
β & γ-BHC	806	0.96	RSL
β-BHC (β-HCH)	14200	0.96	RSL
δ-BHC (δ-HCH)	899	0.96 (S)	No data for δ-BHC, use value for technical BHC from RSLs as surrogate

Chemicals Detected in Soils	Maximum Concentration Reported (mg/kg)	Screening Criteria (mg/kg)	Reference and notes
DDD	114000	7.2 (1000)	RSL (NEPM HIL for DDT+DDD+DDE)
DDE	41300	5.1 (1000)	RSL (NEPM HIL for DDT+DDD+DDE)
DDT	874000	7 (1000)	RSL (NEPM HIL for DDT+DDD+DDE)
endosulfan I	175	3700	RSL
endosulfan II	15900	3700	RSL
endosulfan sulphate	92	3700 (S)	No data available – adopt data for endosulfan as surrogate
endrin	123	180	RSL
endrin aldehyde	2.9	180 (S)	No toxicity data or screening levels available – adopt data for endrin as surrogate
endrin ketone	6.03	180 (S)	
hexachlorobenzene	250	1.1	RSL
methoxychlor	0.6	3100	RSL
trans-chlordane	0.41	6.5	RSL
diazinon	1.2	550	RSL
malathion	10.3	12000	RSL
dibutyltin	0.002	180 (S)	No toxicity data or screening levels available – adopt RSL for tributyltin compounds as surrogate
monobutyltin	0.001	180 (S)	
tributyltin	0.006	180 (S)	
2,4,5-trichlorophenol	16.1	62000	RSL
2,4-dichlorophenol	140	1800	RSL
2,6-dichlorophenol	0.5	1800 (S)	No data available – adopt data for 2,4-dichlorophenol as surrogate
2-chlorophenol	2.4	5100	RSL
2-methylphenol	0.8	30780	Region IX PRG
3-&4-methylphenol	1.1	3078	Value for 4-methylphenol (lower value)
pentachlorophenol	10	9	RSL
2,4,5-T (2,4,5-trichlorophenoxyacetic acid)	86.3	6200	RSL
2,4-D	3.1	7700	RSL
2,4-DB	3.69	4900	RSL
dicamba	11.9	18000	RSL
MCPA	2.51	310	RSL
bis(2-ethylhexyl) phthalate	10	120	RSL
butyl benzyl phthalate	6	910	RSL
di-n-butyl phthalate	99	62000	RSL
2-methylnaphthalene	34.2	4100	RSL
acenaphthene	3.7	33000	RSL
acenaphthylene	6.4	33000 (S)	Limited data available, assume acenaphthene as surrogate – consistent with TEFs and non-carcinogenic classification of chemicals
anthracene	27.5	170000	RSL
benzo(a)anthracene	37	2.1	RSL
benzo(a) pyrene	43	5	NEPM HIL
benzo(b)&(k)fluoranthene	47	2.1	RSL for lower of group
benzo(b)fluoranthene	48	2.1	RSL
benzo(g,h,i)perylene	37	210 (S)	Limited data available, assume chrysene as surrogate – consistent with TEFs
benzo(k)fluoranthene	16	21	RSL
chrysene	33	210	RSL
dibenz(a,h)anthracene	7	0.21	RSL
fluoranthene	130	22000	RSL
fluorene	10.2	22000	RSL
indeno(1,2,3-c,d)pyrene	27	2.1	RSL
naphthalene	7.1	20	RSL
PAHs (Sum of total)	593.2	100	NEPM HIL
phenanthrene	117	17000 (S)	Limited data available, assume pyrene

Chemicals Detected in Soils	Maximum Concentration Reported (mg/kg)	Screening Criteria (mg/kg)	Reference and notes
			as surrogate – consistent with TEFs and non-carcinogenic classification of chemicals
pyrene	106	17000	RSL
octane	0.038	NA	
pentadecane	0.054	NA	
PCBs (sum of total)	12.4	50	NEPM HIL
atrazine	1.4	7.5	RSL
carbon disulfide	63.6	3000	RSL
arsenic *	417	500	NEPM HIL
cyanide (total)	18.4	20000	RSL (also NEPM HIL presented HIL of 2500 for complexed cyanide and 1250 for free cyanide)
manganese	1180	7500	NEPM HIL
cadmium	19	100	NEPM HIL
chromium	358	500	NEPM HIL for Chromium VI
cobalt	111	500	NEPM HIL
copper	1090	5000	NEPM HIL
lead **	1490	1500	NEPM HIL
mercury	187	75	NEPM HIL
molybdenum	850	5100	RSL
nickel	182	3000	NEPM HIL
selenium	366	5100	RSL
Tin	94	610000	RSL
zinc	2990	35000	NEPM HIL
TPH C_6-C_9	3290	65	NSW Service Station Guidelines
TPH C_{10}-C_{14}	9740	1000	NSW Service Station Guidelines for C_{15}-C_{36}
TPH C_{15}-C_{28}	76300		
TPH C_{29}-C_{36}	12500		

Notes:

Shaded rows are chemicals where maximum concentration reported is greater than the adopted criteria.

(S) Criteria based on surrogate compound (no criteria available for chemical detected).

* Maximum concentration of arsenic (417 mg/kg) was reported in Area C (MW12) during sampling undertaken by URS in 2000. The maximum concentration reported is not widespread across the site. The arithmetic average concentration of arsenic reported during sampling of all sources on site in 2000 is approximately 10 mg/kg. The maximum concentration of arsenic reported in subsequent sampling across the site was also lower, with a maximum concentration of 103 mg/kg reported from CH2MHill data from 2003 to 2005.

** Maximum concentration of lead (1490 mg/kg) was reported in Area H (HTP01) during sampling undertaken by URS in 2000. Another elevated (but lower than the adopted screening criteria) concentration of lead (1430 mg/kg) was reported in Area I during sampling by CH2MHill in 2003. The maximum concentrations reported are not widespread across the site. The arithmetic average concentration of lead reported during sampling of all sources on site in 2000 is approximately 45 mg/kg, and the arithmetic average from samples collected in 2003 was approximately 32 mg/kg.

With respect to the assessment presented above, the identification of TPH in soils has been reviewed by URS (2000) and HLA (2006). TPH is a non-specific aggregate analysis that encompasses a wide range of organic compounds, including the organic contaminants of concern identified in **Table 3-1**. Based on reviews by URS and HLA (now AECOM), the presence of TPH is likely to be the result of the presence of elevated concentrations of DDX (DDE, DDD, DDT) (impacting the C_{10}-C_{36} range), BTEX and other volatile halogenated chemicals (such as EDC and TCE that impact the C_6-C_9 range) rather than indicative of a petroleum product. As such, TPH has not been identified as a COPC as it is considered that impacts reported as TPH are adequately addressed by the determination of individual chemical concentrations. However, as only a small number of TPH chromatograms have been assessed to date further characterisation of the TPH is warranted particularly in localised areas where TPH contamination might not be consistent with the presence of elevated concentrations of volatile and semi-volatile COPC.

On the basis of the above the following COPC have been identified in soils at the site:

Table 3-2 COPC Identified in Soils - Orica Villawood Site

COPC	
1,4-dichlorobenzene; 1,2,3-trichloropropane; 1,1,2-trichloroethane; 1,2-dichloroethane (EDC); trichloroethene (TCE); tetrachloroethene (PCE); chlorobenzene vinyl chloride carbon tetrachloride; chloroform; benzene, toluene, ethylbenzene and xylenes (BTEX);	α-BHC, β-BHC, γ-BHC and δ-BHC; dieldrin; DDT, DDE and DDD; endosulfan II; hexachlorobenzene (HCB); pentachlorophenol; PAHs, namely benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene; and mercury

The COPC listed above are applicable to the whole site, however given the history of manufacturing on the site the above table does not reflect the distribution of the COPC across the site.

Appendix B presents a review of the occurrence of COPC associated with Impacted Soil Zones (ISZs) as defined by HLA (2006). The ISZs defined are presented in **Figure 3**. **Table 3-3** presents a summary of the COPC identified in shallow and deep soils (defined as soils 1m and deeper) in each of the ISZs.

Table 3-3 Summary of COPC Identified in ISZs - Shallow and Deep Soil

COPC	ISZ 1a/1b		ISZ 2		ISZ 3		ISZ 4#		ISZ 5		ISZ 6#		ISZ 7		ISZ 8		ISZ 9		ISZ 10
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	D*
hexachlorobenzene (HCB)	•						•		•		•		•		•				
1,2-dichloroethane (EDC)			•		•	•		•		•						•			
vinyl chloride			•																
chloroform	•		•					•		•					•				
carbon tetrachloride	•																		
trichloroethene (TCE)			•	•	•	•		•		•						•			
tetrachloroethene (PCE)															•	•	•		
1,1,2-trichloroethane										•									
chlorobenzene	•	•								•									
benzene	•		•					•							•		•	•	•
toluene	•														•				
ethylbenzene		•								•									
xylenes (total)	•									•									•
PAHs	•		•						•		•				•	•	•		•
1,4-dichlorobenzene	•	•	•	•						•					•				
1,2,3-trichloropropane										•									
α-BHC	•						•		•	•	•		•		•		•		•
β-BHC	•				•		•		•	•	•		•		•		•		•
γ-BHC	•				•		•		•	•	•		•		•		•		•
δ-BHC	•						•			•	•				•				
dieldrin	•														•		•		
DDX	•		•		•		•		•		•		•		•		•		•
endosulfan II																	•		
pentachlorophenol															•				
mercury							•									•			

* COPC identified beneath existing Pharmaceuticals building; S = shallow soil, D – soil 1m and greater (deeper soil)

COPC identified in ISZ4 and ISZ 6 have been remediated as part of works conducted by CH2MHill in 2003 and 2004 (CH2MHill, 2007)

3.3.2 Soil in Off-Site Areas

There is no data available that suggests that shallow soil impacts (derived from the site) extend off site. Due to the historical discharge of contaminants via the drainage line located on the southern side of Christina Road, there is the potential for soil beneath the former drainage line to be impacted with residual contamination. Any impacts beneath the old drainage line will be at depth, beneath the old drainage line which is located within the stormwater drainage corridor adjacent to the existing rail line. Contamination in soil that might remain beneath this drainage line has not been characterised. However due to the depth and location of these potential impacts the potential for exposure is not considered to be significant. The soil is expected to be largely inaccessible (at depth beneath drainage lines) and any vapour migration would be to outdoor areas only where dispersion will mitigate any exposure.

Other soil impacts identified off site are at depths within the saturated groundwater zone and hence considered to be associated with the impacts identified in groundwater. Hence off-site soils have not been considered further within this assessment.

3.4 Groundwater

Perched groundwater has been detected on the site however it is not considered to be continuous across the entire site and it is likely to be a result of the excavation of UST and building footings. The contamination present in the perched groundwater is a direct result of the soil contamination and is similar in nature. The proposed remediation of the site is expected to remove all impacted perched groundwater and old drainage lines. Hence the assessment of potential health risks posed by this perched water has not been considered further. The focus of the following review and assessment is therefore on contamination identified in regional groundwater.

Five groundwater plumes have been identified beneath the site with three extending beneath down-gradient off-site areas. The main contaminants present in groundwater are DDX, 1,2-dichloroethane (EDC), trichloroethene (TCE) and chlorobenzene (MCB), however a range of other chemicals have also been reported in groundwater. Groundwater contaminant distributions as inferred by HLA (2006) are illustrated on **Figure 3** based on data presented by HLA (2006) and **Appendix A** contains Figures 9.12 and 9.13 which illustrate inferred plumes by chemical in on-site and off-site areas. The following presents a summary of the five groundwater plumes identified based on information and data presented by ENSR (2008, 2009).

3.4.1 Plume 1

The source of Plume 1 has been identified as the DDX formulation plant and adjacent benzene/chlorobenzene UST in the vicinity of ISZs 1a and 1b. In addition DNAPL (associated with surface spills and drainage) has been identified underlying these areas with residual DNAPL possibly within the fractured shale. The key contaminants are chlorobenzene, DDX and chloroform. **Table 3-4** presents a summary of the maximum concentrations reported within this plume.

Plume 1 extends south to the vicinity of monitoring well OS02 and continues in a westerly direction in the area of the former No 9 Branch Drain along Christina Road. The mobility of DDX appears to be influenced by the presence of chlorobenzene that potentially acts as a solvent carrier. The extent of Plume 1 has been defined and is stable due to a combination of matrix diffusion and biodegradation.

3.4.2 Plume 2

The source of Plume 2 has been identified as: the IHPT process building, tank farm and EDC recovery plant in association with the Tetramisole Plant; the effluent stripping plant (ESP); and the trade waste Line (TWL) in the vicinity of ISZs 2 and 3. In addition DNAPL (sheen) has been identified underlying these areas and on-site near the southern site boundary. The key contaminants identified in Plume 2 are EDC and DDX. **Table 3-4** presents a summary of the maximum concentrations reported within this plume.

Plume 2 extends south to the site boundary then in a westerly direction in the area of the former No 9 Branch Drain along Christina Road, similar to Plume 1. The mobility of DDX appears to be influenced by the presence of EDC that potentially acts as a solvent carrier. The extent of Plume 2 has been defined and is stable due to a combination of matrix diffusion and biodegradation.

3.4.3 Plume 3

The source of Plume 3 has been identified as the effluent treatment plant (ETP) in the vicinity of ISZ 4. In addition DNAPL has been identified underlying the area of the former ETP and within the fractured shale. The key contaminants identified in Plume 3 are EDC, TCE, toluene, benzene, chlorobenzene and DDX. **Table 3-4** presents a summary of the maximum concentrations reported within this plume.

Plume 3 extends to the west-southwest beneath the site and an adjacent off-site industrial property located to the west of Area A. The migration of Plume 3 appears to be controlled by fracture pathways within the shale bedrock and not by potentially more permeable pathways (e.g., trenches) associated with historical/current utilities.

3.4.4 Plume 4

The source of Plume 4 has been identified as the former drum storage area and other unknown practices/storages in the vicinity of ISZ 5 (Area B). In addition DNAPL (sheen) has been identified underlying the area. The key contaminant identified in Plume 4 is EDC, with DDX and TCE also identified. **Table 3-4** presents a summary of the maximum concentrations reported within this plume.

Plume 4 extends to the southwest with a plume length of approximately 100-150 m. Plume 4 does not migrate beyond the site boundary. The migration of Plume 4 appears to be controlled by fracture pathways within the shale bedrock and not by potentially more permeable preferential pathways (e.g., trenches) associated with historical/current utilities.

3.4.5 Plume 5

The source of Plume 5 has been identified as the TWL in the vicinity of ISZ 6 (east of Pharmaceutical Building). The key contaminants identified in Plume 5 are EDC and DDX. **Table 3-4** presents a summary of the maximum concentrations reported within this plume.

Plume 5 is limited in extent (on-site only) and is likely to be sourced from residual materials not removed during the 2004 remediation works.

3.4.6 Key Issues Associated with Groundwater Plumes

Table 3-4 presents a summary of the key organic contaminants and maximum concentrations reported (HLA 2006, ENSR 2007) in each of the five groundwater plumes identified. The table only provides a summary of the maximum concentrations reported for compounds detected in at least one groundwater monitoring well. It is noted that the analytical limit of reporting for a number of compounds were elevated due to the presence of elevated concentrations of contaminants.

Table 3-4 Summary of Maximum Groundwater Concentrations – Plumes 1 to 5

Chemicals Detected in Groundwater	Maximum Concentration Reported (µg/L)			
	Plumes 1 and 2	**Plume 3**	**Plume 4**	**Plume 5**
1,2-dichlorobenzene	122	140		
1,3-dichlorobenzene	213	5		
1,4-dichlorobenzene	519	760		
chlorobenzene	298000	41800		
1,1,2-trichloroethane	35	61	69	
1,1,1-trichloroethane	902	73		
1,1-dichloroethane		79		
1,1-dichloroethene	5	270	6	
1,2-dichloroethane (EDC)	383000	55500	6750	715
cis-1,2-dichloroethene	310	7	83	
trichloroethene (TCE)	11300	43300	74	
tetrachloroethene (PCE)	34	24		
vinyl chloride	2600		10	
carbon tetrachloride	353		480	
chloroform	14800	3590	290	
1,3-chloropropane	27			
benzene	4810	4390		
toluene	3180	14800	2	
ethylbenzene	2	97		
total xylenes		359	2	
tert-butylbenzene	8340			
α-BHC (α-HCH)	2.26	16		
aldrin	20.9			
dieldrin	3.6			
β-BHC (β-HCH)	16.8			
γ-BHC (γ-HCH)	6.71	35.8		
δ-BHC (δ-HCH)	0.011	155		
DDD	1510000*	6.6		0.374
DDE	2840*	15		0.354
DDT	4080000*	9.6		2.2
endosulfan	1.06			
hexachlorobenzene	1	1		
2-chlorophenol	14			
2,4,5-T (2,4,5-trichlorophenoxyacetic acid)	1	72		
2,4-D		48		
dicamba	4.87			
MCPA	0.11			
TPH C_6-C_9	34000			
TPH C_{10}-C_{14}	126			

Notes:

Blank cells – where compounds were not reported above the analytical limit of reporting in any of the monitoring wells defined within the Plumes considered.

* Maximum concentration reported in BP106 (6m port). It is noted that total concentrations of DDD+DDE+DDT were reported in other wells within Plumes 1 and 2 to be significantly lower than the maximum presented in this table. The maximum reported in off-site wells OS 10A was 24.9 µg/L.

While impacts have been identified in groundwater plumes beneath the site and down-gradient off-site areas, further consideration of the data must be made in conjunction with the potential for exposure. The only exposure pathway relevant to human health issues associated with the presence of contaminants in groundwater both on and off the site is the inhalation of volatile chemicals that might be present at the top of the groundwater table, the vapours of which could migrate through overlying soils and into buildings, outdoor air and excavations. The COPCs in groundwater considered relevant to human health have therefore been identified using soil gas and flux emissions data (refer to **Section 3.5**) rather than concentrations in shallow groundwater.

The potential for groundwater to present an unacceptable risk to the environment relates to the potential for groundwater plumes to reach Byrnes Creek and to adversely affect surface water quality. This is discussed in **Section 8.2**. Specific COPC for surface water quality have not been identified.

3.5 Vapour Data

3.6 Soil Gas and Flux Emission Rates

Data relevant to the characterisation of vapour phase COPC that may be derived from impacts identified in soil and/or groundwater have been collected over a number of programs using a range of methods. These include the sampling of soil gas (from the soil profile), sampling of flux emissions (from the surface of the ground) and sampling of indoor air (from existing buildings off-site).

