Available online at www.sciencedirect.com
ScienceDirect
Journal of Cleaner Production 15 (2007) 819–832
Journal of Cleaner Production
www.elsevier.com/locate/jclepro

Australian characterisation factors and normalisation figures for human toxicity and ecotoxicity

Sven Lundie [a,*], Mark A.J. Huijbregts [b], Hazel V. Rowley [a], Nellemieke J. Mohr [b], Andrew J. Feitz [a]

[a] *Centre for Water and Waste Technology, School of Civil and Environmental Engineering, University of New South Wales, Building H22, Vallentine Annex, Botany Street, Gate 11, Sydney, NSW 2052, Australia*
[b] *Department of Environmental Studies, Nijmegen University, The Netherlands*

Accepted 21 June 2006
Available online 6 September 2006

Abstract

The fate, exposure and effects model USES-LCA 2.0 has been adapted to calculate characterisation factors for toxic chemicals emitted under Australian conditions. Normalisation data for Australian ecotoxicity and human toxicity have been calculated using the emission data from the National Pollutant Inventory (2002/2003) and pesticide use information. National freshwater ecotoxicity and terrestrial ecotoxicity impacts are dominated by pesticide use. Total marine ecotoxicity is dominated by fluoride, originating from air emissions from the electricity supply and non-ferrous metals' (and products) manufacturing industry sectors and water emissions from the sewerage treatment plants. The human toxicity is primarily attributed to the inhalation of toxic metal dust. There is a large diffuse component (primarily from road dust) and the remaining human toxicity contributions can be attributed to air emissions from the mining (non-ferrous metal ores), electricity supply and non-ferrous metals' (and products) manufacturing industry sectors. Future research should investigate the feasibility of combining NPI emissions with regional (climate) specific characterisation factors.

Keywords: Aquatic; Terrestrial; Ecotoxicity; Human toxicity; LCA; LCIA; Characterisation; NPI; Normalisation

1. Introduction

Life Cycle Assessment (LCA) is a tool for determining the potential environmental impact of a product or service. The total quantities of emissions and inputs required for a product or service are summed across its entire life cycle, from extraction of raw resources to waste disposal, and compiled in a Life Cycle Inventory (LCI). In Life Cycle Impact Assessment (LCIA) environmental impact models are used to translate the inventory data (that may contain hundreds of substances) into potential environmental effects [23]. The environmental models cover a range of impact categories and consider environmental effects at the midpoint or endpoint (damage) level [14,35]. Normalisation is one of three optional elements of LCIA described by AS/NZS ISO 14042 [41]. Its aim is to better understand the relative magnitude of each indicator result of the system under study. Normalisation can be helpful in providing information on the relative significance of the indicator results.

For toxicity impact models, the fate, route of exposure and toxicity (effect) of a substance can be taken into account in the calculation of the characterisation factor [14]. The fate component is commonly calculated with environmental multimedia fate models [e.g. Refs. 11,15,21]. LCIA toxicity models that incorporate fate components include TRACI [7], IMPACT 2002+ [25], LIME [24], USES-LCA [20–22] with an extensive model (OMNIITOX) under development [12]. Huijbregts [16] recently updated the fate and exposure part of USES-LCA to account for several shortcomings in the model. The new

* Corresponding author. Tel.: +61 2 9385 5097; fax: +61 2 9313 8624.
E-mail address: s.lundie@unsw.edu.au (S. Lundie).

0959-6526/$ - see front matter
doi:10.1016/j.jclepro.2006.06.019

USES-LCA 2.0 model is now able to account for air emissions in low and high population areas, rain and no rain conditions, vertical stratification in the soil compartment, and export of food production.

USES-LCA 2.0 was developed for the characterisation of toxic emissions in western Europe and has limited applicability outside that region. If such a European model was applied in the Australian context, there is a risk of generating implausible results as the population density is lower and the climatic conditions in Australia are different to those in Europe. Hence, there is a clear need for modification to account for different environmental conditions and human characteristics. In this study, USES-LCA 2.0 is modified to calculate characterisation factors for selected toxic substances emitted under Australian conditions. The substances chosen reflect reportable substances under the National Pollutant Inventory (NPI) scheme and commonly used pesticides in Australian agriculture.

For current Life Cycle Assessment (LCA) practice, normalisation data are available on a national level (Netherlands, Denmark), western Europe and the world [18]. However, Australian normalisation figures for toxicity have not yet been calculated.

This article presents Australian characterisation factors for 38 human carcinogenic and 68 human non-carcinogenic substances, and 100 substances for freshwater, terrestrial and marine ecotoxicity substances per emission compartment. Additionally, we have calculated normalisation figures for these five impact categories using Australian emission data from the National Pollutant Inventory (NPI) and annual pesticide use figures for the year 2002/2003.

2. Methodology

2.1. Fate factor

The marginal change in the steady state concentration in an environmental compartment due to a marginal emission change is defined as the compartment-specific fate factor [16,29]:

$$F_{j,i,s} = \frac{\partial C_{j,s}}{\partial M_{i,s}} \tag{1}$$

in which $F_{j,i,s}$ represents the compartment-specific fate factor that accounts for the transport efficiency of substance s from compartment i to and its persistence in compartment j (yr m^{-3}), $\partial C_{j,s}$ is the marginal change in the steady state dissolved concentration of substance s in compartment j (kg m^{-3}), and $\partial M_{i,s}$ is the marginal change in the emission of substance s to compartment i (kg yr^{-1}). USES-LCA calculates compartment-specific fate factors for one freshwater, one sea, three oceanic and seven soil compartments. Emission compartments identified were urban air, rural air, freshwater, seawater, agricultural soil and industrial soil on the Australian scale.

The marginal change in steady state intake of substance s in the total human population at scale k via intake route r due to a marginal emission change in compartment i is defined as the route-specific intake fraction of the human population [16,44]:

$$iF_{r,i,s,a} = \frac{\partial I_{r,s,a}}{\partial M_{i,s}} = \frac{\partial I_{r,s,a}}{\partial C_{j,s}} \times \frac{\partial C_{j,s}}{\partial M_{i,s}} \tag{2}$$

in which $iF_{r,i,s,a}$ represents the human population intake fraction at geographical scale a that accounts for transport of substance s via intake route r from emission compartment i (dimensionless), and $\partial I_{r,s}$ is the marginal change in the intake of substance s by the human population via intake route r (kg day^{-1}). Table 1 shows the emission compartments that were specified in the fate factor calculations. The environmental receptors and human intake routes identified in the fate factor calculations are also shown in Table 1.

The parameterisation of USES-LCA for Australian and Southern Hemispheric conditions was obtained from Huijbregts et al. [18] and is shown in Table 2. Compared to the previous version, USES-LCA 2.0 also requires a specification of the number of people and land surface of urban and rural areas of Australia. From a total of 20 million people, approximately 14 million people live in urban areas in Australia (i.e. defined as >100 people km^{-2}). The land surface of the urban area is equal to 3.8×10^4 km^2 or 0.5% of the total land area [5]. The west-European USES-LCA 2.0 uses a definition of 2000 persons km^{-2} for (sub)urban area [16]. Adopting such a definition for Australia would limit urban air emissions to the inner city regions for Australia's two largest cities, Sydney and Melbourne (0.007% of total land area). We have modified the definition so that other capital cities, major industrial cities, such as Newcastle and Wollongong, and large tracts of urban sprawl along Australia's eastern coastline are included as (sub)urban areas.

In USES-LCA 2.0 human exposure via food items has been calculated using food production rates instead of food consumption rates. As food production reflects how much of the pollutant occurring in the food ultimately ends up in the human population [28], region-specific food item production rates for the year 2000 have been derived from food production statistical databases provided by the Food and Agriculture Organisation of the United Nations [10]. These production statistics were corrected to reflect the amount produced for human consumption in Australia. Additionally, for fruits, vegetables, tree nuts, pulses, roots and tubers a second correction

Table 1
Emission compartments, environmental receptors and human intake routes in USES-LCA 2.0 [16]

Emission compartments	Environmental receptors	Human intake routes
Urban air	Terrestrial environment	Inhalation
Rural air	Freshwater environment[a]	Ingestion
Freshwater	Marine environment[a]	
Sea water		
Agricultural soil		
Industrial soil		

[a] The aquatic part of the freshwater and marine environment was taken into account, neglecting the sediment part.

Table 2
Input parameters for fate analysis and human exposure assessment [19]

	Unit	Australia
Fate analysis		
Fresh water area [C]	km^2	6.0×10^4
Rural natural soil area [C]	km^2	3.2×10^6
Rural agricultural soil area [C]	km^2	4.4×10^6
Rural other soil area [C]	km^2	4.9×10^4
Urban soil area [C]	km^2	3.8×10^4
Sea area [C]	km^2	2.5×10^6
Suspended matter (fresh water) [C]	$mg\ l^{-1}$	30
Settling velocity of suspended particles [C]	m (water) day^{-1}	10
Depth (fresh water) [C]	m	1
Temperature [C]	°C	22
Rain rate [C]	$mm\ yr^{-1}$	450
Soil erosion rate [C]	$mm\ yr^{-1}$	2.0×10^{-1}
Wind speed [C]	$m\ s^{-1}$	3.2
Fraction of precipitation that runs off agricultural soil [C]	–	0.12
Fraction land [M]	–	0.04
Fraction sea [M]	–	0.96
Fraction land [T]	–	0.21
Fraction sea [T]	–	0.79
Fraction land [A]	–	0.33
Fraction sea [A]	–	0.67
Human exposure assessment		
Fraction drinking water from surface water [C]	–	0.80
Fraction drinking water from ground water [C]	–	0.20
Daily intake of drinking water [C]	$l\ day^{-1}$	1.8

C = Continental scale (Australia); M = moderate zone; A = Antarctic zone; T = tropic zone; R = rural area; U = urban area.

factor is introduced to reflect the edible part of the human food produced. Table 3 shows the effective human production rates of the food items included.

2.2. Effect factor

The environment-specific effect factor is equal to [42]

$$E_{j,s} = \frac{\partial msPAF_j}{\partial C_{j,s}} \approx 0.7 \frac{1}{HC50_s} \tag{3}$$

where $E_{j,s}$ represents the effect factor of substance s for compartment j ($yr\ m^{-3}$), $\partial msPAF_j$ is the marginal change in the Potentially Affected Fraction of species due to exposure to a mixture of chemicals in compartment j, and $HC50_s$ is the Hazardous Concentration of substance s where 50% of the species is exposed above an acute or chronic toxic value ($kg\ m^{-3}$). All HC50 values are based on acute aquatic toxicity data.

The human effect factor is calculated for carcinogenic and non-carcinogenic effects separately [17].

$$E_{nc,r,s} = \frac{\partial R_e}{\partial D_{r,s}} \approx 0.16 \frac{1}{ED50_{r,s}} \tag{4}$$

and

$$E_{c,s} = \frac{\partial R_e}{\partial D_{r,s}} \approx 0.03 \frac{1}{ED50_s} \tag{5}$$

where $E_{nc,r,s}$ represents the non-carcinogenic human effect factor of substance s via intake route r (kg^{-1}), $E_{c,s}$ represents the carcinogenic human effect factor of substance s (kg^{-1}) and $ED50_{r,s}$ is the life-time dose of substance s via exposure route r affecting 50% of the human population (kg). Carcinogenic $ED50_s$ were reported as an average of all exposure routes considered, while non-carcinogenic $ED50_s$ were reported for oral and inhalatory exposure separately [17]. As for most of the substances insufficient data were available to derive a non-carcinogenic ED50 with dose–response models, the non-carcinogenic ED50 has been extrapolated from the No Observed Effect Level (NOEL) for most chemicals. Detailed information about the extrapolation procedure can be found in Huijbregts et al. [17].

2.3. Damage factor

For humans, damage factors were derived from the extensive 'burden of disease' and health statistics provided by Murray and Lopez [30,31] on a world level for 1990. Applying equal weightings for the importance of one year of life lost for all ages and no discounting for future damages, the damage factor D_e is the sum of Years of Life Lost (YLL_e) and Years of Life Disabled (YLD_e) caused by disease type:

$$D_e = YLL_e + YLD_e \tag{6}$$

Table 3
Effective human production rates applied in the exposure factor calculations, based on FAO statistics [10]

Parameter	Unit	C	M	A	T
Freshwater fishery production	$kg_{wwt}\ yr^{-1}$	2.1×10^7	na	ng	na
Marine fishery production	$kg_{wwt}\ yr^{-1}$	1.5×10^6	1.3×10^{10}	1.1×10^8	1.7×10^{10}
Cereal production	$kg_{wwt}\ yr^{-1}$	1.9×10^{10}	2.1×10^{10}	ng	7.9×10^{10}
Fruit production	$kg_{wwt}\ yr^{-1}$	2.2×10^9	7.9×10^9	ng	5.6×10^{10}
Vegetable production	$kg_{wwt}\ yr^{-1}$	1.4×10^9	4.1×10^9	ng	1.7×10^{10}
Tree nuts production	$kg_{wwt}\ yr^{-1}$	4.0×10^7	1.7×10^7	ng	4.7×10^8
Pulses production	$kg_{wwt}\ yr^{-1}$	1.1×10^9	2.2×10^8	ng	3.2×10^9
Roots and tubers production	$kg_{wwt}\ yr^{-1}$	5.5×10^8	1.9×10^9	ng	4.8×10^{10}
Meat production	$kg_{wwt}\ yr^{-1}$	3.7×10^9	6.0×10^9	ng	2.4×10^{10}
Milk production	$kg_{wwt}\ yr^{-1}$	9.3×10^9	1.9×10^{10}	ng	2.9×10^{10}
Egg production	$kg_{wwt}\ yr^{-1}$	1.3×10^8	4.7×10^8	ng	2.8×10^9

C = Continental scale (Australia); M = moderate zone; A = Antarctic zone; T = tropic zone; R = rural area; U = urban area; na = not applicable; ng = negligible.