HLA and CH2MHill have undertaken sampling of soil gas and flux emission rates from the most heavily impacted areas of the site. Some additional data has been collected from off-site areas including the collection of some indoor-air samples (CH2MHill). An additional two rounds of soil gas (at all locations) and flux emissions (off-site locations) sampling has been undertaken by URS in 2006/2007 (URS, 2007) and 2008 (URS, 2009) at the HLA locations plus some additional locations. Some indoor air samples have been collected by URS (2007 and 2009) from down-gradient off-site buildings.

There is a reasonably large data set available for the site and off-site areas, however it is noted that there are limitations associated with use of the data from CH2MHill (no information available on sampling methods and no QA assessment) and HLA (no QA assessment). Noting these limitations and utilising all available data, the data collected requires further review prior to use within the risk assessment.

With respect to the soil gas data, the data collected reflects volatile COPC identified in soils and groundwater as well as a range of other chemicals reported at low concentrations. It is not practical to include all chemicals detected in the soil gas within the HHERA. Hence, in order to identify those chemicals that have the potential to significantly contribute to the assessment of inhalation exposures on the site, the soil gas concentrations have been compared with screening levels based on ambient air guidelines[2]. Actual concentrations in indoor air will be at least 100 to 1000 times lower[3] than in soil gas directly beneath a building due to diffusion (through soil and concrete) and dispersion within the building. Concentrations in outdoor air will be even lower due to diffusion and dispersion outdoors. Hence the direct use of ambient air guidelines for the purpose of screening the soil gas data is considered conservative. In order to provide a more realistic methodology for screening the soil gas data, it has been assumed that concentrations indoors could be at least 100 times lower than the measured soil gas concentration. This is conservative for commercial buildings where a 1000-fold factor is more appropriate, however a lower attenuation value has been adopted for the purpose of screening. Applying this factor results in a soil gas screening level that is 100 times greater than the relevant ambient air

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[2] Ambient air guidelines adopted are considered protective of exposures by all people in the population associated with inhalation over a lifetime. Hence use of these guidelines is considered conservative for a commercial/industrial area.

[3] USEPA (December, 2004/Revised February 2005). *Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air*. USEPA, Department of Toxic Substances Control, California Environmental Protection Agency. This document presents a default/generic attenuation factor (concentration indoors/concentration in soil gas) of 0.01 (for a residence with a basement) and 0.001 (for a commercial building) hence concentrations in a commercial building will be at least 1000 time lower than in soil gas directly beneath the slab.

guideline. These screening levels have been used to identify those chemicals in soil gas that are sufficiently high to warrant inclusion in the detailed calculations.

With respect to the available flux emissions data, there are no relevant screening levels available in Australia or overseas for screening this data. As this data relates to the emission rate of a volatile chemical from the surface the method is generally not as sensitive to the range of volatile chemicals typically reported within the soil gas. Hence, the approach adopted for the purpose of screening soil gas to identify key volatile chemicals is considered adequate for identifying key chemicals likely to be associated with significant flux emissions from the surface. On this basis, if a volatile chemical is detected in flux emissions data (at a level just above the LOR) and not in the soil gas at a level that is identified to be of potential significance, the chemical has not been assessed further. If the volatile chemical detected in flux emissions is not at a low level and is a chlorinated compound potentially associated with impacts derived from the Orica Villawood site, then the data has been considered further in the assessment regardless of the soil gas data. If a volatile chemical is detected in flux emissions as well as soil gas at a level of potential significance, then the chemical has been assessed further.

The ambient air guidelines adopted for the purpose of screening indoor air and soil gas data (after consideration of an attenuation factor of 100) are derived from the NEPC Air Toxics Measure (2004), WHO ambient air guidelines and (where guidelines are not available from these sources) industrial air Regional Screening Levels (RSLs) from the USEPA (2008). As chronic (long-term) health risks are being considered in this assessment, guidelines relevant to an annual average have been adopted.

Appendix C presents a review of the soil gas and flux emissions data relevant to each key area assessed on and off the site. These include areas located above ISZ on the site as well as areas located above identified groundwater plumes both on and off the site.

The following table presents a summary of the significant chemicals reported in soil gas and flux emissions data, based on the review presented in **Appendix C**, that have been considered as COPC for further consideration within this assessment.

Table 3-5 COPC Identified in Soil Gas and Flux Emissions

Significant COPC Identified in Soil Gas	Significant COPC Detected in Flux Emissions
cis- 1,2-dichloroethene	chloroform
chloroform	chlorobenzene
1,2-dichloroethane (EDC)	benzene
benzene	trichloroethene (TCE)
trichloroethene (TCE)	1,2-dichloroethane (EDC)
toluene	carbon tetrachloride
1,1,2-trichloroethane	1,2-dichloropropane
tetrachloroethane (PCE)	toluene
vinyl chloride	1,1,2-trichloroethane
chlorobenzene	trimethylbenzenes
1,1,1,2-tetrachloroethane	
ethylbenzene	
xylenes	
1,2,3-trichloropropane	
trimethybenzenes	
1,1-dichloroethene	
naphthalene	

Table 3-6 presents a summary of the COPC identified in soil gas, flux emissions and indoor air (where relevant) for the areas located above impacted soil and/or groundwater plumes on and off the site.

Issue Identification and Data Evaluation

Table 3-6 Summary of COPC Identified in Vapour Data – On and Off-Site

COPC	**On-Site Areas**													**Off-Site Areas**								
	ISZ 1a, 1b and 2 and Plume 1*		**ISZ 3**		**ISZ 4 and Plume 3**		**ISZ 5**		**Plume 2**		**Plumes 3, 4 and 5**			**Plume 1**			**Plume 2**			**Plume 3**		
	SG	**Flux**	**SG**	**Flux**	**SG**	**Flux**	**SG**	**Flux**	**SG**	**Flux**	**SG**	**Flux**	**IA**	**SG**	**Flux**	**IA**	**SG**	**Flux**	**IA**	**SG**	**Flux**	**IA**
cis-1,2-dichloroethene	●																					
chloroform	●	●			●	●	●															
1,2-dichloroethane (EDC)	●		●		●	●	●		●		●	●					●			●	●	
trichloroethene (TCE)	●				●	●	●		●		●	●					●	●		●	●	
1,1,2-trichloroethane							●	●	●					●			●					
tetrachloroethene (PCE)	●						●															
1,1,1,2-tetrachloroethane							●															
1,1-dichloroethene							●	●														
carbon tetrachloride										●												
vinyl chloride	●				●		●															
1,2-dichloropropane							●															
1,2,3-trichloropropane							●		●								●					
chlorobenzene	●		●		●	●	●		●													
benzene	●				●	●																
toluene	●	●	●		●	●	●	●	●	●							●	●				
ethylbenzene					●	●																
xylenes (total)					●	●																
trimethylbenzenes	●				●	●																
naphthalene									●								●					

* Data collected also relevant for the assessment of potential vapour issues in ISZ 8, ISZ9 (benzene and PCE only);
SG = soil gas data (including sub-slab soil gas data where relevant), Flux = flux emissions data, IA = indoor air data.

3.7 Summary of COPC Identified

On the basis of the above (and detailed reviews presented in **Appendices B and C**), COPC have been identified in a number of areas on and off the site. The COPC identified reflect the characteristics of the source zones and groundwater plumes relevant. The following presents a summary of the COPC identified in the key areas assessed on the site.

Table 3-7 Summary of COPC identified in Soil and Air - Orica Villawood Site

COPC	On Site											Off Site		
	ISZ 1a, 1b and 2	ISZ 3	ISZ 4	ISZ 5	ISZ 6	ISZ 7	ISZ 8	ISZ 9	ISZ 10	Plume 2 (and Plume 1)	Plume 3 and 4	Plume 3	Plume 2	Plume 1
hexachlorobenzene (HCB)	●		●	●	●	●	●							
1,2-dichloroethane (EDC)	●○	●○	●○	●○			●○			○	○	○	○	
vinyl chloride	●○		○	○			○							
chloroform	●○		●○	●○			●○							
carbon tetrachloride	●						●			○				
trichloroethene (TCE)	●○	●	●○	●○			●○			○	○	○	○	
tetrachloroethene (PCE)	○			○			●○	●○						
1,1,2-trichloroethane				○			○	●		○			○	○
chlorobenzene	●○	○	○	●○			○			○				
benzene	●○		●○				●○	●○	●					
toluene	●○	○	○	○			●○			○			○	
ethylbenzene	●		○	●										
xylenes	●		○	●			●		●					
PAHs (BaP equivalent)	●			●	●		●	●	●					
1,4-dichlorobenzene	●			●			●							
1,2,3-trichloropropane				●○						○			○	
bis(2-chloroethyl)ether				●										
α-HCH	●		●	●	●	●	●	●	●					
β-HCH	●	●	●	●	●	●	●	●	●					
δ-HCH	●		●	●	●		●							
γ-HCH (lindane)	●	●	●	●	●	●	●	●	●					
DDX	●	●	●	●	●	●	●	●	●					
dieldrin							●	●						
endosulfan II								●						
pentachlorophenol							●							
cis-1,2-dichloroethene	○						○							
1,1,1,2-tetrachloroethane				○										
1,1-dichloroethene				○										
1,2-dichloropropane				○										
trimethylbenzenes	○		○				○							
naphthalene										○			○	
mercury			●				●							

Notes:

● COPC identified in soil based in maximum concentrations reported in area

○ COPC identified in air, namely soil gas and flux emissions in areas overlying source zones and/or groundwater plumes

3.8 Suitability of Data for Risk Assessment

Each of the investigations has completed assessments of accuracy and precision using quality control data collected in the field and at the laboratory with the exception of data provided from CH2MHill and HLA (soil gas and flux emissions). No further evaluation of accuracy and precision has been undertaken by URS in completion of the HHERA. The data is considered to be suitable for use in the assessment of risks to human health for the following reasons:

- The accuracy and precision are acceptable for the purposes of the investigations as indicated by the data evaluations presented in the relevant reports. Data available from CH2MHill has been used as provided with no quality assessment presented. In addition, soil gas and flux emissions data provided by HLA has been used in this assessment (with some review of data by URS provided on carbon tubes to correct for the presence of benzene in the solvent extractant).
- The amount of data collected is generally considered to be sufficient to allow a conservative estimate of potential concentrations of COPC within the relevant exposure media. This is a result of staged investigations that have utilised targeted sampling on the basis of the historical review followed by detailed assessments of selected areas of the site.
- Sampling locations have been spread across the site to provide coverage of areas removed from immediate areas of historical manufacturing and waste management activities.

The soil data therefore provides an appropriate basis for identifying COPC and assessment of the expected range of concentrations.

In relation to groundwater the prime pathway of concern for human health is the inhalation of volatile COPC. The various stages of investigations have defined the general extent of contamination in groundwater, however the soil gas, surface emission and ambient air data provides the most relevant data for the assessment of risks to human health. This data has been collected using recognised procedures across areas of both high and low levels of soil and groundwater contamination and provides an appropriate basis for assessment of the potential for vapours from soil and groundwater to present an unacceptable risk to human health. Some limitations have been noted with respect to data collected by CH2MHill (no detail available on sampling methods, depth of soil gas samples and not QA assessment provided) and HLA (no QA assessment provided).

HLA (2006) provides a detailed assessment of the migration of dissolved phase plumes in groundwater. This assessment provides an appropriate basis for assessment of both short-term and long-term issues relating to off-site migration of groundwater.

No specific data gaps have been identified, however risk assessment and subsequent risk management are an iterative process that should focus on key uncertainties identified in the HHERA in developing requirements for additional investigations to assess risks or develop remediation requirements and strategies. The assessment has identified the following areas that might warrant further assessment:

- Characterisation of TPH which can be undertaken by reviewing relevant chromatograms. Whilst it is considered that the assessment of individual COPC identified will adequately address risk issues and define remediation requirements, there remains uncertainty as to the nature of the TPH contamination. Limited data is available and no further evaluation has been undertaken to date.
- Air data collected from a number of sampling programs show variability in chemicals detected as well as concentrations reported. For on-site areas sufficient data is available to enable risk issues to be identified for the purpose of remediation. Further sampling of soil gas in off-site areas, where remediation is not expected might be required to further assess the potential variability. Given the number of off-site vapour sampling rounds conducted, it is expected that an additional two or three sampling rounds (addressing other seasons) might be required to adequately address the variability.

Section 4 Toxicity Assessment

4.1 General

The objective of the toxicity assessment is to identify toxicity values for the COPC that can be used to quantify potential risks to human health associated with calculated intake. Toxicity can be defined as *"the quality or degree of being poisonous or harmful to plant, animal or human life"* (NEPM, 1999).

The steps involved in this process include the following:

- Obtain relevant qualitative and quantitative toxicity information on the chemicals of potential concern relevant to the significant exposure pathways being assessed (namely oral, dermal or inhalation); and
- Identify the appropriate toxicity values for assessing both threshold effects and non-threshold carcinogenic effects.

The toxicity assessment distinguishes between those chemicals that can be assessed on a non-threshold and a threshold basis as described below.

4.1.1 Non-Threshold

Non-threshold toxicity values assume that any amount of exposure to the chemical has the potential to result in an increased risk. These chemicals are typically carcinogens with their toxicity values referred to as cancer risk slope factors. The WHO assigns slope factors to chemicals identified as genotoxic carcinogens with other carcinogens evaluated generally identified as exhibiting a threshold relationship (refer below). A slope factor is an upper bound estimate of the probability of a response occurring following the intake of a chemical over a lifetime via a specific exposure pathway (such as ingestion or inhalation). Therefore the higher the slope factor, the higher the risk which may be associated with a given exposure.

4.1.2 Threshold

This relationship assumes that there is a level of exposure below which there is no (or no appreciable) risk of an adverse health effect. This is in contrast to the non-threshold relationship where there is an increased risk associated with any exposure. The WHO identifies threshold chemicals as those which are not suspected of exhibiting carcinogenic effects (non-carcinogens) or those which exhibit non-genotoxic carcinogenicity. Toxicity factors for these chemicals are referred to as an acceptable daily intake (ADI, by the WHO) or reference dose (RfD, by the USEPA) for oral exposures (in units of mg per kg body weight per day) and a tolerable concentration (TC, by WHO) or reference concentration (RfC, by USEPA) for inhalation exposures (in units of mg per cubic metre of air). The lower the ADI, RfD, TC or RfC, the more toxic the chemical and the lower the concentration above which there exists a potential for an adverse health effect.

4.1.3 Identification of Toxicity Values

The identification of toxicity values undertaken in this risk assessment has followed ANZECC (1992) guidance, which is in accordance with the NEPC (1999) policy. enHealth (2002) provides a list of toxicological data sources. These are classified as Level 1, 2 or 3 data, with Level 1 sources recommended. In order of preference the Level 1 sources are:

1) National Health and Medical Research Council documents and documents from other joint Commonwealth, State and Territory organisations.
2) ADI List from the Therapeutic Goods Administration.
3) World Health Organisation (WHO) documents.
4) enHealth Council documents.
5) National Environmental Health Forum documents.
6) International Agency for Research on Cancer (IARC) monographs.
7) WHO/FAO Joint Meeting on Pesticides (JMPR) monographs.
8) NICNAS Priority Existing Chemical (PEC) reports.
9) US Agency for Toxic Substances and Disease Registry (ATSDR) documents.
10) National Toxicology Program (NTP) carcinogenicity appraisals.
11) OECD Standard Information Data Sets (SIDS) and SID Initial Assessment Reports (SIAR).
12) EPA Reference Doses.

Level 2 sources include peer-reviewed journals and industry publications and reference to Level 2 sources is considered warranted where Level 1 sources do not provide applicable criteria. Level 3 sources are those not covered by Level 1 or 2 and require careful consideration and justification for use. Level 3 sources have not been considered in the toxicity reviews presented in this report.

4.2 Toxicity Reviews

Toxicity profiles have been prepared for the COPC identified in **Section 3**. These profiles provide a review of potential health effects associated with exposure and identification of relevant toxicity values for the quantification of risk associated with oral, dermal and inhalation exposures. The toxicity profiles for the COPC identified in this assessment are presented in **Appendix D** of this report. The profiles provide an overview of current consensus of the toxicity of the chemicals with an aim of identifying toxicity values that reflect the enHealth (2002) guidance. It is not the purpose of the reviews to derive alternate toxicity values.

Table 4-1 presents a summary of the toxicity values identified for use in this HHERA. The toxicological data presented are considered to be appropriate for the assessment of risks to human health associated with potential exposure to the COPC. It is accepted that toxicological data has many uncertainties (as outlined in **Section 10** of this report). However, the approaches adopted by the different regulatory bodies in determining the relevant toxicological values are considered to be conservative and likely to overestimate the risks.

Occupational Inhalation Exposures

The assessment of inhalation exposures has been undertaken in accordance with NEPM (1999) guidance for workers at commercial premises using guidance from the Australian Safety and Compensation Council (ASCC), in particular NOHSC *Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment* [NOHSC:1003(1995)] and subsequent amendments.

Following this guidance the assessment of exposures within the workplace has been undertaken on the basis of threshold values, referred to as Time Weighted Average (TWA) inhalation exposure standards. For chemicals classified by ASCC as carcinogenic, a carcinogenic risk has also been evaluated to ensure exposures by workers to carcinogens has been assessed. The assessment of threshold TWA and carcinogenic risk has also considered exposure to multiple chemicals assuming an additive effect.

The threshold exposure standards are standards that represent airborne concentrations of individual chemical substances, which, based on current knowledge, *"should neither impair the health of, nor cause undue discomfort to, nearly all workers"* (ibid). The exposure standards are expressed as TWA values, based on exposure to an airborne substance over an eight-hour working day, for a five-day working week, over an entire working life.

Use of the above approach for the assessment of occupational exposures, while recommended in the NEPM, is generally accepted as being appropriate only under some circumstances. Situations where the approach is accepted are in the evaluation of exposure in an occupational environment for workers who work with or handle the COPC identified or those who undertake works using suitable workplace exposure standards for intrusive or confined space works. Hence, the evaluation of on-site workers using the above approach should the Orica Villawood site be an operating facility (eg. workers involved in the ongoing use of the site) for exposure to the COPC would be an appropriate approach and application of the standards. However, it is less clear as to the applicability of the approach for ongoing commercial/industrial use of the site given that the future use is unlikely to involve manufacture or handling of most if not all of the COPC. Assessment of potential exposures by intrusive workers using the above approach is considered relevant as they would be expected to work under relevant occupational health and safety legislation and industry guidance on a site-by-site basis.

The use of the above approach might not be acceptable for the evaluation of inhalation exposures on sites not involved in the manufacture, storage or handling of the COPC.