Table 4
Reported annual pesticide use in Australia [4]

Category	Class	Total class use ($t\,yr^{-1}$)	Pesticide	Pesticide estimate ($t\,yr^{-1}$)	Notes
Insecticides ($10,000\ t\,yr^{-1}$)	Organophosphates	5000	Parathion, methyl	1000	>1000 $t\,yr^{-1}$
			Chlorpyrifos	1000	Similar amount to parathion, methyl
	Carbamates	3000	Metham sodium	2000	Predominant in class
	Organochlorines	>500	Endosulfan	500	Predominant in class
Herbicides ($30,000\ t\,yr^{-1}$)	EPSP synthase inhibitor	15,000	Glyphosate	15,000	Given
	Photosynthesis (photosystem) II inhibitors	8000	Atrazine	3000	Given
			Simazine	3000	Given
	Phenoxys, benzoic acids and pyridines	>1000	MCPA	500	Major in class
			2,4-D	500	Major in class
	Pyridils	>1000	Paraquat	800	Primary and dominant in class
			Diquat	200	Primary in class
Fungicides ($4000\ t\,yr^{-1}$)	Multi-site activity	>3000	Captan	500	Most significant
			Mancozeb	500	Most significant

For carcinogenic substances, the typical cancer damage factor is 11.5 years of life lost per incidence case, ranging from 4 years lost for prostate cancer to 28 years lost due to leukemia. The typical non-carcinogenic damage factor is 2.7 years of life lost per incidence case, ranging from 0.1 years lost for panic disorder to 80 years lost due to a number of congenital anomalies, such as renal agenesis [17].

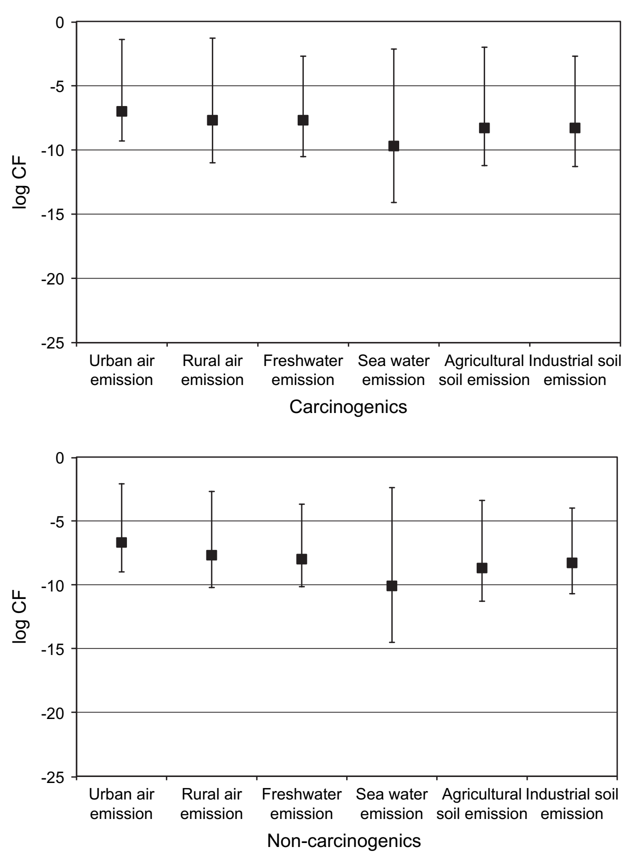

Fig. 1. Median, 5 percentile and 95 percentile of the characterisation factors for 38 human carcinogenic substances and 68 human non-carcinogenic substances per emission compartment (years of life lost per kg emission). The top line is the 95th percentile, the mark the median and the bottom line is the 5th percentile.

2.4. Characterisation factor

The compartment-specific environmental characterisation factor consists of a fate factor and an effect factor:

$$CF_{j,i,s} = F_{j,i,s}E_{j,s} \quad (7)$$

where $CF_{j,i,s}$ is the compartment-specific environmental characterisation factor of chemical s emitted to compartment i and transported to compartment j ($yr\,kg^{-1}$).

In a next step, the compartment-specific characterisation factors were aggregated on the basis of the compartment's area to an environment-specific fate factor for the marine and terrestrial environment, respectively

$$CF_{p,i,s} = \sum_{j\in p} f_{j\in p}CF_{j,i,s} \quad (8)$$

where $CF_{p,i,s}$ represents the environment-specific characterisation factor for substance s emitted to compartment i causing effects in environment p (for each of the marine and soil environments) ($yr\,kg^{-1}$) and f_j is the area fraction of (marine or soil) compartment j (−). For the freshwater environment, the compartment-specific characterisation factor (Eq. (7)) is equal to the environment-specific characterisation factor, as only one freshwater compartment is defined in USES-LCA.

The scale-specific human characterisation factor consists of a fate factor, an effect factor, and a damage factor:

$$CF_{c/nc,r,i,s,k} = F_{r,i,s,k}E_{c/nc,r,s}D_{c/nc} \quad (9)$$

where $CF_{r,i,s,k}$ represents the human characterisation factor (carcinogenic or non-carcinogenic) at scale k that accounts for transport of substance s via intake route r (ingestion, inhalation) from emission compartment i (yr kg^{-1}). For substances that lack relevant effect data on the exposure route of interest, route-to-route extrapolation with help of allometric scaling factors was performed, assuming complete oral and inhalatory absorption when chemical-specific information was lacking [9].

The route-specific (oral, inhalation), and scale-specific (continental, moderate, tropic, arctic) human characterisation factors were aggregated to an overall human population characterisation factor for each of the carcinogenic and non-carcinogenic effects of substance s emitted to compartment i:

$$CF_{c/nc,i,s} = \sum_r \sum_k CF_{n/nc,r,i,s,k} \tag{10}$$

2.5. Normalisation figures

Total annual emissions for a reference year in a reference region are usually used to calculate normalisation figures:

$$A_e = \sum_i \sum_s CF_{e,i,s} M_{i,s} \tag{11}$$

where A_e is the normalisation score for category indicator e (yr yr^{-1}); $CF_{e,i,s}$ is the characterisation factor related to category indicator e for substance s emitted to compartment i (yr kg^{-1}); and $M_{i,s}$ is the annual emission of substance s to compartment i (kg yr^{-1}).

The NPI is Australia's national database of 90 pollutant emissions to air, water and land from industrial facilities and diffuse sources. Facilities that use more than 10 t of a listed NPI substance, burn more than 400 t of fuel, consume more than 60,000 MW of electricity, or emit more than 15 t of nitrogen or 3 t of phosphorus are required to report their emissions of all listed substances. The database also includes diffuse emission estimates for non-industry sources (e.g. motor vehicles) and selected sub-threshold facilities. Data were obtained from the NPI, showing emitting facilities, emission type, quantity and emission compartments for the 2002/2003 financial year [33]. Based on their NPI industry classification, each emitting facility was allocated to one of 106 industry sectors as classified by the Australian Bureau of Statistics [6] in order to identify the most environmentally relevant industry sectors. NPI substances that are not included in the toxicity normalisation are total phosphorus, total nitrogen, total volatile organic compounds and organo-tin compounds. Benzo-*a*-pyrene is used as a surrogate for polycyclic aromatic hydrocarbons and TCDD for polychlorinated dioxins and furans.