Therefore, as the site is to be developed within the existing zoning that could include a range of commercial/industrial uses, the assessment of exposure by workers on the site has been undertaken using sensitive inhalation toxicity values (discussed above) as well as occupational inhalation exposure standards (TWAs and carcinogenic risk) for comparison.

Values selected for use for assessment of volatile COPCs have been obtained from ASCC (or equivalent) for the COPCs identified

Table 4-1 Summary of Toxicity for COPC Identified - Orica Villawood Site

Chemical	**Non-Cancer Toxicity Endpoint**	**Animal Carcinogen and Mechanism**	**Genotoxic**	**Oral Slope Factor (mg/kg/day)$^{-1}$**	**Oral TDI (mg/kg/day)**	**Inhalation Unit Risk (μg/m^3)$^{-1}$**	**Inhalation TC (or equivalent) (mg/m^3)**	**Occupational Inhalation Standard TWA (6) (mg/m^3)**	**Potential for background intake**
hexachlorobenzene (HCB)	Liver	Yes, NG	No	T	0.00016(1)	T	O	0.002(7)	negligible
1,2-dichloroethane (EDC)	Liver	Yes, M,G	Yes	0.012(1),(3)	NT	(0.5 to 2.8)x10^{-6} (2) 2.8x10^{-6} proposed	NT	40	nd-
vinyl chloride	Liver	Yes, G	Yes	1.2(1) adulthood 2.3(1) lifetime	NT	4.4x10^{-6} adulthood 8.8x10^{-6} lifetime (4)	NT	13	nd-
chloroform	Liver, kidney, CNS	Yes, P, C	No	T	0.013(1)	4.2x10^{-7} (2)*	0.14(2)	10	Yes (50%)
carbon tetrachloride	Liver, kidney	Yes, P, C	No	T	0.00142(1)	T	0.0061(2)	0.63	Yes (65%)
trichloroethene (TCE)	CNS, liver	Yes, P, C, MG	Equivocal	T	0.00146(1)	4.3x10^{-7} (2)	NT	54	Yes, low
tetrachloroethene (PCE)	Liver, kidney, CNS	Yes, P, C, MG	No	T	0.014(3)	T	0.25(2)	335	Yes (34%)
1,1,2-trichloroethane	Liver, immune	Yes, C	No	T	0.004(5)	T	O	55	negligible
1,1,1-trichloethane	CNS	Limited data	No	T	0.6(1)	T	2[1]	555	negligible
chlorobenzene	Liver, kidney, CNS	No	No	T	0.086 (1),(3)	T	0.5 (2)	46	Yes, low
benzene	Immune	Yes, G	Yes	0.035(1)	NT	6x10^{-6} (2)	NT	3.2	nd
toluene	Kidney	No	No	T	0.22 (1),(3)	T	0.26 (2)	191	Yes (10%)
ethylbenzene	kidney, liver	Possible?	No	T	0.097 (1),(3)	T	22 (2)	434	negligible
xylenes	CNS	No	No	T	0.179 (1),(3)	T	0.87 (2)	350	Yes (2%)
PAHs – benzo(a)pyrene equivalent		Yes, G	Yes	0.5 (1)	NT	8.7x10^{-2} (2)	NT	NA	nd
1,2-dichlorobenzene (and 1,3-)	Liver, kidney, CNS	No	No	T	0.43(1), (3)	T	0.6(8)	150	negligible
1,4-dichlorobenzene	Liver, Kidney	Yes	No	T	0.0107 (3)	T	1 (2)	150	Yes, low
1,2,3-trichloropropane	Stomach, liver	Yes, G	Yes	7 (4)*	NT	O	NT	60	nd
α-HCH (α-BHC)	CNS, Liver Kidney	Equivocal	No	T	0.008 (5)	T	0.00025 (8)	0.1 (lindane)	Yes, low
β- and δ-HCH (β- and δ-BHC)	Liver, kidney	Possible	No	T	0.00002 (8)	T	0.00025 (α-HCH)	0.1 (lindane)	Yes, low
γ-HCH (γ-BHC, or lindane)	CNS, Liver Kidney	Yes	No	T	0.003 (3)*	T	0.00014 (8)	0.1	Yes, low
dieldrin	CNS	Yes	No	T	0.0001 (1),(3)	T	O	0.25	Yes, low

Chemical	Non-Cancer Toxicity Endpoint	Animal Carcinogen and Mechanism	Genotoxic	Oral Slope Factor (mg/kg/day)$^{-1}$	Oral TDI (mg/kg/day)	Inhalation Unit Risk ($\mu g/m^3$)$^{-1}$	Inhalation TC (or equivalent) (mg/m^3)	Occupational Inhalation Standard TWA (6) (mg/m^3)	Potential for background intake
DDX (sum of DDT, DDE and DDD)	CNS, liver	Yes	No	T	0.002 (3)*	T	O	1 (7)	Yes, low
endosulfan II	Kidney	No	No	T	0.006 (1)	T	O	0.1	Yes (10%)
pentachlorophenol	Liver	Yes	No	T	0.003 (3)	T	O	0.5	Yes, low
cis-1,2-dichloroethene	Liver	Insufficient data	equivocal	T	0.01 (4)	T	O	793	negligible
1,1,1,2-tetrachloroethane	CNS, liver	Limited data	No	T	0.03 (4)	T	O	6.9	negligible
1,1-dichloroethene	CNS, liver	Limited data	No	T	0.046 (1)	T	0.2 (2)	20	negligible
1,1-dichloroethane	CNS	Limited data	No	T	0.1(4)*	T	0.5(4)*	412	negligible
1,2-dichloropropane	CNS, liver, kidney	Limited data	equivocal	T	0.014 (1)	T	0.004 (4)	347	Yes (10%)
1,2,4- and 1,3,5-trimethylbenzene	CNS, respiratory	Insufficient data	Insufficient	T	0.05 (4)**	T	0.006 (4)**	125 (7)*	Yes (50%)
naphthalene	Haemic, respiratory	Yes, Possible	No	T	0.02 (4)	T	0.003 (4)	52 (9)	Low (5%)
mercury (inorganic)	Kidney	No	No	T	0.00071 (1)	T	Not assessed	Not assessed	Yes (50%)

(1) Derived from WHO Drinking Water Guidelines (1993, 1996, 1998 and 2004) including rolling revision to TCE (2005)
(2) Derived from WHO Air Quality Guidelines (2000, 2000b or CICAD 58 (2004) for chloroform).
Where a range is presented, the most conservative value (higher unit risk and lower ADI) has been adopted.
(3) Derived from NHMRC Australian Drinking Water Guidelines (1996 and draft 2002)
(3)* ADI recommended by the Office of Chemical Safety as part of Therapeutic Goods Administration (2006)
(4) Derived by USEPA (IRIS evaluations, current 2006)
(4)* Derived from USEPA (evaluation presented within HEAST and referenced in RAIS database)
(4)** Derived from provisional peer reviewed data available from USEPA and referenced by OEHHA and Region IX PRGs (2004).
(5) Derived by ATSDR based on chronic exposures
(6) Occupational data available from NOHSC except where noted, TWA values based on 8-hour average
a. Occupational data available from ACGIH
(7)* Data available from NIOSH
(8) Value derived from review undertaken by RIVM (2001).

O Inhalation exposure evaluated using oral data as no relevant chronic inhalation data available.
T Threshold approach adopted, hence no oral slope factor or inhalation unit risk considered relevant.
NT Non-threshold approach adopted
NA Not available

NG = Non-genotoxic C = Cytotoxic P = Peroxisome proliferation G = Genotoxic
M = metabolite mediated with questionable relevance to humans
MG = species specific α2-microglobulin mechanism
TEQ = Toxicity Equivalence

References and background provided in relevant toxicity summaries.

Section 5

Exposure Assessment

5.1 General

This section identifies the human populations (receptors) who could be exposed to the COPC, outlines the mechanisms (pathways) by which these populations could be exposed and provides a quantitative estimate of exposure and chemical intake.

The exposure assessment is undertaken to be representative of a particular population and does not calculate the exposure for a given individual. Populations are grouped so as to reflect common activities undertaken by that group (such as intrusive workers or office workers) or by the location of the population in relation to the contaminant distribution. For this reason it is important that the exposure assessment be undertaken in such a way that the most sensitive individuals within the potentially exposed population are adequately protected. The exposure assessment has been structured in the following way:

- Identification of the group that could be exposed to the COPC;
- Identification of the activities by which exposure could take place for each group;
- Identification of parameters which define activity (such as time spent indoors) and physiological exposure parameters (such as body weight and inhalation rate); and
- Identification of the chemical concentration at the point of exposure. This may include the identification and use of models to estimate chemical concentrations for receptors and exposure pathways that cannot be measured directly.

5.2 Key Pathways and Receptors

Receptor populations are similar groups of people who work in areas affected by the contamination and who might be exposed to the COPC in the workplace.

An exposure pathway describes a unique mechanism by which an individual within the population might be exposed to chemicals or physical agents at or originating from a source. Each exposure pathway includes:

- a source or release from a source;
- a transport/exposure medium or exposure route; and
- an exposure point.

If any one of these mechanisms is missing (such as transport mechanism or exposure point) then the pathway is considered to be incomplete. An exposure pathway can be considered to be insignificant if the potential for a receptor or population to be exposed to the COPC is considered to be low. This could be due to a number of factors, which could include dilution during the transport from the source to the point of exposure or limited time for exposure.

The Orica Villawood site is zoned commercial/industrial and it is expected that future use/development of the site would be consistent with this zoning. It should be noted that the description for this zoning includes child care centres and motels. For the purposes of this risk assessment these land uses have not been considered.

In addition surrounding areas, in particular the area located hydraulically downgradient to the south-southwest of the site, are also commercial/industrial.

The closest residential area is located approximately 500 m to the east and north (Villawood Detention Centre) of the site and there are no recreational areas located within 500 m of the site.

Groundwater is not considered to have a beneficial use of note and as such has not been identified as an environmental receptor itself. Groundwater is not extracted and used in the area. Groundwater is at least

2 m below ground level beneath the site and off-site areas where impacts have been identified. Hence direct contact with groundwater during normal day-to-day work on the site and off-site areas would not be expected and there would also be limited potential for direct contact during intrusive works associated with the maintenance of underground utilities (where the depth to such services is unlikely to be greater than 1-2 m below ground level as per ANZECC 1992).

In off-site areas groundwater in the vicinity of Plume 3 is most shallow (minimum of approximately 2.3 m below ground level at OS06). The depth to groundwater beneath the off-site portions of Plumes 1 and 2 varies between 2.3 m (OS08) and 3.5 m (OS01) below ground level. While this is not expected to be encountered during normal intrusive works, the potential for contact with shallow groundwater within the off-site Plumes 1 and 2 and Plume 3 has been included in this assessment at the request of DECCW to assist in future planning issues in the off-site areas.

The depth to groundwater on site is variable; however any deep excavation work is expected to be managed under a site management plan where the potential for contact and exposure with impacted groundwater should be adequately addressed.

As noted in **Section 3.4**, perched groundwater has been detected on the site however it is not considered to be continuous across the entire site and it is likely to be a result of the excavation of UST and building footings. The proposed remediation of the site is expected to remove all the contaminated perched groundwater and old drainage lines. Hence the assessment of potential health risks posed by this perched water has not been considered further and would need to be addressed as part of job specific health and safety plans associated with the remediation activities proposed.

Based on the land use of the site and surrounding area and the nature and extent of impacts identified in soils and groundwater, the following exposure pathways are considered to be complete and to warrant further assessment for the key receptor groups identified.

Table 5-1 Summary of Key Exposure Pathways

Receptor	Exposure Pathway	Activity
Adult workers – on site and off site	Inhalation of volatile chemicals (indoors, outdoors)	Working on the site following redevelopment Working in areas located off-site and down-gradient
Adult workers – on site	Ingestion of soil Dermal contact with soils	Working on the site following redevelopment
Intrusive workers	Inhalation of volatile chemicals (in excavations) on site and off site; Ingestion of soil on site Dermal contact with soils on site	Undertaking intrusive activities on the site following redevelopment or undertaking intrusive activities in areas offsite above impacted groundwater. Activities include the maintenance of services that could be undertaken by workers who might be unaware of the presence of impacts in soil or groundwater. This does not include construction workers on the site who would be required to work under a relevant occupational health and safety plan or workers involved in significant major excavation works such as maintenance of major water drainage or sewer lines where such works would require intrusive activities to be undertaken in accordance with relevant occupational health and safety plans. Deep works in off-site areas has been considered, however exposure to shallow groundwater is only expected to occur infrequently.
Intrusive workers – deep works off site	Ingestion of shallow groundwater off site Dermal contact with shallow groundwater off site	

Exposures by visitors would be lower than long-term workers due to the short duration of exposure. Hence quantification of risks to visitors is not proposed to be undertaken. As the assessment area is commercial/industrial and does not include recreational areas, only adults are relevant to the assessment.

5.3 Quantification of Chemical Intake

5.3.1 Methodology

When calculating chemical intake or exposure, the risk assessment process focuses on exposure occurring over a prolonged period, that is, chronic exposure that occurs over years and possibly a lifetime. Whilst an activity might occur infrequently (i.e. several days a year), it could occur over a long period (i.e. every year for years or decades) and therefore have the potential to increase long term or chronic intake of the chemical. Activities that occur on a once-off basis only have limited potential to make a significant contribution to long term chemical intake.

The calculation of daily chemical intake requires the estimation of relevant exposure parameters that describe physical and behavioural variables relevant to the exposure evaluated, as well as chemical concentrations that are considered relevant to the exposure evaluated (refer to **Sections 3.2 and 3.4**).

The assessment presented has addressed potential worst-case exposure to COPC and exposure has been calculated for a ***Reasonable Maximum Exposure (RME)*** scenario estimated by using intake variables and chemical concentrations that define the highest exposure that is reasonably likely to occur in the area assessed. The RME is likely to provide a conservative or overestimate of total exposure and therefore health risk. This approach follows ANZECC/NHMRC guidance (1992) supplemented by USEPA guidance (USEPA, 1989).

The calculation of daily chemical intake has been undertaken using the following equations:

Intakes via Inhalation

The assessment of inhalation exposures has been undertaken using the following equation to calculate intake of volatile chemicals via all inhalation pathways:

$$\textit{Daily Chemical Intake}_V = C_a \bullet \frac{InhR \bullet ET \bullet FI \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

where:

Ca = Concentration of chemical in air (as relevant for each pathway assessed) (mg/m^3)
InhR = Inhalation rate (dependent on age and activity) (m^3/hr)
ET = Exposure time (dependent on activity) (hr/day)
FI = Fraction inhaled from contaminated source assumed to be 1 or 100% (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (dependent on age) (kg)
AT = Averaging time for threshold and non-threshold exposures (days)

Ingestion of Soil

The following equation has been used to calculate intake of chemicals via the ingestion of soil:

$$Daily\ \ Chemical\ \ Intake_{Is} = C_s \bullet \frac{IRs \bullet FI \bullet B \bullet CF \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

where:

Cs = Concentration of chemical in soil (mg/kg)
IRs = Ingestion rate of soil (dependent on age and activity) (mg/day)
FI = Fraction of daily ingestion that is derived from contamination source assumed to be 1 or 100%
B = Bioavailability or absorption of chemical via ingestion assumed to be 1 or 100% (unitless)
CF = Conversion factor of 1×10^{-6} to convert mg to kg
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (dependent on age) (kg)
AT = Averaging time for threshold and non-threshold exposures (days)

Ingestion of Water (Shallow Groundwater)

The following equation has been used to calculate intake of chemicals via the ingestion of shallow groundwater:

$$Daily\ \ Chemical\ \ Intake_{IW} = C_w \bullet \frac{IRw \bullet B \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

where:

Cw = Concentration of chemical in water (as relevant for each pathway assessed) (mg/L)
IRw = Ingestion rate of water (dependent on age and activity and can be derived using ingestion rate per hour and number of hours undertaking activity or simply an intake per day) (L/day)
B = Bioavailability or absorption of chemical via ingestion assumed to be 1 or 100% unless noted otherwise (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (dependent on age) (kg)
AT = Averaging time for threshold and non-threshold exposures (days)

Intakes via Dermal Exposures

The approach to be adopted for the quantification of dermal contact with soils is consistent with the approach presented in the Orica Botany Consolidated Human Health Risk Assessment (URS, 2005) for the assessment of dermal contact. That is:

Dermal Contact with Soil

Dermal absorption of chemicals from soil depends on the area of contact, duration of contact, bond between chemical and the soil and the ability of the chemical to penetrate the skin. The assessment of dermal absorption of chemicals in soil has followed the approach adopted for the evaluation of dermal absorption of chemicals in soils.

US Approach

The USEPA (1989 and 2004) provide a simple approach to the evaluation of dermal absorption associated with soil contact. This is presented in the following equation:

$$\mathit{Daily\ Chemical\ Intake} = C_s \bullet \frac{SAs \bullet AF \bullet ABSd \bullet CF \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

where:

Cs = Concentration in soil (mg/kg)

SAs = Surface area of body exposed to soil per day (cm^2/day)

AF = Adherence factor, amount of soil that adheres to the skin per unit area which depends on soil properties and area of body (mg/cm^2 per event)

ABSd = Dermal absorption fraction (unitless – refer to discussion below)

CF = Conversion factor of 1x10^{-6} to convert mg to kg

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (dependent on age) (kg)

AT = Averaging time for threshold and non-threshold exposures (days)

Dermal Absorption Fraction (ABSd)

The approach undertaken by the USEPA utilises a dermal absorption fraction typically derived from experimental studies on different chemicals. On the basis of the studies undertaken and a number of simplifications, ABSd values have been recommended for a range of 10 chemicals and default values for other semi-volatile chemicals. No default is defined (in USEPA 2004) for volatile organic chemicals or inorganic chemicals. It is considered that, with regards to soil exposures, volatile organic chemicals would volatilise from soil on skin and should be accounted for in the assessment of inhalation exposures. For inorganics, the speciation is critical to dermal absorption and hence no generic default values have been determined.

More commonly used values for the assessment of dermal exposure to organics and inorganics utilise defaults for ABSd for organics of 0.01 and inorganics of 0.001 as presented on RAIS (Risk Assessment Information System Database[4]), along with the few chemical-specific values available.

The value of ABSd has no consideration of exposure time. Experimental studies used to define ABSd values are associated with dermal application over 24 hours (i.e. the event is considered to be a 24 hour day by default). Due to the lack of information about the rate and relationship of absorption of chemicals through the skin over shorter exposure periods, the USEPA methodology does not recommend adjusting the ABSd to account for exposures over times less than 24 hours, rather it recommends adjusting exposure frequency and exposure duration to reflect site conditions. This approach is utilised to evaluate dermal intake per exposure event (commonly adopted as a day) and is considered to be conservative in the assessment of exposure events that are less than 24 hours in duration or multiple short-term exposure events where absorption would be “double-counted”.