Emissions to air were allocated to rural or urban air based on the emitting facility's geographic coordinates. Approximate latitude and longitude boundaries for major Australian regional centres were estimated from a set of maps showing the extent of built-up areas [1]. Emissions to water were also allocated to fresh or marine water based on their place of origin. Data on treated wastewater emissions from each major population area were collected from relevant city councils or water service providers and used to allocate the proportion of wastewater emitted to fresh and marine waters from each urban centre. Rural treated wastewater emissions were allocated to fresh water. Many industrial facilities in Australia pretreat their wastewater onsite and send the pretreated wastewater to the sewer for final treatment at the local sewage treatment plant. Reportable water emissions from industrial facilities are therefore likely to be mostly stormwater emissions, but could also include treated effluent from onsite treatment plants. Allocation of such water emissions from the over 3000 industrial facilities in the database to marine or freshwater was performed using postcodes. Facilities located in a postcode (or cluster of postcodes for urban centres) that border the Australian coastline are assumed to emit to the marine

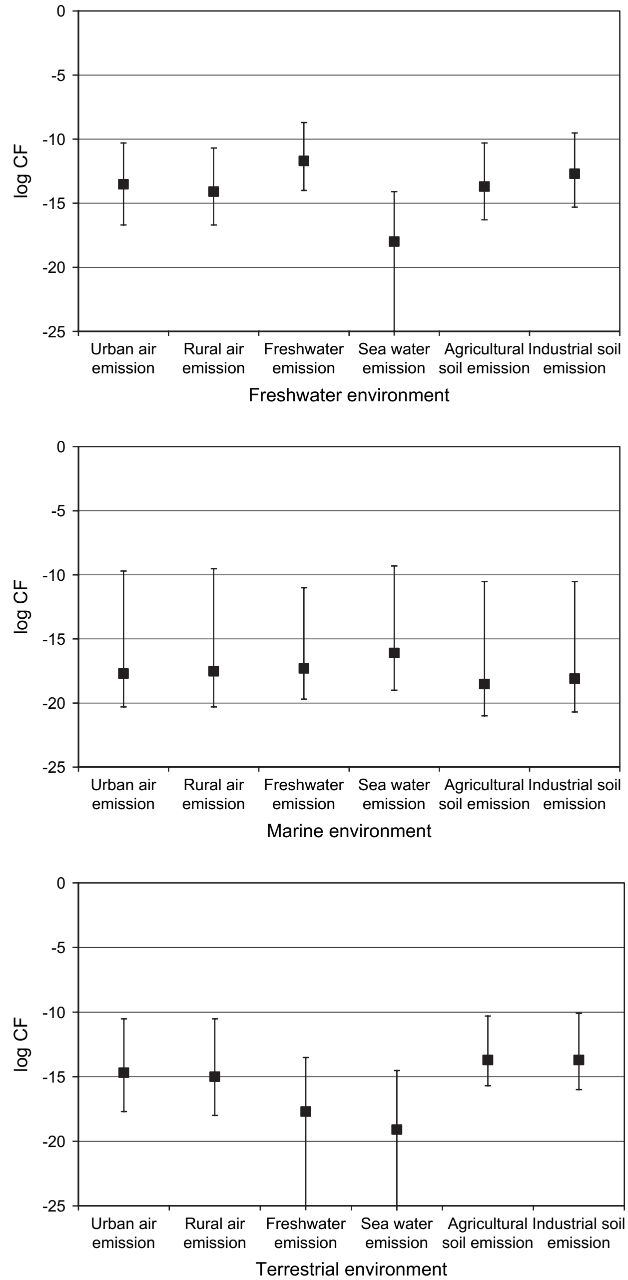

Fig. 2. Median, 5 percentile and 95 percentile of the characterisation factors for freshwater, terrestrial and marine ecotoxicity of 100 substances per emission compartment (yr kg^{-1} emission), respectively. The top line is the 95th percentile, the mark the median and the bottom line is the 5th percentile.

Table 5
Characterisation factors and emission data for each substance and emission compartment