Further Review of Dermal Absorption

In reviewing the approach to the assessment of dermal exposure presented in source documents “The Health Risk Assessment and Management of Contaminated Sites” (CSMS, 1991, 1993, 1996, 1998 and enHealth 2002b) that are referenced in enHealth (2002) it is noted that the approach suggested by Hawley (1985) has been adopted. The approach is similar to the USEPA approach presented above, with some differences with respect to the evaluation of absorption.

Hawley (1985) provides a review of dermal uptake from soils for organic chemicals based on studies of a number of compounds by humans, rats, rabbits and pigs. The absorption rates obtained for application of a pure compound (or in acetone solvent) were determined to be 11% for an adult over 24 hours. For a 12

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[4] RAIS database available on-line at: http://risk.lsd.ornl.gov/index.shtml

hour contact time, the dermal absorption rate was taken to half or 6% (as rounded up from half of 11%) of the applied dose.

Absorption of contaminants in soils or dust was discussed by Hawley to be limited by the physical-chemical binding to the matrix. On this basis Hawley also applied a factor to account for the matrix effect of absorption from soils (or relevant matrix) by comparison to the absorption study data that used the pure compound or solvent solution. The value used by Hawley (for TCDD and other organic compounds where no data is available) was 15%.

This approach is also adopted in the assessment of dermal intake of organic chemicals presented in the Dutch sediment exposure model SEDISOIL (1996) and the soil exposure model CSOIL (2001). These models express the dermal absorption of organics presented by Hawley as an absorption rate per hour. Hence for adults the absorption rate is 0.005 or 0.5% per hour.

This approach was generally utilised by Fitzgerald D.J (CSMS 1991) in the setting of a response level for benzo(a)pyrene where intake via skin absorption for an adult the intake via skin absorption considers exposure to soils over 12 hours and adjusts the intake using a linear relationship (from that for 24 hours) for absorption. Other references where dermal absorption over shorter exposure periods than 24 hours (assuming a linear relationship) are presented in the following:

- Di Marco P.N. and Buckett K.J in CSMS 1996 in “Derivation of Health Investigation Levels for Beryllium and Beryllium Compounds”
- Di Marco P.N. in CSMS 1993 in “The Assessment and Management of Organochlorine Termiticides” where exposures are assessed over 8 and 10 hours (adults).
- Di Marco P.N. and Buckett K.J in CSMS 1993 in “Derivation of A Health Investigation Level for PCBs”

The methodology presented by Hawley (1985), SEDISOIL (1996) and CSOIL (2001) has been adopted for the assessment of dermal exposures to chemicals identified in soils. On this basis, dermal intake from exposure to soil will be determined using the following equation:

$$\textit{Daily Chemical Intake}_{Ds} = C_s \bullet \frac{SAs \bullet AF \bullet Abs \bullet ET \bullet ME \bullet CF \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

where:

Cs = Concentration in soil (mg/kg)
SAs = Surface area of body exposed to soil (cm^2)
AF = Adherence factor, amount of soil that adheres to the skin per unit area which depends on soil properties and area of body (mg/cm^2 per event)
Abs = Dermal absorption rate (per hour) – based on chemicals specific information or use of default values of 0.005 per hour for adults (as above)
ET = Exposure time to soil (hours/day)
ME = Matrix effect (unitless) – dependent on the nature of dermal data available, by default 0.15 or 15% assumed (discussed above)
CF = Conversion factor of 1x10^{-6} to convert mg to kg
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (dependent on age) (kg)
AT = Averaging time for threshold and non-threshold exposures (days)

Section 5 Exposure Assessment

For the COPC identified in soils, where there are no chemical-specific dermal absorption parameters available and default values as noted above have been used in the assessment.

URS considers that the method of Hawley (1985), SEDISOIL (1996) and CSOIL (2001) is the most appropriate basis for assessment of risks, however given that the variation in methods presented above the calculations have also been presented on the basis of the US approach for the purposes of assessing the sensitivity and uncertainty.

Dermal Contact with Shallow Groundwater

The following equation (as detailed in USEPA 1989 and 1992) has been used to calculate intake of chemicals via dermal exposure to chemicals in shallow groundwater.

$$\textit{Daily Chemical Intake}_{DW} = C_W \bullet \frac{SAw \bullet ET \bullet Kp \bullet CF \bullet EF \bullet ED}{BW \bullet AT} \quad \text{(mg/kg/day)}$$

where:

Cw = Concentration in water (mg/L)
SAw = Surface area of body in contact with water (cm^2)
ET = Exposure time in contact with water (hr/day)
Kp = Dermal permeability/absorption via skin for each chemical in water (cm/hr)
CF = Conversion factor of 1x10^{-3} to convert cm^3 to L
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (dependent on age) (kg)
AT = Averaging time for threshold and non-threshold exposures (days)

Kp is a chemical-specific factor that has been derived for a wide range of chemicals. Values for chemicals evaluated have been obtained from the Risk Assessment Information System (RAIS) database available on the website (http://risk.lsd.ornl.gov/index.shtml) which is maintained by the Oak Ridge Operations of the US Department of Energy. These are also listed in the Toxicity Summaries presented in **Appendix D**.

5.3.2 Exposure Parameters

Exposure parameters that are considered representative of reasonable maximum exposure (RME) have been selected for the receptor groups evaluated. Where available, exposure data has been obtained from Australian sources (CSMS, 1991, 1993, 1996 and 1998, ANZECC 1992, NEPM 1999 and enHealth 2002 and 2003). **Appendix F** presents the calculation on daily intake including the exposure parameters selected and used in the assessment. The following presents a summary of the key assumptions:

Table 5-2 Exposure Parameters Adopted – On- and Off-Site Workers

Receptor Population	Exposure Pathways	Chemical Concentrations	Exposure Parameters
			Parameters relevant for all pathways Body weight of 70 kg Exposure for 12 hours per day (i.e. long work shifts) for 240 days/year (5 days per week for 48 weeks) for 30 years
Worker On site (Adult)	Inhalation of volatile chemicals present in soil and groundwater	Measured soil gas and flux emission data collected (CH2MHill, HLA and URS) from key impacted areas on the site	Inhalation of 1.17 m^3 air per hour indoors (10 hours) and 2.2 m^3 air per hour outdoors (2 hours).
	Ingestion and dermal contact with chemicals in soil	Soil concentrations from available data. Maximum concentration from data for top 1m of soils on site (as mixed during construction works).	Ingestion of 25 mg of soil per day by adults. Once ingested it is assumed that 100% is absorbed into the body. When outdoors it is assumed that the hands and forearms get dirty each day (2300 cm^2 of skin). Once dirty it is assumed that 0.51 mg of soil adheres to each cm^2 of skin. Assume an adult will wash at the end of each day resulting in up to 12 hours of the day dirty.
Worker Off site (Adult)	Inhalation of volatile chemicals present in groundwater	Measured soil gas and flux emission data collected (CH2MHill, HLA and URS) from impacted areas (above impacted groundwater plumes)	Inhalation of 1.17 m^3 air per hour indoors (10 hours) and 2.2 m^3 air per hour outdoors (2 hours).

Table 5-3 Exposure Parameters Adopted - Intrusive Maintenance Workers

Receptor Population	Exposure Pathways	Chemical Concentrations	Exposure Parameters
			Parameters relevant for all pathways Body weight of 70 kg Exposure for 10 hours per day (i.e. long work day) for 60 days/year over 1 year
Intrusive Worker (Adult)*	Inhalation of volatile chemicals present in soil and groundwater (on site and off site)	Where no groundwater is intersected (on site) measured soil gas and flux emission data collected (CH2MHill, HLA and URS) from key impacted areas on the site	Inhalation of 2.2 m^3 air per hour outdoors (assuming all 10 hours is spent in an excavation with no groundwater seepage).
	Ingestion and dermal contact with chemicals in soil (on site only)	Soil concentrations from available data. Maximum concentrations from data for all depths of soil on site.	Ingestion of 25 mg of soil per day by adults. Once ingested it is assumed that 100% is absorbed into the body. When outdoors it is assumed that the hands, forearms and lower legs get dirty each day (4860 cm^2 of skin). Once dirty it is assumed that 0.51 mg of soil adheres to each cm^2 of skin. Assume an adult will wash at the end of each day resulting in up to 12 hours of the day dirty.
	Deep Excavations Off Site		Groundwater is expected to be encountered for only half the days working in the area (30 days per year).
	Ingestion and dermal contact with chemicals in shallow groundwater seepage	Maximum reported concentrations in off site groundwater associated with Plumes 1&2 and Plume 3	Incidental ingestion of 5 mL of groundwater per day. Once ingested it is assumed that 100% is absorbed into the body. When in deep excavations it is assumed that only a portion of the workday will be spent in the excavation when shallow groundwater is present, with up to 2 hours each day considered conservative. When working in the deep excavation it is assumed that the hands, forearms and lower legs get wet (4860 cm^2 of skin) and stays wet for 2 hours.
	Inhalation of volatile chemicals derived from shallow groundwater seepage	Estimated based on maximum shallow groundwater concentrations and a volatilisation factor	Inhalation of 2.2 m^3 air per hour outdoors. Assumed up to 2 hours per day spent in excavation where groundwater seepage is present.

*This includes workers involved in the maintenance of subsurface services in areas on the site or off-site areas by workers who might not be aware of the presence of impacted soils and/or groundwater. Such works are not expected to result in excavations deeper than 2 m depth (as per ANZECC 1992). This assessment does not include a remediation or construction worker on the site as it would be expected that such works would be managed under an appropriate safety, health and environmental management plan that would include appropriate occupational health and safety measures.

5.3.3 Chemical Concentrations in Soil

The assessment of risks associated with the presence of soil contamination has been undertaken for each of the ISZ (i.e. ISZ 1a to 10 located in Areas A to I). This approach has been undertaken to reflect the large area of the site and the distribution of contamination which reflects the industrial activities. Soil contamination is not relevant to the off-site areas. The following process has been used for each area:

- A COPC list is prepared for each Area based on the site COPC list. A COPC is identified for an Area when it is present in any sample above the LOR.
- The maximum concentration of the Area COPCs present in the surface (i.e. 0 to 1 m below ground level) has been identified. This value has been used to assess soil ingestion and dermal contact by all workers on the site.
- The maximum concentration of the Area COPCs present at any depth has been identified. This value has not been used in the assessment and is provided for descriptive purposes and for comparison with the air data.

The maximum concentration has been used in order to provide a conservative assessment of risks and thereby assist in the development of risk management strategies for the site. In the event that the maximum concentration of a specific COPC within an area does not present an unacceptable risk to human health, then there is a low likelihood that the chemical is present across that area at concentrations of concern. However this would be subject to final review of sampling density and validation of the site. In the event that consideration of the maximum concentration exceeds risk targets indicative of acceptable health risks, then there is a likelihood that the COPC warrants either further detailed assessment or consideration with respect to risk management strategies. In this way the assessment of risks associated with ingestion and dermal contact with soil provides an overestimate of actual risks and provides a basis for identification of COPC which warrant management and calculation of risk-based soil concentrations (**Section 7**).

The maximum soil concentrations for each Area that has been used in the risk calculations are summarised in **Section 3**.

5.3.4 Chemical Concentrations in Air

The concentration of volatile COPC that might be present in air has been assessed using the data summarised in **Section 3**.

Due to the soil gas sampling depth (approximately 1 to 2.5 m bgl for maximum concentrations reported) degradation of some volatiles during migration to the surface (through silty clays) could be significant (CSIRO 2004). Hence, where available and detected, measured flux emissions data has been used in preference to soil gas data in the quantification of potential inhalation exposures. Where flux emissions were not detected, or limited data is available, the maximum measured soil gas concentration has been used in the calculation. It should be noted that vapour degradation processes are dominated by aerobic degradation and the rate of degradation is dependent on the following:

- The rate at which a chemical could be degraded aerobically. For example, chlorinated compounds are generally less subject to aerobic degradation than non-chlorinated compounds.
- The rate at which oxygen can be replaced in the soil gas. This is dependent on the nature of the surface cover as well as soil physical properties. The presence of a surface slab can limit the rate of oxygen migration from the surface and reduce the amount of degradation occurring under the slab. Vapour concentrations might therefore be higher under a slab than an uncovered surface. However, in relation to the Orica Villawood site, the rate of oxygen migration would be expected to be limited by the clay soil. The development of differing vapour profiles as a consequence of restricted oxygen migration under a slab occurs predominantly in sand soils with shallow contamination and chemicals with high aerobic degradation rates (CSIRO 2004, Abreu & Johnson 2006). It is expected that the vapour profiles at the Orica Villawood site would be similar beneath and adjacent to slabs,

particularly for chlorinated compounds, thus surface flux data, where available, provides the best estimate of vapour movement from the surface.

Indoor and outdoor (and within excavations) air concentrations in areas on the site (derived from impacts identified in soil and groundwater and calculated from measured soil gas and fluxhood results) and off the site (derived from impacts identified in groundwater and calculated from measured soil gas, fluxhood and ambient air results) have been estimated using a box model adapted from vapour partitioning and transport algorithms published in the USEPA's Superfund Exposure Assessment Manual Farmer Model (USEPA, 1988), also presented within USEPA Soil Screening Guidance (1996 and Supplement 2001) and San Diego Department of Environmental Health, Land and Water Quality Division, Site Assessment and Mitigation, Vapor Risk Model and Guide (December 2000), which has been set up in an Excel^{tm} spreadsheet format.

Vapour concentrations in excavations have been estimated on the basis of measured soil gas concentrations (assumed to be 1 cm from the base of the excavation) and the outdoor volatilisation model presented in ASTM (2002) guidance. Where groundwater is assumed to seep into excavations (off-site areas only), the potential vapour concentrations in the excavation have been estimated using a USEPA volatilisation model relevant to the presence of water (where shallow groundwater concentrations are considered) in an excavation.

Details on the vapour migration modelling undertaken are presented with in **Appendix E**.

5.3.5 Chemical Concentrations in Off-Site Shallow Groundwater

The quantification of potential exposure by workers undertaking deep excavation works in off-site areas has been included at the request of DECCW to assist in planning issues in the off-site areas. The quantification of potential exposure in the offsite areas has considered direct contact with shallow groundwater in the off-site portions of Plumes 1 and 2 as well as Plume 3. The concentrations considered in this assessment are the maximum reported concentrations in shallow off site monitoring wells relevant to these plumes. Only groundwater data from shallow wells and shallow ports of bundled piezometers has been considered as deeper impacts are not considered relevant for the quantification of exposure in this scenario. The relevant concentrations of compounds detected are summarised in **Table 5-4**.

Table 5-4 Maximum Shallow Groundwater Concentrations Off-Site Plumes 1, 2 and 3

Chemicals Detected in Off Site Groundwater	Maximum Concentration Reported (ug/L)	
	Plumes 1 and 2	Plume 3[2]
1,2-dichlorobenzene		47
1,3-dichlorobenzene		5
1,4-dichlorobenzene		230
chlorobenzene	11600	9680
1,1,2-trichloroethane	35	61
1,1,1-trichloroethane		73
1,1-dichloroethane		79
1,1-dichloroethene		270
1,2-dichloroethane (EDC)	82500	150
cis-1,2-dichloroethene	9	7
trichloroethene (TCE)	3750	9430
tetrachloroethene (PCE)	9	5
vinyl chloride	30	
chloroform	1020	55
benzene	1990	140
toluene	5	2770
ethylbenzene		87
total xylenes		238
α-BHC (α-HCH)	0.087	6.2
dieldrin	0.058	
β-BHC (β-HCH)	0.078	
γ-BHC (γ-HCH)	0.08	35.8
δ-BHC (δ-HCH)	0.011	
DDD	9.17	3.7
DDE	4.59	
DDT	11.1	4
hexachlorobenzene	1	0.55

Notes:

Blank cells – where compounds were not reported above the analytical limit of reporting in any of the monitoring wells defined within the Plumes considered.

1 Maximum reported from shallow groundwater from off-site wells within Plumes 1 and 2, namely MW31/41/42, OS01A, OS02A, OS03A, OS04A, OS05A, OS08, OS09A and OS10A.

2 Maximum reported from shallow groundwater from off-site wells within Plume 3, namely MW24, MW25, MW304, OS06A and OS07A and shallow (2m) ports from BP114 and BP216.

* Maximum concentration reported in BP106 (6m port). It is noted that total concentrations of DDD+DDE+DDT were reported in other wells within Plumes 1 and 2 to be significantly lower than the maximum presented in this table. The maximum reported in off-site wells OS 10A was 24.9 µg/L.

Section 6 Risk Characterisation

6.1 General

Risk characterisation is the final step in a quantitative risk assessment. It involves the incorporation of the exposure assessment and toxicity assessment to provide a quantitative assessment of non-threshold carcinogenic risk and threshold health effects. Calculations of risk have been undertaken using an in-house Excel spreadsheet based risk model RiskE (Version 5, 2004). Calculations undertaken in the assessment of risk for each exposure pathway and receptor are presented in **Appendix F**.

6.2 Approach and Assessment Criteria

6.2.1 Risk for Non-Threshold Effects

The potential for unacceptable non-threshold carcinogenic risks associated with exposure to COPC has been evaluated using US EPA methodology.

Non-threshold carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential non-threshold carcinogen. The numerical estimate of excess lifetime cancer risk is calculated as follows:

Carcinogenic Risk = Daily Chemical Intake • Cancer Slope Factor

The total non-threshold carcinogenic risk is the sum of the risk for each chemical for each pathway.

Deciding whether the calculated cancer risk is of concern or not requires identification of an acceptable cancer risk value. The calculation of a cancer risk implies that any exposure to these chemicals could result in an increased risk or probability of contracting cancer over a lifetime. The cancer risk value is expressed as a probability such as 1 in 10,000 ($1x10^{-4}$) or 1 in 1,000,000 ($1x10^{-6}$). At the simplest level these probability values can be converted to population risks as follows:

- An incremental lifetime cancer risk of $1x10^{-6}$, means that in a population of 1 million people which has been exposed to the chemical for their lifetime one additional cancer is predicted over and above the background incidence of cancer in that population (1 million people). For the same population a cancer risk of $1x10^{-4}$ implies that 100 additional cancers are predicted over and above the background incidence (for 1 million people).

These values are extremely low when compared to the background incidence of cancer in our society. The background incidence is in the order of 1 in 4 to 1 in 3 (Fitzgerald, CSMS 1993). This means that for a population of 1,000,000 around 250,000 individuals are expected to contract cancer over a lifetime. An additional $1x10^{-6}$ risk predicts 1 additional individual might develop cancer.

Specific Australian guidance related to the significance of cancer risk estimates is not currently available. Current US EPA policy states that: *"Where the cumulative site risk to an individual based on reasonable maximum exposure for both current and future land use is less than 10^{-4}, … action is generally not warranted unless there are adverse environmental impacts"* (US EPA, 1991). If risks are found to be greater than the 10^{-4} probability, then the US EPA recommends that a preliminary remediation goal of 10^{-6} cancer risk be developed as the point of departure (ibid).

A review of the origins of the 10^{-6} cancer risk number has been undertaken by Kelly (1991) and a review of the development of an Australian approach to the assessment of carcinogenic contaminants has been prepared for discussion by Fitzgerald (1993). Both these reviews indicate that the 10^{-6} was suggested by the United States Food and Drug Authority (USFDA) in 1961, as representing the *de minimis* legal risk. That is, the level of risk that can be identified, in a legal sense, as being representative of negligible or trivial risk. As the more recent US EPA policy (quoted above) indicates, the application of cancer risks has seen the acceptance of higher risk values i.e. 10^{-4} or 1 in 10,000 in the assessment of contaminated sites.

The application of cancer risk values in Australia and elsewhere is generally consistent with the US EPA policy. That is, the 10^{-6} risk value is commonly identified as the point of departure from negligible risk and the 10^{-4} risk value is commonly adopted as indicative of unacceptable risks. The 10^{-6} risk value is sometimes used as the basis for defining ambient standards applicable to wide scale population exposure, for example, the NHMRC and the Agricultural and Resources Management Council of Australia and New Zealand (NHMRC/ARMCANZ 2004) have used the 10^{-6} value for the derivation of the Australian drinking water guidelines for genotoxic carcinogens. The WHO, on the other hand, have used the 10^{-5} risk as the basis for the derivation of the WHO drinking water guidelines (WHO 2004) and the Dutch use the 10^{-4} lifetime cancer risk as the basis for the derivation of human Intervention Values for soil and groundwater for genotoxic carcinogens.

URS understands that a goal of 10^{-5} is generally accepted by Victorian EPA accredited auditors as indicating conditions that might warrant specific management or remedial action. Nonetheless, URS is not aware of any stated policy by the DEC.

Based on the above discussion URS considers that the following guidance with respect to incremental lifetime cancer risks is representative of current practice in NSW:

- Calculated incremental risks below 1 x 10^{-6} would be considered to be effectively zero;
- Calculated incremental risks between 1 x 10^{-6} and 1 x 10^{-5} would be considered acceptable; and
- Calculated risks greater than 1x 10^{-4} would be considered to warrant some form of action or management to reduce the risk.

Where risks fall between 1 x 10^{-5} and 1 x 10^{-4}, then this could warrant further evaluation of the risks to determine whether action is required to reduce the risks.

URS has adopted a Target Risk value of 1 x 10^{-5} as indicating conditions that would warrant further assessment. Risks values below 1 x 10^{-5} are representative of acceptable risks.

6.2.2 Hazard Index for Threshold Effects

The potential for adverse threshold effects, resulting from exposure to a COPC, has been evaluated by comparing an exposure level, expressed as a daily chemical intake, with the adjusted acceptable daily intake (ADI) or equivalent threshold value (tolerable daily intake (TDI), reference dose (RfD)). The resulting ratio is referred to by the USEPA as the hazard quotient (USEPA, 1989) and is derived in the following manner:

$$\textbf{\textit{Hazard Quotient}} = \frac{(\textbf{\textit{Daily Chemical Intake}})}{(\textbf{\textit{ADI}}) - (\textbf{\textit{Background Intake}})}$$

The evaluation of risk associated with threshold chemicals involves a comparison of the total daily intake with the adjusted ADI. The adjusted ADI is that which has been adjusted for background intake (refer to **Appendix D** for details on background intakes) from all other sources so that the hazard quotient calculated compares the chemical intake derived for the specific exposure scenario with the ADI allowable from sources other than background. If the total daily chemical intake exceeds the adjusted ADI, TDI or RfD (i.e. if the hazard quotient exceeds one), then this would indicate potentially unacceptable chemical intakes. The hazard quotient does not represent a statistical probability of an effect occurring.

To assess the overall potential for adverse health effects posed by simultaneous exposure to multiple chemicals, the hazard quotients for each chemical and exposure pathway have been summed. The resulting sum is referred to by the USEPA as the hazard index (HI) (USEPA, 1989). The HI approach assumes that multiple sub-threshold exposures to several chemicals could result in a cumulative adverse health effect, and exposures are summed over all intake routes.

If the Hazard Index is less than one, cumulative exposure to the site chemicals is judged unlikely to result in an adverse effect. If the index is greater than one, a more detailed and critical evaluation of the risks (including consideration of specific target organs affected and mechanisms of toxic action of the chemicals of concern) would be required to ascertain whether the cumulative exposure would in fact be likely to harm exposed individuals.

6.3 Summary of Risk

The assessment of risks to human health for the Orica Villawood site has been undertaken for the key exposure pathways identified in **Section 5**, intake calculations as presented in **Section 6** and toxicity values as presented in **Section 4** (**Table 4-1**). The following presents a summary and discussion of the calculated risks. Spreadsheet outputs from the risk calculations are included in **Appendix F**.

6.3.1 Impacted Soil Zones 1a, 1b and 2 (On-Site)

The following tables present a summary of calculated risks for ISZ 1a/1b and ISZ 2 located within Area I on the site. The calculations presented are based on the maximum soil concentrations and representative air data for the COPC identified in the area.

Table 6-1 Calculated Risks for ISZ 1a and 1b for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
Commercial/Industrial Worker			
Ingestion of COPC Identified in Shallow Soils	2.3×10^{-6}	120	120
Dermal Contact with COPC Identified in Shallow Soils	9.7×10^{-7}	50	50
Inhalation of volatile COPC derived from soils and groundwater	4.5×10^{-7}	0.018	0.00030
Total Risk	$\mathbf{4 \times 10^{-6}}$	**170**	**170**
Intrusive Worker			
Ingestion of COPC Identified in Soils	1.9×10^{-8}	29	
Dermal Contact with COPC Identified in Soils	1.7×10^{-8}	26	
Inhalation of volatile COPC derived from soils and groundwater (occupational assessment)	2.7×10^{-7}	0.0079	
Total Risk	$\mathbf{3 \times 10^{-7}}$	**56**	
Target Risk	1×10^{-5}	1	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 1a and 1b can be made:

- Non-threshold risks are **less than** the target risk for all workers assessed.
- The threshold HI is **greater than** the target risk for all workers assessed. In the order of 70% of the risk is attributable to soil ingestion and 30% dermal contact. The bulk of the risk is attributable to DDX in soil (92%).

Table 6-2 Calculated Risks for ISZ 2 for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
Commercial/Industrial Worker			
Ingestion of COPC Identified in Shallow Soils	3.4×10^{-6}	0.18	0.18
Dermal Contact with COPC Identified in Shallow Soils	1.4×10^{-6}	0.075	0.075
Inhalation of volatile COPC derived from soils and groundwater	4.5×10^{-7}	0.018	0.00030
Total Risk	$\mathbf{5 \times 10^{-6}}$	**0.3**	**0.3**
Intrusive Worker			
Ingestion of COPC Identified in Soils	2.8×10^{-8}	0.045	
Dermal Contact with COPC Identified in Soils	2.5×10^{-8}	0.040	
Inhalation of volatile COPC derived from soils and groundwater (occupational assessment)	2.7×10^{-7}	0.0079	
Total Risk	$\mathbf{3 \times 10^{-7}}$	**0.09**	
Target Risk	1×10^{-5}	1	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 2 can be made:

- Non-threshold risks are **less than** the target risk for all workers assessed.
- The HI (threshold risk) is **less than** the target risk for all workers assessed.

6.3.2 Impacted Soil Zone 3 (On-Site)

The following table presents a summary of calculated risks for ISZ 3 located within Area F on the site. The calculations presented are based on the maximum soil concentrations and representative air data for the COPC identified in the area.

Table 6-3 Calculated Risks for ISZ 3 for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
Commercial/Industrial Workers			
Ingestion of COPC Identified in Shallow Soils	2.7 $\times 10^{-7}$	0.26	0.26
Dermal Contact with COPC Identified in Shallow Soils	1.2 $\times 10^{-7}$	0.11	0.11
Inhalation of volatile COPC derived from soils and groundwater	9.1 $\times 10^{-9}$	0.00041	0.0000045
Total Risk	**4 $\times 10^{-7}$**	**0.4**	**0.4**
Intrusive Workers			
Ingestion of COPC Identified in Soils	6.9 $\times 10^{-8}$	0.065	
Dermal Contact with COPC Identified in Soils	6.2 $\times 10^{-8}$	0.058	
Inhalation of volatile COPC derived from soils and groundwater (occupational assessment)	3.5 $\times 10^{-9}$	0.000051	
Total Risk	**1 $\times 10^{-7}$**	**0.1**	
Target Risk	1 $\times 10^{-5}$	1	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 3 can be made:

- Non-threshold risks are **less than** the target risk for all workers assessed.
- The HI (threshold risk) is **less than** the target risk for all workers assessed.

6.3.3 Impacted Soil Zone 4 (On-Site)

The following table presents a summary of calculated risks for ISZ 4 located within Area A on the site. The calculations presented are based on the maximum soil concentrations and representative air data for the COPC identified in the area.

Table 6-4 Calculated Risks for ISZ 4 for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
Commercial/Industrial Workers			
Ingestion of COPC Identified in Shallow Soils	NA	5.9	5.9
Dermal Contact with COPC Identified in Shallow Soils	NA	2.5	2.5
Inhalation of volatile COPC derived from soils and groundwater	1.9×10^{-7}	0.011	0.000022
Total Risk	**2×10^{-7}**	**8**	**8**
Intrusive Workers			
Ingestion of COPC Identified in Soils	3.2×10^{-9}	1.5	
Dermal Contact with COPC Identified in Soils	2.9×10^{-9}	1.3	
Inhalation of volatile COPC derived from soils and groundwater (occupational assessment)	7.4×10^{-6}	0.012	
Total Risk	**7×10^{-6}**	**3**	
Target Risk	1×10^{-5}	1	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 4 can be made:

- Non-threshold risks are **less than** the target risk of 1×10^{-5} for all workers assessed.
- The HI (threshold risk) is **greater than** the target risk for all workers assessed. This is attributable to the ingestion of COPC in soil with approximately 90% of the HI being due to DDX. It is noted that DDX impacted soil has been remediated in this area (CH2MHill 2007) and the calculated HI is expected to be relevant to the excavated impacted soil from this area stored in the shed onsite rather than remaining soil impacts within ISZ 4.

6.3.4 Impacted Soil Zone 5 (On-Site)

The following table presents a summary of calculated risks for ISZ 5 located within Area B, with some overlap into Area G on the site. The calculations presented are based on the maximum soil concentrations and representative air data for the COPC identified in the area.

Table 6-5 Calculated Risks for ISZ 5 for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
Commercial/Industrial Workers			
Ingestion of COPC Identified in Shallow Soils	7.5×10^{-7}	1.9	1.9
Dermal Contact with COPC Identified in Shallow Soils	3.2×10^{-7}	0.82	0.82
Inhalation of volatile COPC derived from soils and groundwater	6.4×10^{-5}	0.24	0.00018
Total Risk	**7×10^{-5}**	**3**	**3**
Intrusive Workers			
Ingestion of COPC Identified in Soils	9.5×10^{-9}	0.51	
Dermal Contact with COPC Identified in Soils	8.5×10^{-9}	0.46	
Inhalation of volatile COPC derived from soils and groundwater (occupational assessment)	3.6×10^{-5}	0.0028	
Total Risk	**4×10^{-5}**	**1**	
Target Risk	1×10^{-5}	1	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 5 can be made:

- Non-threshold risks are **greater than** the target risk for all workers assessed in ISZ 5. This is attributable to inhalation of 1,2,3-trichloropropane which accounts for 98% of the total inhalation risk.
- The threshold HI is **greater than** the target value for potential exposures by commercial/industrial workers on ISZ5. In the order of 85% of the risk is attributable to soil ingestion and dermal contact. The bulk of the risk is attributable to β-BHC (35%) and DDX (60%).
- The threshold HI for intrusive workers is **equal** to the target risk.

6.3.5 Impacted Soil Zones 6 and 10 (On-Site)

The following tables presents a summary of calculated risks for ISZ 6 and ISZ 10, both located within Area C of the site. The calculations presented are based on the maximum soil concentrations and representative air data for the COPC identified in the area.

Table 6-6 Calculated Risks for ISZ 6 for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI
Commercial/Industrial Workers		
Ingestion of COPC Identified in Shallow Soils	4.1×10^{-6}	0.84
Dermal Contact with COPC Identified in Shallow Soils	1.7×10^{-6}	0.36
Total Risk	**6×10^{-6}**	**1**
Intrusive Workers		
Ingestion of COPC Identified in Soils	3.4×10^{-8}	0.30
Dermal Contact with COPC Identified in Soils	3.1×10^{-8}	0.27
Total Risk	**7×10^{-8}**	**0.6**
Target Risk	1×10^{-5}	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

Table 6-7 Calculated Risks for ISZ 10 (Pharmaceutical Building) for Workers On-Site#

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI
Commercial/Industrial Workers		
Ingestion of COPC Identified in Shallow Soils	1.4×10^{-6}	1.2
Dermal Contact with COPC Identified in Shallow Soils	5.9×10^{-7}	0.5
Total Risk	**2×10^{-6}**	**2**
Intrusive Workers		
Ingestion of COPC Identified in Soils	1.2×10^{-8}	0.30
Dermal Contact with COPC Identified in Soils	7.5×10^{-8}	0.30
Total Risk	**9×10^{-8}**	**0.6**
Target Risk	1×10^{-5}	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

\# Risks to human health only relevant of the existing building is removed and impacted soil located beneath the slab is exposed. While the slab remains risks to workers are negligible.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 6 and ISZ 10 can be made:

- Non-threshold risk is **less than** the target risk in both ISZ 6 and ISZ 10 (beneath the pharmaceutical building) for all workers assessed.
- The HI (threshold risk) for commercial/industrial workers is **equal to** the target risk for ISZ 6 and **greater than** the target risk for ISZ 10, the area beneath the pharmaceutical building (if the existing building is removed).. In the order of 70% of the risk is attributable to soil ingestion and 30% to dermal contact. The bulk of the risk is attributable to β-BHC (50%) and DDX (50%). It is noted that impacted soil has been remediated in ISZ 6, in the vicinity of the former trade waste lines, (CH2MHill 2007). Hence the calculated HI is expected to be relevant to the excavated impacted soil from this area stored in the shed onsite rather than remaining soil impacts within ISZ 6. Impacted soil from ISZ 10 was not remediated during these works as the material was beneath the Pharmaceuticals Building. The Pharmaceuticals Building is to remain on the site and hence current/future risks, where impacted soil remains beneath the slab, are negligible.
- The HI (threshold risk) for intrusive workers is **less than** the target risk.

6.3.6 Impacted Soil Zone 7 (On-Site)

The following tables presents a summary of calculated risks for ISZ 7, located within Area H of the site. The calculations presented are based on the maximum soil concentrations and representative air data for the COPC identified in the area.

Table 6-8 Calculated Risk for ISZ 7 for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI
Commercial/Industrial Workers		
Ingestion of COPC Identified in Shallow Soils	NA	7.5
Dermal Contact with COPC Identified in Shallow Soils	NA	3.2
Total Risk		**11**
Intrusive Workers		
Ingestion of COPC Identified in Soils	NA	1.9
Dermal Contact with COPC Identified in Soils	NA	1.7
Total Risk		**4**
Target Risk	$1x10^{-5}$	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 7 can be made:

- The threshold HI for commercial/industrial workers is **greater than** the target risk. In the order of 70% of the risk is attributable to soil ingestion and 30% dermal contact. The bulk of the risk is attributable to β-BHC (90%).
- The threshold HI for intrusive workers is **greater than** the target risk and is essentially all attributable to soil ingestion and dermal contact and the presence of β-BHC.

6.3.7 Impacted Soil Zone 8 (On-Site)

The following table presents a summary of calculated risks for ISZ 8, located within Area H of the site. The calculations presented are based on the maximum soil concentrations and representative air data for the COPC identified in the area.

Table 6-9 Calculated Risks for ISZ 8 for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
Commercial/Industrial Workers			
Ingestion of COPC Identified in Shallow Soils	$4.9x10^{-7}$	180	180
Dermal Contact with COPC Identified in Shallow Soils	$2.1x10^{-7}$	76	76
Inhalation of volatile COPC derived from soils and groundwater	$3.8x10^{-7}$	0.018	0.00030
Total Risk	**$1x10^{-6}$**	**260**	**260**
Intrusive Workers			
Ingestion of COPC Identified in Soils	$1.2x10^{-8}$	45	
Dermal Contact with COPC Identified in Soils	$1.1x10^{-8}$	41	
Inhalation of volatile COPC derived from soils and groundwater (occupational assessment)	$2.3x10^{-7}$	0.0078	
Total Risk	**$3x10^{-7}$**	**86**	
Target Risk	$1x10^{-5}$	1	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 8 can be made:

- Non-threshold risks are **less than** the target risk for all workers assessed in ISZ 8.
- The threshold HI for commercial/industrial workers is **greater than** the target risk. In the order of 70% of the risk is attributable to soil ingestion and 30 % dermal contact. The bulk of the risk is attributable to β-BHC (95%). Hazard quotients greater than 1 were also calculated δ-BHC, DDX and dieldrin.
- The threshold HI for intrusive workers is **greater than** the target risk and essentially all attributable to soil ingestion and dermal contact and the presence of β- and δ-BHC.

6.3.8 Impacted Soil Zone 9 (On-Site)

The following table presents a summary of calculated risks for ISZ 9, located in an area overlapping a portion of Areas G and H. The calculations presented are based on the maximum soil concentrations and representative air data for the COPC identified in the area.