Name	CAS	characteri-sation factor unit group	CFfw day/kg uair	CFsw day/kg uair	CFter day/kg uair	CFhum-carc yr/kg uair	CFhum-noncarc yr/kg uair	CFfw day/kg rair	CFsw day/kg rair	CFter day/kg rair	CFhum-carc yr/kg rair	CFhum-noncarc yr/kg rair	CFfw day/kg freshwater	CFsw day/kg freshwater	CFter day/kg freshwater
1,1,1,2-Tetrachloroethane	630-20-6	NPI	6,7E-13	5,9E-15	1,8E-13	6,3E-08	1,7E-07	6,7E-13	5,9E-15	1,8E-13	3,9E-08	1,1E-07	1,1E-09	5,8E-15	1,6E-13
1,1,2-Trichloroethane	79-00-5	NPI	3,0E-13	3,5E-14	6,6E-14	1,4E-07	4,2E-06	2,9E-13	3,5E-14	6,3E-14	6,2E-08	1,8E-06	2,7E-10	3,6E-14	6,2E-14
1,2-Dibromoethane	106-93-4	NPI	1,5E-12	6,2E-14	1,9E-13	2,5E-06		1,4E-12	6,2E-14	1,8E-13	9,6E-07		1,3E-09	6,4E-14	1,7E-13
1,2-Dichloroethane	107-06-2	NPI	1,3E-13	2,3E-14	3,1E-14	8,3E-07		1,2E-13	2,3E-14	3,0E-14	3,8E-07		1,3E-10	2,4E-14	2,9E-14
1,3-Butadiene	106-99-0	NPI	2,1E-18	2,9E-21	8,9E-19	3,7E-09	8,8E-08	3,4E-18	7,9E-21	4,3E-19	1,7E-11	4,0E-10	2,4E-10	3,1E-16	3,9E-19
2-ethoxyethyl acetate	111-15-9	NPI	1,7E-12	1,2E-16	1,1E-13			9,1E-13	1,6E-16	7,2E-14			2,8E-10	9,1E-17	1,0E-14
2-methoxyethanol	109-86-4	NPI	5,1E-17	9,7E-20	8,0E-18		4,3E-08	6,1E-17	1,3E-19	5,5E-18		8,5E-10	1,2E-12	1,5E-18	4,9E-18
2-methoxyethyl acetate	110-49-6	NPI	8,0E-12	1,1E-16	7,0E-13			1,4E-12	1,4E-16	4,7E-13			2,3E-10	5,9E-17	8,4E-15
4,4´-Methylene-bis(2-chlo	101-14-4	NPI				1,6E-07					8,3E-08				
Acetaldehyde	75-07-0	NPI	2,1E-13	1,0E-16	1,8E-14	1,5E-08	7,8E-08	2,5E-13	1,4E-16	1,1E-14	2,4E-10	1,1E-09	2,0E-10	1,5E-16	7,2E-15
Acetic acid	64-19-7	NPI	1,5E-11	2,6E-16	1,8E-12			2,8E-12	2,9E-16	1,4E-12			1,8E-10	5,7E-17	1,0E-14
acetone	67-64-1	NPI	2,7E-14	1,5E-17	1,4E-15		3,6E-09	2,6E-14	1,6E-17	1,2E-15		3,4E-10	2,8E-12	1,0E-17	6,9E-16
acetonitrile	75-05-8	NPI	2,0E-13	3,8E-16	1,5E-14		8,7E-09	1,9E-13	3,8E-16	1,2E-14		8,1E-10	1,7E-11	3,6E-16	1,1E-14
Acrylamide	79-06-1	NPI	1,2E-11	6,9E-17	2,4E-13	4,4E-07	8,9E-06	1,2E-12	1,3E-16	1,3E-13	2,6E-08	2,1E-07	1,8E-10	3,0E-17	5,2E-18
acrylic acid	79-10-7	NPI	2,3E-11	7,8E-17	9,1E-13		7,1E-06	2,1E-12	1,3E-16	7,5E-13		8,6E-08	1,6E-10	5,5E-17	1,2E-17
Acrylonitrile	107-13-1	NPI	2,5E-12	2,9E-15	1,9E-13	1,9E-07	9,7E-07	2,6E-12	3,2E-15	1,5E-13	1,1E-08	5,7E-08	8,9E-10	3,1E-15	1,2E-13
Ammonia (total)	7664-41-7	NPI													
aniline	62-53-3	NPI	7,0E-11	1,5E-16	1,1E-12	1,0E-09	7,0E-08	4,2E-12	3,5E-16	6,4E-13	1,4E-10	3,5E-09	2,5E-09	2,2E-15	8,2E-16
antimony (SbII)	7440-36-0	NPI	5,0E-10	1,9E-08	1,3E-09		2,3E-03	3,0E-10	2,0E-08	1,2E-09		2,3E-03	3,3E-09	1,7E-09	2,5E-29
arsenic (AsII)	7440-38-2	NPI	3,5E-10	1,3E-08	2,2E-09	9,6E-05	4,7E-01	2,1E-10	1,4E-08	2,3E-09	1,0E-04	8,4E-02	2,3E-09	5,2E-10	8,9E-30
Benzene	71-43-2	NPI	2,3E-14	1,6E-16	3,8E-15	2,3E-08	1,3E-08	2,3E-14	1,6E-16	3,5E-15	4,5E-09	2,4E-09	1,9E-10	3,3E-16	3,1E-15
Benzo-a-pyrene	50-32-8	NPI	4,4E-12	4,6E-17	1,1E-11	9,6E-07		4,1E-12	1,9E-16	2,3E-12	2,2E-07		1,9E-08	3,1E-17	1,0E-15
beryllium (BeII)	7440-41-7	NPI	3,3E-08	1,7E-06	2,1E-08	1,3E-05	9,7E-03	2,0E-08	1,8E-06	2,1E-08	1,1E-06	9,8E-04	2,3E-07	5,0E-07	1,4E-26
Boron (BIII)	7440-42-8	NPI													
cadmium (CdII)	7440-43-9	NPI	1,4E-10	5,3E-09	5,7E-09	1,2E-01	2,1E-03	8,4E-11	5,7E-09	4,9E-09	1,3E-01	2,1E-03	9,9E-10	6,3E-11	7,8E-31
carbon disulphide	75-15-0	NPI	3,2E-14	2,0E-16	5,1E-15		8,3E-07	3,2E-14	2,0E-16	4,5E-15		1,2E-07	8,3E-10	1,3E-15	4,0E-15
carbon monooxide	630-08-0	NPI													
cellosolve	110-80-5	NPI					1,0E-08					1,2E-09			
chlorine	7782-50-5	NPI	9,3E-12	1,9E-12	1,9E-11		4,1E-06	9,3E-12	1,9E-12	1,9E-11		4,0E-06	5,3E-08	1,7E-12	1,7E-11
chlorine dioxide	10049-04-4	NPI													
Chloroethane	75-00-3	NPI				9,8E-10	1,9E-10				3,9E-10	7,8E-11			
Chloroform	67-66-3	NPI	1,3E-13	2,6E-14	5,7E-14	2,5E-08	4,7E-07	1,3E-13	2,6E-14	5,6E-14	1,6E-08	3,0E-07	3,9E-10	2,7E-14	5,4E-14
Chromium (III)	7440-47-3	NPI	1,5E-11	5,3E-10	2,6E-09		2,1E-08	8,9E-12	5,7E-10	2,7E-09		1,3E-08	9,9E-11	5,6E-12	1,1E-31
Chromium (VI)	7440-47-3	NPI	5,1E-11	1,8E-09	8,9E-09	6,4E-05	9,0E-05	3,0E-11	1,9E-09	9,2E-09	6,0E-06	1,5E-05	3,4E-10	1,9E-11	3,7E-31
Cobalt (CoII)	7440-48-4	NPI	1,0E-09	3,9E-08	2,7E-09	5,7E-03		6,3E-10	4,2E-08	2,7E-09	5,9E-03		7,0E-09	3,4E-09	6,1E-29
Copper (CuII)	7440-50-8	NPI	3,4E-09	9,1E-08	2,2E-08		3,2E-06	2,5E-09	9,8E-08	1,6E-08		3,4E-06	1,7E-08	1,4E-09	1,5E-29
cumene	98-82-8	NPI	2,1E-14	2,0E-17	1,6E-15		1,9E-09	2,3E-14	2,4E-17	1,2E-15		7,9E-11	1,1E-09	5,6E-16	9,1E-16
cyanide, free	57-12-5	NPI	1,1E-10	1,2E-13	1,1E-11		1,6E-07	1,1E-10	1,2E-13	9,2E-12		2,7E-08	1,7E-08	8,7E-14	6,4E-12
cyclohexane	110-82-7	NPI	1,4E-14	1,0E-16	1,2E-15		2,0E-09	1,6E-14	1,2E-16	9,0E-16		6,9E-11	1,4E-10	6,9E-16	8,6E-16
di(2-Ethylhexyl)phthalate	117-81-7	NPI	2,6E-13	2,4E-15	3,0E-15	5,1E-09	6,8E-07	3,0E-13	3,0E-15	1,7E-15	2,7E-09	1,0E-07	1,6E-10	3,0E-16	4,2E-17
dibutylphtalate	84-74-2	NPI	3,0E-10	2,1E-14	2,4E-12		1,9E-08	1,1E-10	2,7E-14	1,2E-12		1,6E-09	4,0E-08	2,0E-14	2,9E-14
Diphenyl	92-52-4	NPI	9,9E-15	6,5E-19	4,2E-14		5,1E-08	1,1E-14	7,7E-19	3,0E-14		2,0E-09	1,9E-11	2,6E-21	4,1E-17
ethyl acetate	141-78-6	NPI	7,9E-14	6,3E-17	4,8E-15		3,5E-09	8,0E-14	6,6E-17	4,1E-15		3,5E-10	2,6E-11	5,2E-17	2,7E-15
Ethyl alcohol	64-17-5	NPI	2,1E-14	3,2E-18	1,6E-15	2,5E-10		1,7E-14	3,5E-18	1,0E-15	1,0E-11		2,2E-12	4,4E-19	8,3E-17
ethyl butyl ketone	106-35-4	NPI													
Ethylbenzene	100-41-4	NPI	1,5E-14	1,8E-17	1,4E-15	6,5E-10	9,4E-10	1,7E-14	2,2E-17	1,1E-15	2,2E-11	3,3E-11	6,4E-10	4,3E-16	8,7E-16
ethylene glycol	107-21-1	NPI	2,8E-13	2,5E-18	1,1E-14		5,7E-09	3,5E-14	3,3E-18	8,1E-15		3,3E-10	3,3E-12	2,1E-18	6,8E-17
Ethylene oxide	75-21-8	NPI	6,9E-13	1,0E-15	4,6E-14	1,9E-07		6,8E-13	1,0E-15	4,0E-14	3,3E-08		1,1E-10	1,0E-15	3,6E-14
Fluoride ion	16984-48-8	NPI	1,5E-09	4,8E-06	6,3E-11			4,8E-10	4,2E-06	6,8E-11			5,6E-09	6,0E-06	6,6E-13
Formaldehyde	50-00-0	NPI	2,0E-11	5,6E-16	1,2E-12	2,1E-06	7,8E-08	4,5E-12	7,1E-16	7,1E-13	1,9E-07	2,5E-09	6,4E-10	2,4E-16	2,3E-14
Glutaraldehyde	111-30-8	NPI													
hexachlorobenzene	118-74-1	NPI	8,1E-11	6,5E-11	3,7E-11	1,3E-05	9,5E-06	8,0E-11	6,5E-11	3,7E-11	1,2E-05	8,3E-06	4,6E-08	5,1E-11	2,8E-11
hexane	110-54-3	NPI	5,3E-17	2,9E-19	9,7E-18		2,4E-08	5,7E-17	3,3E-19	7,6E-18		1,1E-09	3,5E-10	7,6E-16	6,7E-18
hexone	108-10-1	NPI	1,1E-14	5,7E-18	6,2E-16		3,4E-10	1,3E-14	7,7E-18	4,0E-16		5,8E-12	1,8E-11	1,1E-17	2,6E-16
hydrogen chloride	7647-01-0	NPI					3,2E-07					1,3E-08			
hydrogen sulphide (h2s)	7783-06-4	NPI					1,4E-06					4,0E-08			
lead (PbII)	7439-92-1	NPI	1,2E-11	2,5E-10	2,1E-10	6,5E-06	1,6E-03	9,3E-12	2,7E-10	3,6E-11	6,8E-06	1,6E-03	4,5E-11	2,4E-12	1,6E-33
Magnesium oxide fume	1309-48-4	NPI													
manganese (MnII)	7439-96-5	NPI	9,4E-11	3,2E-09	8,0E-10		1,8E-03	5,4E-11	3,5E-09	8,6E-10		1,8E-03	6,0E-10	9,8E-11	1,8E-30
mercury (HgII)	7439-97-6	NPI	2,6E-10	5,1E-08	3,2E-08		7,9E-02	1,6E-10	5,2E-08	3,1E-08		8,0E-02	5,7E-09	3,3E-10	1,3E-10
methanol	67-56-1	NPI	9,5E-14	2,2E-17	5,2E-15		6,0E-09	7,7E-14	2,2E-17	3,7E-15		2,7E-10	6,4E-12	8,5E-18	1,0E-15
methyl ethyl ketone	78-93-3	NPI	4,1E-14	2,1E-17	2,0E-15		1,0E-10	4,0E-14	2,2E-17	1,6E-15		1,9E-11	5,5E-12	1,4E-17	8,9E-16
methyl methacrylate	80-62-6	NPI	7,1E-15	1,2E-17	8,7E-16		1,4E-07	9,8E-15	2,1E-17	5,1E-16		1,3E-09	4,9E-11	9,0E-17	4,6E-16
Methylene chloride	75-09-2	NPI	3,0E-14	1,4E-15	7,7E-15	7,6E-09	5,3E-07	3,0E-14	1,4E-15	7,5E-15	4,0E-09	2,8E-07	6,6E-11	1,3E-15	6,8E-15