Table 6-10 Calculated Risks for ISZ 9 for Workers On-Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
Commercial/Industrial Workers			
Ingestion of COPC Identified in Shallow Soils	$7.6x10^{-7}$	4.9	4.9
Dermal Contact with COPC Identified in Shallow Soils	$3.2x10^{-7}$	2.0	2.0
Inhalation of volatile COPC derived from soils and groundwater	$3.8x10^{-8}$	0.00015	0.0000093
Total Risk	**$1x10^{-6}$**	**7**	**7**
Intrusive Workers			
Ingestion of COPC Identified in Soils	$6.4x10^{-9}$	1.2	
Dermal Contact with COPC Identified in Soils	$5.7x10^{-9}$	1.1	
Inhalation of volatile COPC derived from soils and groundwater (occupational assessment)	$2.3x10^{-8}$	0.00017	
Total Risk	**$3x10^{-8}$**	**2**	
Target Risk	$1x10^{-5}$	1	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

The following conclusions in relation to exposure by commercial/industrial workers and intrusive workers within ISZ 9 can be made:

- Non-threshold risks are **less than** the target risk for all workers in ISZ 9.
- The threshold HI for commercial/industrial workers is **greater than** the target risk. In the order of 70% of the risk is attributable to soil ingestion and 30 % dermal contact. The bulk of the risk is attributable to DDX (55%) and dieldrin (26%).
- The threshold HI for intrusive workers is **greater than** the target risk and essentially all attributable to soil ingestion and dermal contact and the presence of DDX and dieldrin.

6.3.9 Groundwater Plumes (On and Off-Site)

The following tables presents a summary of calculated risks for areas that overlie groundwater plumes on site (excluding areas on site that also overlie ISZ areas) (**Table 6-11**) as well as areas located off-site and downgradient of the site (**Table 6-12**).

Risks associated with potential inhalation exposures have been calculated for Plume 3 (on and off site), Plumes 4 and 5 (on site based on data from Plume 3), Plume 2 (on site and off site) and Plume 1 (off site) based on available and representative air data.

Risks associated with potential direct contact with shallow groundwater by intrusive works in off-site areas above Plumes 1 and 2 and Plume 3 have also been calculated and are presented in the following table.

Table 6-11 Calculated Risks for Areas Located Above Groundwater Plumes Only – Workers on Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
<u>Commercial/Industrial Workers</u>			
Above Groundwater Plumes 4 and 5 (above plumes only based on calculations for Plume 3)			
Inhalation of volatile COPC derived from groundwater	1.3×10^{-9}	NA	NA
Above Groundwater Plume 3 (excluding ISZ 4)			
Inhalation of volatile COPC derived from groundwater	1.3×10^{-9}	NA	NA
Above Groundwater Plume 2 (also relevant to Plume 1)			
Inhalation of volatile COPC derived from groundwater	8.3×10^{-6}	0.0022	0.000015
<u>Intrusive Workers</u>**			
Above Groundwater Plume 3 (excluding ISZ 4) – also relevant for areas above Plumes 4 and 5			
Inhalation of volatile COPC (occupational)	6.2×10^{-10}	0.00000086	
Above Groundwater Plumes 1 and 2			
Inhalation of volatile COPC (occupational)	2.6×10^{-6}	0.000089	
Target Risk	1×10^{-5}	1	1

<u>Notes:</u>

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

** Assessment of potential exposure by intrusive works on site above groundwater plumes (not above ISZs) based on measured soil gas data and the assumption that groundwater will not be intersected and any deep works will be managed under an appropriate site management plan.

Table 6-12 Calculated Risks for Areas Located Above Groundwater Plumes Only – Workers Off Site

Exposure Pathway	Calculated Non-Threshold Risk	Calculated HI	Calculated HI TWA Exposure Standards
Commercial/Industrial Workers			
Above Groundwater Plume 3			
Inhalation of volatile COPC derived from groundwater	1.3×10^{-9}	NA	NA
Above Groundwater Plume 2			
Inhalation of volatile COPC derived from groundwater	7.6×10^{-6}	0.0081	0.0000065
Above Groundwater Plume 1			
Inhalation of volatile COPC derived from groundwater	NA	0.0025	0.0000012
Intrusive Workers – No Groundwater Intersected			
Above Groundwater Plume 3			
Inhalation of volatile COPC (occupational)	6.2×10^{-10}	0.00000086	
Above Groundwater Plumes 1 and 2			
Inhalation of volatile COPC (occupational)	2.6×10^{-6}	0.000089	
Intrusive Workers - Deep Works where Groundwater Intersected**			
Above Groundwater Plume 3			
Inhalation of volatile COPC (occupational)	1.8×10^{-7}	0.0012	
Incidental ingestion of shallow groundwater	5.6×10^{-10}	0.0035	
Dermal contact with shallow groundwater	6.1×10^{-9}	0.074	
Above Groundwater Plumes 1 and 2			
Inhalation of volatile COPC (occupational)	8.4×10^{-6}	0.014	
Incidental ingestion of shallow groundwater	9.5×10^{-8}	0.0028	
Dermal contact with shallow groundwater	4.1×10^{-7}	0.096	
Target Risk	1×10^{-5}	1	1

Notes:

* Risk values from the spreadsheet have been rounded to no more than two significant figures; hence the sum of individual risks might not add up exactly to the total presented.

** Assessment of potential exposure by intrusive works on site above groundwater plumes off-site based on the assumption that deep works might be undertaken and shallow groundwater intersected. The assessment is considered to be be overly conservative for most scenarios where shallow groundwater will not be intersected where exposures and risks presented for intrusive workers (no groundwater intersected) are considered more representative.

The following conclusions for areas located above only groundwater plumes on and off the site can be made:

- Non-threshold risk for the commercial/industrial worker on and off the site is **less than** the target risk.
- The HI (threshold risk) for commercial/industrial workers on and off the site is **less than** the target risk.
- The non-threshold risks and threshold HI for intrusive workers are **less than** the target risks.

6.4 Overall Assessment

6.4.1 On-Site

The risk characterisation indicates the potential for unacceptable risks to be associated with many of the source zones identified. The prime exposure pathways for concern are ingestion and dermal contact with soil. Inhalation generally presents a minor contribution to the risk with the calculated risk associated with inhalation exposures less than the adopted target for all areas with the exception of ISZ 5 where the presence of 1,2,3-trichloropropane dominates the calculated non-threshold risk.

As the assessment has been based on the maximum concentrations present in soil within the site areas, the assessment provides a guide to those source zones and COPC that would require particular consideration in the further management and development of the site. The assessment presents an overestimate of risks for a worker who would spend time across many areas of the site as the average exposure concentration will be substantially less than that used in this assessment.

The following presents a summary of outcome of the risk characterisation presented for key areas of the site. The prime COPC driving the calculated risk are also presented.

Table 6-13 Summary of Key Risk Issues on Site

Key Area On Site	**Calculated Risk (√ acceptable or less than or equal to target and X greater than target and requires management)**		
	Commercial/ Industrial Workers	**Intrusive Workers**	**Comments and Prime COPC**
ISZ 1a and 1b	X	X	Ingestion and dermal contact with DDX in soil
ISZ 2	√	√	
ISZ 3	√	√	
ISZ 4	X	X	Ingestion and dermal contact with DDX in soil – excavated and stored in shed onsite
ISZ 5	X	√	Ingestion and dermal contact with β-BHC and DDX in soil Inhalation for 1,2,3-trichloropropane
ISZ 6	√	√	Soil is noted to have been excavated and stored in shed onsite
ISZ 10	√ (where building remains) X (if building is removed)	√	Negligible risks where impacted soil remains beneath slab. If the building is removed key exposures are associated with ingestion and dermal contact with β-BHC and DDX in soil.
ISZ 7	X	X	Ingestion and dermal contact with β-BHC in soil.
ISZ 8	X	X	Ingestion and dermal contact with β- and δ-BHC, dieldrin and DDX in soil
ISZ 9	X	X	Ingestion and dermal contact with β- and dieldrin and DDX in soil
On site plumes			
Groundwater Plume 3	√	√	
Groundwater Plumes 4 and 5	√	√	
Groundwater Plume 2 (and 1)	√	√	

6.4.2 Off-Site

The assessment of inhalation exposure off site indicates a low and essentially negligible risk for existing off-site (slab-on-grade) commercial premises that might be located above inferred groundwater Plumes 1, 2 or 3. In addition risks to off-site workers undertaking intrusive works (including deep works that could intersect shallow groundwater) are considered to be low and essentially negligible. This conclusion is also valid for visitors to areas surrounding the site.

The assessment of this area relies directly on measured soil gas, sub-slab soil gas and ambient air data. While a number of sampling events have been conducted in the off-site areas, it is appropriate that additional data is collected to enable an assessment of variability over different ambient conditions and following remediation of the site.

Section 7 Environmental Risk

7.1 General

The Orica Villawood site is located within an industrial area and the land use is to remain commercial/industrial which limits the need to consider risks to the terrestrial environment on site. It is noted however, that a small area of regenerated bush land is located along the western boundary of Area B and might be of a type that is listed as endangered. Any development of the site including implementation of works to address risks to human health would need to be cognisant of the bush land and regulatory requirements for protection.

The prime focus of environmental risks is the potential for migration of contaminants off site and the degradation of the receiving environment. As groundwater is characterised as being of poor quality with respect to salinity and yield then the prime issue with respect to degradation of the environment is potential effects on receiving water.

7.2 Contaminant Migration

The groundwater investigations conducted since 2000 have shown the presence of contamination from volatile and semi-volatile organic compounds consistent with historical site operations and identified soil contamination. HLA (2005) and HLA (2006) describe the groundwater plume configurations and migration pathways. The prime groundwater contaminant plumes identified in HLA (2005) are for:

- Chlorobenzene (MCB);
- EDC;
- TCE; and
- DDT/DDD.

The current understanding of the extent of these plumes is illustrated in Figure F5 for ENSR (2009), reproduced in **Appendix A**. Further detailed contaminant plots are presented in the HLA (2005) report.

Based on the available data, the existing groundwater plumes have not migrated to or discharged to Byrnes Creek. The network of monitoring wells includes bundled piezometers (BP109 and BP110) adjacent to Byrnes Creek. These bores confirm that groundwater is expected to discharge to the creek and show no evidence that the dissolved phase plumes associated with the Orica Villawood site have reached the creek.

The potential for groundwater impacts identified beneath the site and in down-gradient off-site areas to migrate further towards Byrnes Creek has been subject to ongoing investigation from 2005 to 2009 as additional data has been collected and groundwater modelling has been completed. The Conceptual Site Model presented in the ENSR (2009) Addendum to the RAP (as summarised in **Section 3.2**) provides the most comprehensive review of all available information (including groundwater modelling undertaken by Laase [2007]) with respect to the off-site migration of the groundwater plumes. The following conclusion was provided within the Conceptual Site Model (ENSR 2009) that relates to the potential for off-site groundwater migration and discharge to Byrnes Creek:

> *"The groundwater contaminant plumes are stable due to matrix diffusion and to some extent biodegradation, so even though groundwater may reach the Byrnes Creek concrete lined channel, the contaminants will not. Off-site monitoring points within and south of Christina Road indicate no contamination has reached the Byrnes Creek concrete lined channel. Laase (2007) indicated plumes attenuated by matrix diffusion and contaminants would not reach the Byrnes Creek concrete lined channel within 100 years and, based on the 100 year EDC plume, the edge of Plumes 1 and 2 would still be hundreds of metres from the Byrnes Creek concrete lined channel...". "There is very little change between 5 and 140 years, which further supports the conceptual model of contaminants not migrating to the Byrnes Creek concrete lined channel."*

Site investigations have intersected perched groundwater at various locations across the site. The perched groundwater does not appear uniformly across the site and has been found to be associated with site features such as backfill sands in former tank pits. The perched groundwater shows contamination consistent with the locations on the site with the degree of contamination being highly variable.

Perched groundwater can provide a mechanism for short-circuiting groundwater flow from the site via stormwater drains and other service lines. The extent to which this might be occurring or might have occurred in the past is unknown. It is therefore not possible to estimate the risk associated with this potential migration pathway. The proposed remediation of the site, as outlined in the RAP will remove remaining contaminated perched groundwater from the site, removing the potential for future issues associated with potential discharge to drains.

Similarly, surface water discharge also presents a mechanism whereby contaminants could discharge from the site. The extent to which this might have occurred in the past is unknown and risks cannot be estimated. Surface water control is part of the site management requirements and needs to be considered in the development of remediation options.

7.3 Conclusions

The site investigations indicate a low potential for contamination associated with the Orica Villawood site to adversely affect off-site environmental receptors. This conclusion is based on the following:

- Given the industrial land use, consideration of on-site terrestrial environmental receptors would not normally be considered relevant. However, site management and remediation might need to be cognisant of the regenerated bush land located on the north-western boundary;
- The current understanding that the existing groundwater plumes are stable due to matrix diffusion and, to a lesser degree, biodegradation. Hence groundwater plumes will not reach or discharge to Byrnes Creek; and
- The proposed removal of contaminated perched groundwater and management of surface water within the RAP.

On the basis of the above, environmental issues associated with on-site soil or groundwater do not need to be further considered in the derivation of risk-based concentrations (refer to **Section 8**).

Section 8 Risk-Based Soil Concentrations

8.1 Approach

Risk-based soil concentrations (RBSC) have been calculated for each ISZ where the potential for elevated risk has been identified. These are ISZ 1a/1b, ISZ 4, ISZ 5, ISZ 7, ISZ 8, ISZ 9 and ISZ 10. In addition, risk-based site-wide criteria (RBSWC) have been derived that can be applied in any area on the site and are recommended for use in the RAP.

The RBSC/RBSWC have been derived for on-site areas only based on the protection of human health. No environmentally sensitive areas have been identified on the site and future use is expected to remain commercial/industrial. The conceptual model developed by ENSR (RAP Addendum, 2009) summarises the key aspects associated with historical contamination and current groundwater conditions. Specifically the RAP Addendum identified that the groundwater plumes are stable and that the contamination identified in groundwater (on and off the site) would not reach Byrnes Creek (nearest point of discharge) at any point in the future. Groundwater beneath the site or in down-gradient industrial premises is not (and would not be in the future) extracted for any purpose. No unacceptable risks to human health in off-site areas have been identified (refer to **Section 6** for summary). Hence the derivation of the RBSC/RBSWC has not further considered impacts to groundwater. It is noted that the RAP has focused on the removal of soil source zones and impacts on the Villawood site (refer to ENSR 2009 for further discussion on issues associated with groundwater remediation).

RBSC have been calculated using the exposure and toxicity assumptions detailed in **Sections 4 and 5**. Values have been calculated for each COPC with consideration of the potential contribution (or significance) to the total risk. For example, DDX and BHC contribute significantly to the total risk in a number of key areas on the site, hence a greater proportion of the total target risk has been assumed for these chemicals, with lower targets set for less significant chemicals.

Target risks (refer to **Section 8.2** below) have been set assuming a combined exposure to all of the COPC identified in the key areas and across the whole site. While it is considered unlikely that any one business would occupy the entire site, it is expected that during remediation and subsequent development of the site soil will be moved across the site (irrespective of ISZ areas). Hence the RBSWC have been developed and are recommended for use in the RAP.

The criteria derived for an individual chemical assumes that all other COPC are present on the site (or within the ISZ) at the respective criteria.

The magnitude of the RBSC has been set by adjusting concentrations of key contributors to the total risk in each area down from the maximum values until the target risks are achieved for the sum of risks derived from all chemicals, with consideration of the most significant contributors to the total risk. This means that the RBSC might be substantially lower than values that would be calculated for an individual chemical or for a mixture of a smaller number of chemicals. Where the RBSC has been calculated for a COPC that does not contribute significantly to the risk in any area, then the RBSC value selected might be higher than the maximum concentration found on site (and remaining at a level where the calculated risk remains low and does not contribute significantly to the total risk) reflecting the potential for higher concentrations to be present on the site. For volatile COPC, this has only involved a rounding up of the maximum concentrations reported on the site. While inhalation exposures generally do not contribute significantly to the total risk, a significant increase in allowable soil concentrations could result in unacceptable inhalation exposures. Increased RBSC for volatile COPC that are greater than presented could be possible, however relevant soil gas and/or flux emissions sampling must be undertaken to validate such values.

The identification of the RBSWC has considered the following in relation to the RBSC for each area:

- For most key chemicals the lowest RBSC from each area has been adopted as the RBSWC, with the exception of the following:
    - For volatile key chemicals, the highest RBSC has been adopted - where data is available to demonstrate that there are no significant vapour issues from these locations, and the

overall contribution to the target risk is low. This has been undertaken for all the volatile key chemicals with the exception of PCE, benzene and 1,4-dichlorobenzene, where the risk contributed significantly to the total, hence the lower RBSC from all areas was adopted; and

  - For others, the RBSWC has been derived to balance the total risk from all key chemicals such that it remains acceptable, and the size of remediation areas (based on available data).

The derivation of RBSC/RBSWC on the site has assumed that COPC identified at any depth in soil could be brought to the surface during excavation and construction. Hence the values presented are relevant for all soil depths on the site.

It should be noted that the RSBC/RBSWC for 1,2,3-trichloropropane has been presented based in direct exposure pathways only at this stage. The chemical was only detected above the LOR in one soil sample in ISZ 5, yet is detected in soil gas at a concentration that is sufficiently high to be of potential concern. Further assessment of the presence of this compound would be warranted with further validation of soil gas concentrations as required.

It is also noted that the calculation of RBSC/RBSWC has adopted the most conservative methodology for the calculation of intake derived from dermal exposures using the maximum intake derived from either method as outlined in **Section 5.3.1**.

As a consequence of the above approach, the RBSC/RBSWC are only applicable to the Villawood site and are not generic guidelines that could be applied to other sites.

The RBSC/RBSWC may be used for the following purposes:

- Reviewing soil data from any ongoing investigations. If all COPC are below the RBSC/RBSWC, then further assessment of the health risks would not be warranted.
- Use of the RBSWC as conservative remediation criteria. However, the final selection of remediation criteria could be determined by issues other than risk to human health. In addition criteria relevant to scheduled chemicals, as outlined in the Scheduled Chemical Wastes Chemical Control Order 2004 (EPA NSW 2004) might need to be considered in the use of RBSWC as remediation criteria. The scheduled chemicals are covered under the Stockholm Convention on Persistent Organic Pollutants and have been identified based on their persistence, tendency for bioaccumulation and toxicity. Also, concentrations might be varied to reflect different proportions of COPC in the event that non health-based criteria are used for selected COPC.

8.2 Target Risk for RBSC/RBSWC

The RBSC/RBSWC have been calculated for non-threshold and threshold COPC assuming exposure via ingestion and dermal contact. The risk characterisation (**Section 6**) indicates that these pathways contribute the majority of the risk with inhalation being a minor component. In order to provide an additional safety margin to account for potential variability in exposure via inhalation the target risk values have been set at 60% to 80% of the target risks used in the risk characterisation (**Section 6**), with a lower risk target adopted in areas where inhalation risks have been identified to contribute up to 40% of the total. Thus the following target risks have been used:

- Non-threshold – Excess lifetime cancer risk of 8×10^{-6}.
- Threshold – HI of 0.6 for ISZ 1a/1b and ISZ 8.
- Threshold – HI of 0.8 for the remaining areas and for the whole-site.