environment (including estuaries). The areas covered by some postcodes (e.g. in the tropics) are extremely large, however, the approximation may not hold for all facilities. It is assumed that the majority of industrial facilities located in these areas that have water emissions will be located on the coast rather than inland. Emissions to land were allocated to agricultural soil if they originated from agricultural industry sectors and to industrial soil for all other industries.

Data on individual pesticide use in Australia are not publicly available. There are over 2000 active ingredients approved for use in Australia and over 250 chemicals of which more than 1 t is imported or manufactured in Australia each year [4]. In a review published by the Australian Academy of Technological Sciences and Engineering [4], lists were published of important insecticides, herbicides and fungicides and the number of substances that exceed 10 t yr^{-1}, 100 t yr^{-1} and 1000 t yr^{-1}. In some cases approximate use figures are provided for individual chemicals (e.g. 15,000 t yr^{-1} for glyphosate, 3000 t yr^{-1} of atrazine and 1000 t yr^{-1} of chlorpyriphos) or classes of chemicals (e.g. aryloxyphenoxypropionates or 'fops'). We have used pesticide use figures reported for 13 pesticides as an initial estimate for pesticide use in the Australia but this figure is known to underestimate total pesticide use by approximately 15,000 t yr^{-1} (Table 4).

3. Results and discussion

3.1. Characterisation factors

A summary of the characterisation factors expressing marginal change in cumulative population-based risk and potential

CFhum-carc yr/kg freshwater	CFhum-noncarc yr/kg freshwater	CFfw day/kg seawater	CFsw day/kg seawater	CFter day/kg seawater	CFhum-carc yr/kg seawater	CFhum-noncarc yr/kg seawater	CFfw day/kg agrisoil	CFsw day/kg agrisoil	CFter day/kg agrisoil	CFhum-carc yr/kg agrisoil	CFhum-noncarc yr/kg agrisoil	CFfw day/kg industsoil	CFsw day/kg industsoil	CFter day/kg industsoil	CFhum-carc yr/kg industsoil	CFhum-noncarc yr/kg industsoil
3,8E-08	1,0E-07	1,7E-14	8,7E-15	4,4E-15	9,9E-10	2,7E-09	1,7E-12	2,6E-15	1,7E-11	1,7E-08	4,8E-08	2,7E-11	3,2E-15	2,2E-11	2,1E-08	5,9E-08
6,4E-08	1,8E-06	1,7E-13	7,2E-14	3,8E-14	3,7E-08	1,1E-06	2,3E-12	2,1E-14	1,9E-11	3,8E-08	1,1E-06	2,1E-11	2,1E-14	1,9E-11	3,8E-08	1,1E-06
1,0E-06		5,0E-13	1,7E-13	6,5E-14	3,5E-07		3,8E-12	3,2E-14	3,5E-11	5,0E-07		5,2E-11	3,3E-14	3,4E-11	5,2E-07	
4,0E-07		8,4E-14	4,7E-14	2,1E-14	2,8E-07		7,8E-13	1,3E-14	6,8E-12	2,3E-07		7,1E-12	1,4E-14	6,8E-12	2,3E-07	
3,8E-10	2,2E-09	5,6E-19	1,3E-14	7,0E-20	2,9E-12	6,6E-11	8,2E-15	1,7E-20	4,9E-14	1,5E-11	3,2E-10	3,6E-14	5,3E-20	4,9E-14	1,4E-11	3,2E-10
		1,9E-15	1,3E-15	1,5E-16			4,6E-12	8,4E-17	6,2E-12			6,6E-11	9,1E-17	4,5E-12		
	1,6E-09	8,5E-18	5,4E-17	7,6E-19		1,2E-10	3,4E-15	8,0E-20	3,4E-14		6,4E-10	2,9E-14	1,1E-19	3,4E-14		6,1E-10
		3,3E-16	9,1E-16	1,1E-16			6,3E-12	5,8E-17	7,2E-12			8,2E-11	6,4E-17	4,4E-12		
7,1E-07					1,5E-10					8,9E-09					5,1E-08	
7,9E-10	1,5E-09	7,0E-15	2,6E-15	3,1E-16	6,5E-12	3,2E-11	7,2E-13	7,1E-17	6,1E-12	1,4E-10	6,0E-10	1,1E-11	7,6E-17	5,8E-12	1,6E-10	6,3E-10
		3,2E-16	8,8E-16	1,6E-16			6,1E-12	6,9E-17	7,8E-12			7,4E-11	7,2E-17	4,6E-12		
	2,3E-10	5,8E-16	3,3E-17	2,6E-17		7,8E-12	2,7E-14	7,9E-18	9,3E-14		1,7E-10	2,6E-13	8,2E-18	8,4E-14		1,8E-10
	7,6E-10	2,1E-14	6,9E-16	1,4E-15		9,0E-11	2,7E-13	2,0E-16	1,6E-12		4,3E-10	3,0E-12	2,3E-16	1,3E-12		5,0E-10
3,4E-08	1,8E-07	7,4E-19	8,2E-16	8,0E-20	4,0E-14	2,6E-13	1,7E-12	4,2E-19	6,3E-13	4,4E-10	2,4E-09	2,8E-11	4,9E-18	5,4E-13	5,4E-09	2,9E-08
	6,6E-10	5,5E-20	7,8E-16	2,0E-20		2,8E-15	5,0E-12	1,8E-18	3,7E-12		9,2E-11	6,6E-11	2,3E-17	2,3E-12		6,9E-10
1,6E-08	5,4E-08	1,6E-13	2,1E-14	9,3E-15	7,1E-10	3,6E-09	4,8E-12	1,6E-15	4,4E-11	6,1E-09	2,9E-08	6,4E-11	1,7E-15	4,1E-11	6,5E-09	3,1E-08
8,7E-10	2,1E-08	9,5E-18	1,3E-14	1,5E-18	1,4E-15	3,3E-14	8,1E-11	8,2E-17	2,7E-11	4,0E-11	9,7E-10	9,4E-10	8,8E-16	1,4E-11	3,5E-10	8,4E-09
	1,8E-04	2,4E-29	3,8E-08	5,6E-28		3,9E-03	9,8E-10	5,1E-10	3,1E-09		5,5E-05	3,0E-09	1,5E-09	2,5E-09		1,6E-04
3,5E-06	1,5E-03	7,3E-30	2,6E-08	4,4E-28	1,7E-04	7,2E-02	6,9E-10	1,5E-10	5,7E-09	1,2E-06	4,9E-04	2,1E-09	4,7E-10	4,7E-09	3,3E-06	1,4E-03
4,7E-09	3,0E-09	2,6E-15	7,4E-15	4,0E-16	5,2E-10	2,8E-10	5,9E-13	1,1E-16	4,8E-12	3,1E-09	1,8E-09	3,9E-12	1,1E-16	4,8E-12	3,0E-09	1,7E-09
2,1E-08		1,0E-17	3,0E-14	5,6E-18	6,8E-13		4,4E-11	2,6E-18	2,2E-10	4,2E-07		2,5E-10	2,9E-18	2,2E-10	3,1E-09	
	4,6E-05	1,5E-26	3,1E-06	9,0E-26		2,9E-04	6,7E-08	1,5E-07	5,5E-08		1,4E-05	2,0E-07	4,5E-07	4,5E-08		4,2E-05
8,3E-05	1,4E-06	2,1E-31	1,1E-08	1,3E-28	1,4E-02	2,2E-04	1,0E-10	6,5E-12	2,3E-09	1,4E-01	2,2E-03	9,2E-10	5,8E-11	2,0E-08	5,0E-04	8,2E-06
	1,1E-07	4,8E-15	4,1E-14	6,7E-16		1,8E-08	1,4E-12	1,4E-16	1,1E-11		7,9E-08	8,6E-12	1,5E-16	1,1E-11		7,9E-08
	2,2E-09					8,8E-13					3,8E-10					1,1E-09
	3,5E-06	1,1E-12	2,3E-12	2,2E-12		4,5E-07	5,5E-11	1,5E-12	3,2E-10		3,1E-06	2,4E-10	1,5E-12	3,2E-10		3,1E-06
3,7E-10	7,0E-11				3,6E-11	7,2E-12				2,3E-10	4,5E-11				2,3E-10	4,5E-11
1,5E-08	2,9E-07	5,7E-14	6,6E-14	2,5E-14	6,9E-09	1,3E-07	1,1E-12	1,5E-14	8,7E-12	9,3E-09	1,8E-07	8,9E-12	1,6E-14	8,7E-12	9,3E-09	1,8E-07
	8,0E-12	1,3E-32	1,1E-09	2,0E-29		1,5E-09	2,9E-11	1,6E-12	6,9E-09		1,6E-10	8,9E-11	5,0E-12	5,6E-09		1,4E-10
	4,7E-09	4,3E-32	3,6E-09	6,8E-29		8,6E-07	9,9E-11	5,6E-12	2,3E-08		9,4E-08	3,0E-10	1,7E-11	1,9E-08		7,9E-08
5,9E-05		5,9E-29	7,8E-08	1,4E-27	1,2E-03		2,1E-09	1,0E-09	6,8E-09	1,0E-04		6,3E-09	3,1E-09	5,6E-09	1,1E-04	
	2,1E-08	1,8E-29	1,8E-07	1,9E-27		2,7E-06	1,5E-09	1,3E-10	3,2E-09		3,3E-07	1,6E-08	1,4E-09	6,1E-08		2,6E-08
	3,7E-10	1,1E-15	2,2E-14	6,1E-17		4,0E-12	8,3E-14	1,2E-17	9,0E-13		4,7E-11	1,3E-12	1,2E-17	9,0E-13		4,0E-11
	2,0E-08	4,0E-12	2,7E-13	3,3E-13		9,6E-10	1,1E-10	5,9E-14	1,1E-09		1,4E-08	1,0E-09	6,1E-14	1,0E-09		1,4E-08
	1,4E-10	7,0E-15	2,0E-14	4,0E-16		3,3E-11	9,0E-14	6,2E-17	1,1E-12		4,1E-11	1,4E-12	6,8E-17	1,1E-12		3,6E-11
1,6E-10	5,7E-09	5,8E-15	3,7E-14	3,3E-17	5,2E-11	2,0E-09	8,7E-14	8,3E-17	9,9E-15	8,6E-11	3,3E-09	4,3E-13	8,4E-17	9,9E-15	7,5E-11	2,9E-09
	2,0E-09	5,7E-14	2,4E-13	6,0E-16		9,0E-13	1,1E-10	2,5E-15	1,3E-11		2,1E-10	1,6E-09	3,2E-15	1,2E-11		2,3E-10
	2,1E-11	7,4E-20	2,9E-17	2,0E-19		1,4E-14	9,7E-15	3,7E-19	2,4E-12		9,8E-10	8,0E-14	3,7E-19	2,4E-12		9,7E-10
	2,6E-10	2,4E-15	3,6E-16	1,2E-16		1,0E-11	1,1E-13	3,3E-17	6,6E-13		1,8E-10	1,2E-12	3,4E-17	6,2E-13		1,8E-10
5,8E-12		2,2E-17	1,1E-17	1,4E-18	1,4E-14		1,9E-14	1,6E-18	3,6E-14	4,9E-12		2,1E-13	1,6E-18	3,2E-14	5,0E-12	
4,8E-11	3,3E-10	1,2E-15	1,6E-14	7,4E-17	1,5E-12	2,3E-12	9,8E-14	1,1E-17	1,4E-12	1,2E-11	2,7E-11	1,6E-12	1,2E-17	1,4E-12	1,1E-11	1,8E-11
	3,0E-10	5,0E-18	1,7E-17	1,2E-18		4,8E-14	1,0E-13	5,8E-19	5,9E-14		6,5E-11	1,3E-12	1,2E-18	3,6E-14		1,6E-10
3,6E-08		4,4E-14	2,4E-15	2,6E-15	2,2E-09		7,4E-13	5,3E-16	4,8E-12	1,7E-08		7,3E-12	5,7E-16	4,5E-12	1,8E-08	
		3,2E-13	6,1E-06	6,6E-13			1,7E-09	2,0E-06	2,2E-10			5,1E-09	5,4E-06	1,8E-10		
2,4E-07	2,3E-09	2,3E-15	3,2E-15	3,7E-16	9,7E-11	1,3E-12	1,2E-11	2,3E-16	1,0E-11	6,6E-08	8,8E-10	1,6E-10	2,5E-16	7,6E-12	1,1E-07	1,3E-09
1,4E-05	8,7E-06	6,3E-11	7,4E-11	3,2E-11	1,1E-05	7,6E-06	1,4E-10	3,2E-11	4,6E-10	6,7E-06	4,4E-06	1,1E-09	3,3E-11	4,5E-10	6,4E-06	4,3E-06
	9,2E-09	1,3E-17	2,9E-14	1,8E-18		2,8E-10	2,0E-14	2,9E-19	9,2E-14		9,2E-10	8,0E-14	4,2E-19	9,2E-14		8,4E-10
	7,7E-12	3,8E-16	2,4E-16	1,2E-17		1,7E-13	3,8E-14	3,9E-18	2,1E-13		2,9E-12	5,9E-13	4,1E-18	2,0E-13		3,1E-12
1,7E-08	4,0E-06	4,0E-33	4,8E-10	3,2E-31	3,4E-06	8,1E-04	3,9E-12	2,1E-13	2,6E-12	9,5E-08	2,3E-05	4,5E-11	2,4E-12	9,1E-11	1,8E-08	4,2E-06
	5,0E-05	1,3E-30	6,5E-09	1,2E-28		3,3E-03	1,8E-10	2,9E-11	2,2E-09		1,5E-05	5,4E-10	8,8E-11	1,8E-09		4,5E-05
	5,2E-04	3,4E-11	5,5E-08	2,0E-08		8,5E-02	9,5E-10	2,7E-08	1,4E-07		4,3E-02	3,1E-09	2,2E-08	1,2E-07		3,4E-02
	1,8E-10	4,8E-16	4,2E-17	2,3E-17		1,7E-12	9,9E-14	1,1E-17	1,2E-13		1,3E-10	1,1E-12	1,1E-17	1,0E-13		1,4E-10
	7,8E-11	8,2E-16	6,0E-17	3,2E-17		4,0E-13	4,7E-14	1,1E-17	1,5E-13		1,2E-11	5,0E-13	1,1E-17	1,3E-13		1,6E-11
	1,3E-09	1,4E-15	2,4E-15	7,5E-17		2,0E-10	1,2E-13	1,1E-17	1,5E-12		6,9E-10	2,1E-12	1,4E-17	1,4E-12		7,2E-10
3,8E-09	2,6E-07	4,8E-15	3,7E-15	1,2E-15	6,6E-10	4,6E-08	7,9E-14	7,3E-16	8,7E-13	2,1E-09	1,5E-07	8,8E-13	7,3E-16	8,7E-13	2,1E-09	1,5E-07