This target applies to the sum of the risks for each COPC present in each ISZ and across the whole site at the RBSC/RBSWC thus assuming an additive effect.

8.3 RBSC/RBSWC Values

Table 8-1 presents a summary of the RBSC derived for each COPC identified in the key ISZ identified on the site. Only those key chemicals that contribute most significantly to the total risk in each ISZ have been adjusted to determine RBSC. In addition the table also presented the derived RBSWC for all the COPC identified across the site. The calculated risk from the RBSC/RBSWC meet the target risk levels defined above for both long-term on-site workers and intrusive workers.

RBSC have not been presented for ISZ 2, ISZ 3 and ISZ 6 as the calculated risks to workers in these areas were less than or equal to the adopted target level indicating acceptable levels of risk in these areas. It should be noted that in the event that further sampling or validation works report concentrations in soil that are greater than considered in this assessment (surface soils), then risks might need to be revised and the RBSWC may be used for the purpose of comparison and/or remediation as required.

It is also noted that while RBSC are presented for ISZ 10, this material remains beneath the slab of the Pharmaceuticals Building that is to remain. Risks are negligible while the building remains and hence the RBSC are relevant to future developments only where the building is removed.

Calculations undertaken to establish the RBSC/RBSWC are presented in **Appendix G**.

The derived RBSWC have been adopted in the RAP (AECOM, 2010) in reviewing the soil data and to assist in the determination Impacted Soil Zones for Remediation (refer to Sections 7 and 8 of the RAP). These zones, illustrated in **Figure 6**, are the soil areas that have been identified in the RAP (AECOM, 2010) as requiring some level of remediation.

Table 8-1 Summary of Risk-Based Soil Concentrations Derived for Key Source Areas - Orica Villawood Site

COPC	**RBSC for Key Source Zones On Site (ISZ) (mg/kg)**							**RBSWC for whole site (mg/kg)**
	ISZ 1a/1b**	**ISZ 4*^**	**ISZ 5****	**ISZ 7**	**ISZ 8****	**ISZ 9**	**ISZ 10##**	
hexachlorobenzene (HCB)***	10	15	5	30	15			5^{C}
1,2-dichloroethane (EDC)	55	700	30		10			700^{A}
vinyl chloride	10							10^{A}
chloroform	80	5	5		45			80^{A}
carbon tetrachloride	10							10^{A}
trichloroethene (TCE)	400	100	5		15			400^{A}
tetrachloroethene (PCE)					650	5		5^{B}
1,1,2-trichloroethane			10					10^{A}
chlorobenzene	2500		600					2500^{A}
benzene	5	10			25	10	5	5^{B}
toluene	200				200			200^{A}
ethylbenzene	200		150					200^{A}
xylenes	200		800				200	800^{A}
PAHs (BaP equivalent)	24		36		40	40	40	10^{D}
1,4-dichlorobenzene	40		15		200			15^{B}
1,2,3-trichloropropane			0.5#					0.5^{A}
a-HCH (a-BHC)***	1.5	5	2	600	500	500	150	30^{D}
b-HCH (b-BHC)***	2.7	15	8	20	8	20	23	15^{D}
d-HCH (d-BHC)***	1.2	2	4		5			1.2^{C}
g-HCH (g-BHC or lindane)***	12	50	8	1000	400	500	150	15^{D}
dieldrin***					50	50		15^{D}
DDX (sum of DDT, DDE and DDD)***	2300	1800	1900	900	400	800	2000	2000^{D}
endosulfan II						1200		100^{D}
pentachlorophenol					15			10^{D}
mercury (as total inorganic)		120			75			75^{C}

Notes:

^	Impacted soil has been remediated (CH2MHill 2007), with impacted soil located within the onsite shed. The RBSC relate to the excavated and stored materials.
*	Higher RBSCs might be allowable for volatile chemicals within this ISZ, however if these were to be identified, verification would need to include soil gas or flux emissions sampling.
**	Presence of a number of volatile COPC in soils in these ISZ. Note further characterisation of key contaminant areas within ISZ 1a, 1b and 2 suggest concentrations of BHC are generally less than derived criteria, with elevated concentrations associated with an isolated area. Such issues are expected to be addressed within the RAP.
***	Chemicals defined as Scheduled Chemicals (as per Schedule A, EPA NSW Scheduled Chemical Waste Chemical Control Order 2004 [CCO]). Remediation of these chemicals might also require consideration of other criteria to address requirements as outlined in the CCO.
#	Presence of 1,2,3-trichloropropane in ISZ 5 requires further investigation. RBSC presented is preliminary only and subject to the outcome of further sampling and analysis of soil, groundwater and soil gas in the area.
##	RBSCs presented for ISZ 10 are only relevant if the existing Pharmaceuticals Building is removed. While the building remains, as is proposed, risks are negligible and no remediation is required.
A	RBSWC for volatiles based on the maximum RBSC as available data suggests vapour inhalation exposures are not significant and other exposures (ingestion and dermal contact) do not contribute significantly to the total risk (for all key chemicals).
B	RBSWC for volatiles based on the lower RBSC as the vapour pathways is not significant but other exposures (ingestion and dermal contact) do contribute significantly to the total risk (for all key chemicals). Hence to ensure the total risk remains acceptable, the lower RBSC has been adopted.
C	RBSWC based on the lowest RBSC.
D	RBSWC derived to ensure a balance of total risk such that it remains acceptable (for all key chemicals), and the extent of remediation (based on available data).

Shaded RBSWC – site-wise criteria recommended for use in the remediation and management of the site.

8.4 Example Calculation – RBSC for ISZ 4

To assist in the understanding of the approach adopted in deriving the RBSC, an example calculation of the RBSC derived for ISZ 4 (or the impacted soil that has been excavated [CH2MHill, 20070] and stored within the onsite shed) has been presented.

8.4.1 Step 1 – Review Risk and Consider all Exposures Relevant

Review of the calculated risks associated with future site development indicates that b-BHC and DDX contribute significantly to the total risk. This is due to the presence of these chemicals in soil with the most significant exposure being associated with direct contact (ingestion and dermal contact). Based on the available soil gas and flux emissions data collected over the maximum groundwater concentrations reported in this area (also above Plume 3), inhalation exposures do not significantly contribute to the total risk (i.e. approximately 1%). However the potential for variability in emissions from these volatile chemicals has been considered by setting the target risk levels at 80% of the adopted target (see below in Step 2). Hence the derivation of RBSC for ISZ 4 is primarily associated with calculation of exposures derived from ingestion and dermal contact with soil.

8.4.2 Step 2 – Identify Target Risk Level

The quantification of risk associated with exposure to COPC identified in ISZ 4 involves the calculation of both a non-threshold risk and threshold HI associated with direct contact exposures. As noted, inhalation exposures are negligible in this area (calculated to be $2x10^{-7}$ non-threshold risk and 0.01 threshold HI), however an allowance of 20% of the target risk levels of $1x10^{-5}$ (non-threshold) and 1 (threshold HI) has been adopted to provide a level of safety with respect to potential variability of emissions from volatile chemicals.

Hence the calculations for ISZ4 relate to ingestion and dermal contact only with a total non-threshold target risk of $8x10^{-6}$ and threshold target HI of 0.8 adopted.

For individual COPC, the key COPC BHC and DDX have been allocated the greatest proportion of the target risk as these chemicals dominate the calculated risk for ISZ 4.

8.4.3 Step 3 – Calculate RBSC

The RBSC for ISZ 4 have been set to ensure that the total risk associated with exposure over all pathways fall within the target risk range. Risks were calculated on the basis of the exposure parameters and equations presented in **Section 5.3**. Toxicity values adopted for the assessment are presented in **Section 4**. The approach and values adopted are consistent with those adopted in the characterisation of risk.

Volatile COPC

With respect to the presence of volatile COPC identified in ISZ4, potential inhalation exposures and risk have been assessed on the basis of measured vapour concentrations collected in areas where maximum concentrations have been reported in soil. In addition it is noted that the calculated risk associated with inhalation exposures is considered acceptable (providing a negligible contribution to total risk) based on the presence of these COPC in soil at the maximum concentrations reported. Hence, from an inhalation exposure perspective the maximum concentrations reported for volatile COPC in ISZ4 are not associated with an unacceptable risk and therefore the RBSC presented are not lower than the maximums currently reported.

Hence, for volatile COPC identified in ISZ 4, the RBSC has been set by rounding up the maximum value reported in soil.

A higher RBSC has not been derived as the relationship between the soil/source concentration and measured soil gas concentration is not consistent (due to the complex nature of processes occurring within the soil profile). Higher RBSC for volatile chemicals could be set if further verification of inhalation exposures associated with higher concentrations in soil (should they be identified in subsequent sampling) is undertaken using soil gas or flux emissions sampling.

On this basis the following is derived for volatile COPC identified in ISZ 4:

- 1,2-dichloroethane (EDC) – maximum concentration reported in the area is 292 mg/kg at depth; it is noted that the maximum reported in the adjacent area ISZ3 was 687 mg/kg at depth where risk was calculated to be acceptable, hence with rounding up, the RBSC is set at 700 mg/kg, which is also considered as a RBSWC;
- chloroform – maximum concentration reported in the area is 2.7 mg/kg at depth; with rounding up, the RBSC is set at 5 mg/kg;
- trichloroethene (TCE) – maximum concentration reported in area is 79 mg/kg at depth; with rounding up, the RBSC is set at 100 mg/kg; and
- benzene – maximum concentration reported in the area is 9.8 mg/kg at depth; with rounding up, the RBSC is set at 10 mg/kg.

The risk associated with the presence of these RBSC in soils at any depth in ISZ 4 has been calculated and contributes to the total risk for the area.

Non-Volatile COPC

For the remaining COPC (i.e. non-volatile), RBSC have been derived to ensure that the total risk meets the adopted target. The approach adopted starts with the maximum concentrations reported on the site. For some COPC the risk associated with the maximum concentration is less than the target and hence the RBSC has been set by rounding (as required) up the maximum concentration.

This relates to the following COPC within ISZ 4:

- mercury – maximum concentration reported in the area is 116 mg/kg which results in a total HI of 0.11. Rounding up, the RBSC is set at 120 mg/kg;
- a-BHC – maximum concentration reported in the area is 3.2 mg/kg which results in a HI of 0.0001. This provides a negligible contribution to the total risk, however to ensure that the contribution remains negligible the RBSC has been rounded up to 5 mg/kg which results in a total HI of 0.0002;
- d-BHC – maximum concentration reported in the area is 1.6 mg/kg which results in a total HI of 0.03. Rounding up, the RBSC is set at 2 mg/kg;
- g-BHC – maximum concentration reported in the area is 32 mg/kg which results in a HI of 0.004. This provides a negligible contribution to the total risk, however to ensure that the contribution remains negligible the RBSC has been rounded up to 50 mg/kg which results in a total HI of 0.006;

For the key COPC identified in the area, namely b-BHC, DDX and HCB, the RBSC has been derived at a concentration lower than the maximum concentration reported on the site such that the total risk in combination with the other COPC meets the adopted target. The RBSC have been derived by lowering the maximum reported concentration to a level where the total risk is acceptable. Not all COPC have been decreased from the maximum reported concentrations equally as some key COPC were identified by HLA (now AECOM) that required less conservative RBSC to assist in the proposed remediation. Hence a higher contribution to the total risk has been allowed for these key COPC. On this basis the following RBSC have been derived:

- HCB – RBSC is set at 15 mg/kg which results in a HI of 0.07. While the RBSC for the chemical is lower than the maximum concentration reported (33 mg/kg) the calculated risk is sufficiently low such that the total risk from all chemicals meets the target;

- b-BHC – RBSC is set at 15 mg/kg which results in a HI of 0.25. This is lower than the maximum reported in the area of 32 mg/kg.
- DDX – RBSC is set at 1800 mg/kg which results in a HI of 0.36. This is lower than the maximum reported in the area of 45750 mg/kg.

As the RBSC are derived on the basis of total cumulative risk (equal to the target risk levels outlined in **Section 8.4.2** – Step 2) from all COPC in the area, the values can be modified if required to enable a higher RBSC for a given chemical. However this would result in lower RBSC for other COPC in the same area.

The following presents a summary of the calculated risks associated with the adopted RBSC for ISZ 4, incorporating the approach presented above (refer to **Appendix G** for detailed calculations).

Table 8-2 Summary of Example RBSC Derived for ISZ 4

		Calculated Risk					
COPC	RBSC (mg/kg)	Ingestion		dermal contact		Total Risk	
		non-threshold	threshold	non-threshold	threshold	non-threshold	threshold
hexachlorobenzene (HCB)	15		0.022		0.052		0.074
1,2-dichloroethane (EDC)	700	8.5E-07		3.6E-07		1.2E-06	
chloroform	5		0.00018		0.000076		0.00026
trichloroethene (TCE)	100		0.00099		0.00042		0.0014
benzene	10	3.5E-08		1.5E-08		5.0E-08	
a-HCH (a-BHC)	5		0.00015		0.000062		0.00021
b-HCH (b-BHC)	15		0.18		0.074		0.25
d-HCH (d-BHC)	2		0.023		0.010		0.033
g-HCH (g-BHC or lindane)	50		0.0039		0.0017		0.0056
DDX (sum of DDT, DDE and DDD)	1800		0.21		0.15		0.36
Mercury (as total, inroganic)	120		0.079		0.034		0.11

Total Risk from Soil Ingestion and Dermal Contact	**1.3E-06**	**0.84**
Total Risk from Inhalation Exposures	**1.9E-07**	**0.011**
Allowable Risk via Inhalation	**2.0E-06**	**0.20**
Total Risk	**3.3E-06**	**1.0**

Section 9 Risk-Based Groundwater Concentrations

9.1 General

Risk-based groundwater concentrations (RBGCs) have been derived for impacts identified in off-site groundwater. It is noted that based on the available data there are currently no unacceptable risks to human health or the environment in any of the off-site areas. However it is expected that the RBGCs will be utilised as trigger levels for the collection of additional data and further assessment in off-site areas.

As there is no complete pathway of exposure relevant for the discharge of any groundwater to a receiving environment, the RBGCs have been derived on the basis of the protection of human health only. Hence the RBGCs have been derived to be protective of all existing exposures off-site and as such the receptors and exposure pathways considered complete are the same, and have nee quantified on the basis of the same exposure parameters, as identified in the assessment of risk in off-site areas (refer to **Section 5**, **Tables 5-2 and 5-3**). The key difference in the derivation of RBGCs is that the risk assessment approach has been used to derive a source concentration that is protective of human health.

9.2 Quantification of Inhalation Exposures

In the off-site areas the quantification of risk has been based on measured soil gas data collected over a number of monitoring rounds above impacted groundwater. Due to the complex nature of vapour phase partitioning from groundwater and migration in the subsurface, it is not possible to directly use a vapour model that estimates vapour concentrations based on a groundwater source concentration. Rather, as soil gas data is available, an attenuation factor can be calculated based on the ratio of measured soil gas (sub-slab where most data has been collected) to groundwater concentrations. The attenuation factor can then be used in the vapour model (using the same assumptions as adopted in the quantification of risk) to estimate exposure concentrations inside a building and risks to workers.

Appendix H presents a summary of the data used to evaluate the ratio of maximum measured sub-slab soil gas concentrations at all off-site locations (and on-site/boundary locations that are above only groundwater impacts) to the maximum reported groundwater concentrations over all rounds of sampling. The ratio calculated has limitations associated with the data set itself, in particular:

- It is assumed that the existing off-site building types remain, that includes slab on grade commercial/ industrial premises. The approach adopted does not address the presence of subsurface basements (that would need to be addressed separately if required);
- It is assumed that the groundwater plumes are stable and that the maximum concentrations reported reflect maximum concentrations that may have been present over the period of time when soil gas data was collected;
- As with the groundwater data it is assumed that the soil gas data collected over all rounds of sampling reflects expected variability in soil gas above a stable plume. Hence the maximum reported soil gas concentrations have been considered in conjunction with the maximum groundwater concentrations;
- At some locations not all the key volatile compounds were reported and hence no ratio could be estimated;
- At some locations some of the key volatile compounds were not detected above the laboratory LOR. In these cases the LOR was adopted in the calculation of the ratio. It is noted that in adopting this approach where the LOR was adopted from the soil gas data the calculated ratio may be overestimated (resulting in a conservative ratio and estimation of risk). Where the LOR was adopted from the groundwater data the calculated ratio may be an underestimate (resulting in an underestimate of risk).

As the available data set used to estimate an attenuation factor from groundwater to soil gas (measured sub-slab) has some limitations as noted above, the most conservative (maximum) attenuation factor from all locations and sample rounds has been used as the attenuation factor that relates soil gas to groundwater in the derivation of RBGCs.

It is noted that the assessment of inhalation exposures by workers conducting intrusive works is based on two approaches:

1) Assuming groundwater is sufficiently deep and excavations do not intersect groundwater. In this case the ratio discussed above has been adopted in the modelling of exposures in an excavation. Given the depth to groundwater in off-site areas this is the most likely exposure scenario. For the purpose of deriving RBGCs it has been assumed that 25 of the 30 days where intrusive workers may be in an excavation no groundwater is intersected; and
2) Assuming groundwater is in a location that is more shallow and excavations intersect water where seepage occurs into the excavation. Inhalation exposures within this excavation have been estimated on the basis of a volatilisation factor that is directly related to the groundwater concentration (refer to **Appendix E** for discussion). The potential for excavations to intersect groundwater is low, however for the purpose of deriving RBGCs it has been assumed that 5 of the 30 days where intrusive workers may be in an excavation groundwater is intersected and seepage (where both inhalation and direct contact exposures) occurs.

9.3 Target Risk for RBGCs

The derivation of RBGCs for the off-site areas has considered all pathways of exposure and hence the target risk levels adopted are based on the overall total target risks adopted and discussed in the risk characterisation (**Section 6**), which are:

- Non-threshold – Excess lifetime cancer risk of 1 x 10^{-5}.
- Threshold – HI of 1.

This target applies to the sum of the risks for each COPC for all pathways of exposure, thus assuming an additive effect associated with exposure to the chemicals identified.

9.4 Derived RBGCs

Table 9-1 presents a summary of the RBGCs derived for the off-site areas. RBGCs have been derived for COPC identified in off-site groundwater. The calculated risks from the RBGCs meet the target risk levels defined above for both long-term on-site workers and intrusive workers. Calculations undertaken to establish the RBGCs are presented in **Appendix H**.

Table 9-1 Calculated RBGCs for Off-Site Areas

COPC	Calculated RBGC (mg/L)
hexachlorobenzene (HCB)***	0.06
1,2-dichloroethane (EDC)	120
vinyl chloride	6
chloroform	100
trichloroethene (TCE)	200
tetrachloroethene (PCE)	30
1,1,2-trichloroethane	3.5
chlorobenzene	200
benzene	50
toluene	6
a-HCH (a-BHC)***	44
b-HCH (b-BHC)***	0.11
d-HCH (d-BHC)***	0.11
g-HCH (g-BHC or lindane)***	16
dieldrin***	0.33
DDX (sum of DDT, DDE and DDD)***	0.3

Section 10 Uncertainties

10.1 General

In general, the uncertainties and limitations of human health risk assessment can be classified into the following categories:

- Sampling and analysis;
- Receptor exposure assessment; and
- Toxicological assessment.

The risk assessment process following both ANZECC/NHMRC and USEPA guidance documents provides a systematic means for organising, analysing and presenting information on the nature and magnitude of risks to public health posed by chemical exposures. Despite the advanced state of the current risk assessment methodology, uncertainties and limitations are inherent in the risk assessment process. This section discusses the uncertainties and limitations associated with this risk assessment.

10.2 Sampling and Analysis

The data collected for soil, groundwater and air from the Orica Villawood site has been based on the knowledge of the site hydrogeological conditions (both on and off site) and former site activities. The selection of analytes has been based on a knowledge of former site activities and hence has focussed on chemicals which were known to have been formerly used at the site. There is the potential for chemicals to be present on the site which have not been characterised based on omission from site history records. The soil and air concentrations utilised in this risk assessment have been collected by HLA, CH2MHill and URS, however there is uncertainty in the sampling protocols and collection methods utilised by CH2MHill as the data has not been formally reported. The HLA soil gas and flux emissions data has not been assessed with respect to quality assurance. The data collected by URS has been reported and assessed in the relevant reports (URS 2007 and 2009). The assessment of risk presented in this report has used maximum concentrations reported to be conservative. In the absence of necessary information the assumptions which have been documented in this report in relation to the adoption of air concentrations reported are conservative.

As noted in Section 3.8, no specific data gaps have been identified; however the following areas that might warrant further consideration to reduce uncertainty in the available data:

- Characterisation of TPH which can be undertaken by reviewing the relevant chromatograms. Whilst it is considered that the assessment of individual COPC identified will adequately address risk issues and define remediation requirements, there remains uncertainty as to the nature of the TPH contamination. Limited data is available and no further evaluation has been undertaken to date.
- Air data collected from a number of sampling programs show variability in chemicals detected as well as concentrations reported. For on-site areas sufficient data is available to enable risk issues to be identified for the purpose of remediation. Further sampling of soil gas in off-site areas, where remediation is not expected might be required to further assess the potential variability. Given the number of off-site vapour sampling rounds conducted, it is expected that an additional two or three sampling rounds (addressing other seasons) might be required to adequately address the variability.

10.3 Exposure Assessment

Risk assessments require the adoption of several assumptions in order to assess potential human exposure. This risk assessment includes assumptions about general characteristics and patterns of human exposure relevant to the Orica Villawood site and surrounding area. The assumptions used are conservative and developed to provide an estimate of reasonable maximum exposures rather than the actual exposures. This approach tends to overestimate the risks. The assessment has been completed using upper bound concentrations reported within soil, groundwater and air reports. This assumption might therefore overestimate the potential for exposure to the COPC in the areas assessed.

Given the uncertainty in the estimate of intake via dermal exposure, intake has been calculated using both methods described above, however URS considers that the method of Hawley (1985), SEDISOIL (1996) and CSOIL (2001) is the most appropriate basis for assessment of risks. The Hawley method allows for determination of exposure time (i.e. time elapsed between exposure and then washing and removing contaminants from the skin surface), the USEPA method has no consideration of exposure time. Experimental studies used to define dermal absorption fraction (ABSd) values are associated with dermal application over 24 hours (i.e. the event is considered to be a 24 hour day by default). Due to the lack of information about the rate and relationship of absorption of chemicals through the skin over shorter exposure periods, the USEPA methodology does not recommend adjusting the ABSd to account for exposures over times less than 24 hours, rather it recommends adjusting exposure frequency and exposure duration to reflect site conditions. Dermal exposures have been calculated using both approaches and the calculated risks are presented in **Appendix F**. It should be noted that comparison between the two approaches results in calculated risks which are slightly higher or lower for individual chemicals with the exception of PAHs using the USEPA approach which uses chemical specific absorption (based on a 24 hour exposure) which results in a more conservative calculated risk. It should be noted that PAHs are not a significant COPC at the Orica Villawood site. In general the calculated risks presented by both approaches (with the exception of PAHs) are consistent and the outcomes and conclusions of the risk assessment are also consistent with the adoption of either approach.

The assessment of exposure by workers in off-site areas above Plumes 1 and 2 has considered a standard exposure scenario where workers may be present for 10 hours per day, 5 days per week, 48 weeks of the year for 30 years. However it is noted that one of the off-site businesses is a brothel where workers may spend longer periods of time (each day) at the premises. If exposures were assumed to occur above Plume 2 (where higher risks have been calculated), for 24 hours per day, 365 days per year for a 5 year period, then inhalation risks would be higher than presented in **Table 6-11**. Risks would increase to $5x10^{-6}$ for non-threshold risk and 0.03 for a threshold HI. While higher, both these risk levels are lower than the target risk levels adopted. Hence potential risks to human health remain and acceptable.

10.4 Toxicological Assessment

In general, the available scientific information is insufficient to provide a thorough understanding of all of the potential toxic properties of chemicals to which humans could be exposed. It is necessary, therefore, to extrapolate these properties from data obtained under other conditions of exposure and involving experimental laboratory animals.

This could introduce two types of uncertainties into the risk assessment, as follows:

1) Those related to extrapolating from one species to another; and

2) Those related to extrapolating from the high exposure doses, usually used in experimental animal studies, to the lower doses usually estimated for human exposure situations.

The majority of the toxicological knowledge of chemicals comes from experiments with laboratory animals, although there might be interspecies differences in chemical absorption, metabolism, excretion and toxic response. There could also be uncertainties concerning the relevance of animal studies using exposure routes that differ from human exposure routes. In addition, the frequent necessity to extrapolate results of short term or subchronic animal studies to humans exposed over a lifetime has inherent uncertainty.

In order to adjust for these uncertainties, ADIs and RfDs incorporate safety factors that can vary from 10 to 1000. The USEPA assumes that humans are as sensitive to carcinogens as the most sensitive animal species. The policy decision, while designed to minimise the potential for underestimating risk, introduces the potential to overestimate carcinogenic risk. Conversely, it also does not allow for the possibility that humans might be more sensitive than the most sensitive animal species. The model used by the USEPA to determine slope factors is a linearised multistage model, which provides a conservative estimate of cancer risk at low doses and is likely to overestimate the actual slope factor. It is assumed in this approach that a genotoxic mechanism applies, however, most carcinogens do not actually cause cancer by this mechanism.

The result is that the use of slope factors has the general effect of overestimating the incremental cancer risks.

The approach for evaluating risks to mixtures of chemicals assumes dose additively and does not account for potential synergism, antagonism or differences in target organ specificity and mechanism of action. In general, the additive approach has the effect of overestimating the risks. This is because chemicals that have no additive effects are included together as well as chemicals that might have additive effects.

Section 11 Conclusions

11.1 Human Health

The risk assessment has identified the potential for soil contaminants to be present at sufficiently high concentrations in some areas of the Orica Villawood site (associated with ISZ 1a, 1b, 2, 4, 5, 7, 8, 9, and 10) to present an unacceptable risk to human health under a commercial/industrial land use. The prime exposure pathways for concern are ingestion and dermal contact with soil.

Inhalation generally presents a minor contribution to the risk with the calculated risk associated with inhalation exposures less than the adopted target for all areas with the exception of ISZ 5 where the presence of 1,2,3-trichloropropane dominates the calculated risk. The presence of this chemical in this area requires further assessment.

Assessment of exposure to volatile COPC via inhalation in areas located above groundwater plumes in areas on the site (where no source zones are present) and off site indicates risks to be low and essentially negligible. This assessment is based on measured data and further data might be required to further assess the potential variability in off-site areas. Given the number of off-site vapour sampling rounds conducted, it is expected that an additional two or three sampling rounds (addressing other seasons) might be required to adequately address the variability.

TPH was not identified as a COPC, however the characterisation of TPH has been limited to a small number of samples. Additional assessment of the nature of the TPH would be warranted to ensure that the COPC list adequately addresses health risks.

11.2 Environment

The environmental risks are assessed as being negligible given the commercial/industrial land use and the hydrogeological conditions. It is noted that contaminated perched groundwater is expected to be removed and surface water managed under the proposed remediation of the site to ensure contaminant discharge via surface water and buried stormwater lines does not occur.

11.3 Risk-Based Soil Concentrations

The RBSC have been calculated for ISZ on the site where risks were identified to be of concern and have been derived to be protective of human health under commercial/industrial land use. The values are applicable only to the Orica Villawood site and have been developed assuming the mixture of COPC identified in each key ISZ identified. The RBSC may be used for the following purposes:

- Screening of data collected as part of ongoing investigations and delineation of areas of concern; and/or
- Remediation criteria for the site. However, the final selection of remediation criteria could be determined by issues other than risk to human health. In addition criteria relevant to scheduled chemicals, as outlined in the Scheduled Chemical Wastes Chemical Control Order 2004 (EPA NSW 2004) might need to be considered in the use of RBSC as remediation criteria. The scheduled chemicals are covered under the Stockholm Convention on Persistent Organic Pollutants and have been identified based on their persistence, tendency for bioaccumulation and toxicity. Also, concentrations could be varied to reflect different proportions of COPC in the event that non health-based criteria are used for selected COPC.

The RBSC have not considered leaching to groundwater, however, groundwater has not been identified as presenting unacceptable risks to human health or the environment, therefore there is no risk-based requirement to consider this further.

11.4 Risk-Based Groundwater Concentrations

Based on the available data and the assessment presented in this report there are currently no unacceptable risks to human health or the environment associated with the presence of impacted groundwater beneath existing (slab-on-grade construction) down-gradient off-site areas. However to assist in the evaluation of further monitoring data RBGCs have been calculated for impacted groundwater beneath existing off-site areas. The RBGCs have been derived for COPC identified in off-site groundwater and are based on the protection of human health, in particular exposures by long-term workers within existing (slab-on-grade construction) buildings and intrusive workers. The derived RBGCs are considered trigger levels, where exceedance of these levels should prompt the need to conduct further sampling (such as soil gas or indoor air) and assessment.

Section 12 Limitations

URS Australia Pty Ltd (URS) has prepared this report for the use of Orica Australia Pty Ltd in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 14 December 2005 (WCIE 4263).

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between July 2006 and February 2011 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Section 13 References

Abreu Lilian D.V, Johnson Paul C, Simulating the Effect of Aerobic Biodegradation on Soil Vapor Intrusion into Buildings: Influence of Degradation Rate, Source Concentration and Depth; Environmental Science and Technology 2006, 40: 2304-2315.

AECOM, 2010. Remediation Acton Plan, 2 Christina Road, Villawood, NSW. Prepared by AECOM, November 2010.

ANZECC and NH&MRC, January 1992. Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites.

ANZECC, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National

ASCC (NOHSC:1003(1995)), Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment, Current guidance and exposure standards are available on the Hazardous Substances Information System, data available from web site: http://www.nohsc.gov.au/applications/hsis/.

CH2MHill, Crop Care Site, Christina Road, Villawood, Stage 2 Environmental Site Assessment

CH2MHill, 2005. 2 Christina Rd, Villawood, NSW, Conceptual Site Model, Final April 2005 (Ref 321277)

CH2MHill, 2003. Pharmaceuticals Site, Christina Road Villawood Remedial Action Plan, Final July 2003 (Ref 312264.TS.003).

CH2MHill, 2007. Pharmaceuticals Site, Christina Road, Villawood, Validation Report. Prepared by CH2MHill in September 2007, reference: 359640.T1.01.

Contaminated Soil Monograph Series (CSMS) 1991. The Health Risk Assessment and Management of Contaminated Sites. Proceedings of a National Workshop on the Health Risk Assessment and Management of Contaminated Sites. Edited by O. El Saadi and A. Langley, South Australian Health Commission, 1991.

Contaminated Soil Monograph Series (CSMS) 1993. The Health Risk Assessment and Management of Contaminated Sites. Proceedings of the Second National Workshop on the Health Risk Assessment and Management of Contaminated Sites. Edited by A. Langley and M. Van Alphen, South Australian Health Commission, Contaminated Sites Monograph Series, No. 2, 1993.

Contaminated Soil Monograph Series (CSMS) 1996. The Health Risk Assessment and Management of Contaminated Sites. Proceedings of the Third National Workshop on the Health Risk Assessment and Management of Contaminated Sites. Edited by A. Langley, B. Markey and H. Hill. Contaminated Sites Monograph Series No. 5, 1996.

Contaminated Soil Monograph Series (CSMS) 1998. The Health Risk Assessment and Management of Contaminated Sites. Proceedings of the Third National Workshop on the Health Risk Assessment and Management of Contaminated Sites. Edited by A. Langley, B. Markey and H. Hill. Contaminated Sites Monograph Series No. 7, 1998.

CSIRO, 2004. Petroleum Solvent Vapours: Quantifying their Behaviour, Assessment and Exposure. CSIRO Land and Water Report.

CSOIL, 2001. Evaluation and revision of the CSOL Parameter Set, RIVM Report 711701021, March 2001.

enHealth, 2002. Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards, June 2002.

enHealth, 2003. Australian Exposure Assessment Handbook, Consultation Draft, December 2003.

References

enHealth, 2002b. Health and Environmental Assessment of Site Contamination. Proceedings of the Fifth National Workshop on the Assessment of Site Contamination, Environment Protection & Heritage Council, 2002.

Fitzgerald J., 1998. *The benchmark dose approach and health-based investigation level for polycyclic aromatic hydrocarbons (PAHs)*, presented in Contaminated Sites Monograph Series, No. 7, 1998.

Hawley J.K., 1985. Assessment of Health Risk from Exposure to Contaminated Soil. Risk Analysis, Vol. 5, No. 4, p289-302.

HLA- Envirosciences Final Report Phase 1 Remedial Investigation Orica Site, 2 Christina Road, Villawood, 22nd December 2005.

HLA- Envirosciences Draft Report Phase 2 Remedial Investigation Orica Site, 2 Christina Road, Villawood, 7th July 2006.

HLA- Envirosciences Phase 3 Data Gap Investigation, 2 Christina Road, Villawood, 31 May 2007.

Kelly, K.E. & Cardon, N.C., 1991. The Myth of 10^{-6} as a Definition of Acceptable Risk (or in hot pursuit of the Superfund’s Holy Grail). 84th Annual Meeting Air & Waste Management Association, Vancouver, Canada 16-21. June 1989.

MDEP, 2004. Supplemental Guidance, Weighted Skin-Soil Adherence Factors. Massachusetts Department of Environmental Protection, Draft for Discussion, 2004.

National Environment Protection Council (NEPC), 1999. National Environment Protection Measure (Assessment of Site Contamination), Schedule B(4), Guideline on Health Risk Assessment Methodology, 1999.

NHMRC and ARMCANZ, 2004. (National Health and Medical Research Council and the Agriculture and Resource Management Council of Australia and New Zealand). Australian Drinking Water Guidelines - 6. National Water Quality Management Strategy.

NSW EPA. 1994. Guidelines for Assessing Service Station Sites EPA 94/119.

NSW EPA, 1999. Technical Report: Organochlorine and Trace Metal Concentrations in Wild Oysters (*Saccostea commercialis*) from 20 NSW Estuaries.

NZ ME, 1997a. Health and Environmental Guidelines for Selected Timber Treatment Chemicals. Ministry of Health and Ministry for the Environment 1997.

NZ ME, 1997b. Guidelines for Assessing and Managing Contaminated Gasworks Sites in New Zealand. Ministry for the Environment 1997.

OCS, 2006. ADI List, Acceptable Daily Intakes for Agricultural and Veterinary Chemicals. Australian Government, Department of Health and Ageing, Office of Chemical Safety (OCS), current to 30 September 2006.

RISC, 2001. $Risk_4$ Users Manual. Risk-Integrated Software for Clean-Ups. Prepared for BP Amoco Oil, July 2001.

RiskE, 2004. Risk Calculation Spreadsheet Model. Developed by URS Australia, Version 5, 2004.

RIVM, 2001. Technical Evaluation of Intervention Values for Soil/sediment and Groundwater. RIVM report 711701 023.

SEDISOIL, 1996. SEDISOIL Model to Calculate Human Exposure to Polluted Sediments. Government Institute for Public Health and Environment. Available in Dutch, translated to English by URS in 2004.

Section 13 References

United States Environment Protection Agency (US EPA) 1989. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual. Interim Final, Office of Emergency and Remedial Response, US EPA, Washington DC. OSWER Directive 9285.7-0/a.

URS Final Report (Issue 3) Stage 1 Phase 2 Environmental Site Audit of the Orica Site located at 2 Christina Rd, Villawood, NSW, 8th January 2001.

URS Workplan Human Health and Environmental Risk Assessment Orica Villawood Site, 8th July 2006

URS, 2007. Soil Gas, Flux Emissions and Indoor Air Sampling, Orica Villawood, Draft June 2007

US EPA, 1991. Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals). Interim. Office of Emergency and Remedial Response, United States Environment Protection Agency (US EPA), Washington, D.C.

USEPA, 1992. Dermal Exposure Assessment: Principles and Applications. EPA/600/8-91/011B, January 1992.

United States Environment Protection Agency (US EPA) 1997. Exposure Factors Handbook. EPA/600/P-95/002Fa, August 1997.

USEPA, 2001. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. United States Environmental Protection Agency, OSWER Publication 9355.4-24, March 2001.

USEPA WATER9, 2001b. Users Guide for WATER9 Software, Office of Air Quality Planning and Standards, USEPA, February 2001.

United States Environmental Protection Agency (US EPA) 2004. Region IX Preliminary Remediation Goals (PRG's). Available on-line from Region IX web site.

USEPA, 2004b. Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final. EPA/540/R/99/005, July 2004.

USEPA, 1996. Soil Screening Guidance: Users Guide. United States Environmental Protection Agency, Publication 9355.4-23, July 1996.

USEPA, 2001. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. United States Environmental Protection Agency, OSWER Publication 9355.4-24, March 2001.

World Health Organisation (WHO) 2004. Guidelines for Drinking-Water Quality, Third Edition. 2004. International Programme on Chemical Safety, ISBN 92 4 154638 7 (NLM Classification WA 675).

WHO, 2003. Guidelines for Sate Recreational Water Environments, Volume 1 Coastal and Fresh Waters. World Health Organisation, 2003.