(continued on next page)

impacts (DALYs) per kilogram emission for 38 human carcinogenic substances and 68 human non-carcinogenic substances per emission compartment is given in Fig. 1. A similar summary of characterisation factors for expressing marginal risk-based factors in terms of potentially affected fraction of species in freshwater, marine and terrestrial environments for 100 substances is given in Fig. 2 (units of yr kg^{-1} emission). Full details on characterisation factors for each substance and emission compartment can be found in Table 5.

Figs. 1 and 2 show large differences in the median characterisation factors between each of the emission compartments. For human toxicity, emissions to air (especially urban air, median $= 10^{-7}$ yr kg^{-1}) have the highest characterisation factors followed by emissions to freshwater for carcinogenics and industrial soil for non-carcinogenics. The median characterisation factors for emission to seawater are at least three orders of magnitude less than those for emissions to air. The 5th and 95th percentiles are at least three orders of magnitude from the median for each environmental and human characterisation factors, regardless of the emission compartment.

Air emissions are less important for freshwater ecotoxicity and marine ecotoxicity impact categories. Emissions directly to the freshwater compartment have the highest characterisation factors for freshwater ecotoxicity (median $= 2 \times 10^{-12}$ yr kg^{-1}) followed by emission to industrial soil (median $= 2 \times 10^{-13}$ yr kg^{-1}). The significance of industrial soil on the freshwater ecotoxicity is due to the higher fraction of runoff used for industrial soils compared to agricultural soils

Table 5 (*continued*)

		characteri-sation factor	CFfw	CFsw	CFter	CFhum-carc	CFhum-noncarc	CFfw	CFsw	CFter	CFhum-carc	CFhum-noncarc	CFfw	CFsw	CFter
		unit	day/kg	day/kg	day/kg	yr/kg	yr/kg	day/kg	day/kg	day/kg	yr/kg	yr/kg	day/kg	day/kg	day/kg
		group	uair	uair	uair	uair	uair	rair	rair	rair	rair	rair	freshwater	freshwater	freshwater
Methylene diphenyl diisoc	101-68-8	NPI					5,5E-06					9,4E-07			
nickel - soluble salts (NiII)	7440-02-0	NPI	2,5E-09	8,8E-08	4,7E-09		2,1E-05	1,6E-09	9,5E-08	3,9E-09		2,2E-05	1,6E-08	4,2E-09	5,2E-29
Nickel carbonyl	13463-39-3	NPI													
Nickel subsulfide	12035-72-2	NPI				2,6E-06					2,4E-07				
Nitric acid	7697-37-2	NPI													
Organo-tin compounds		NPI													
Oxides of Nitrogen	10102-44-0	NPI													
Particulate matter =<10.0 u	##	NPI													
phenol	108-95-2	NPI	3,5E-12	3,2E-17	2,4E-13		1,7E-08	5,8E-13	5,8E-17	1,2E-13		4,1E-10	2,3E-10	1,5E-17	9,5E-16
Phosphoric acid	7664-38-2	NPI													
Polychlorinated dioxins and furans		NPI													
Polycyclic aromatic hydrocarbons		NPI													
selenium (SeIV)	7782-49-2	NPI	8,5E-09	4,5E-07	4,1E-09	1,1E-02	1,2E-01	5,1E-09	4,7E-07	4,0E-09	1,2E-02	1,3E-01	5,7E-08	1,8E-07	3,1E-27
Styrene	100-42-5	NPI	7,7E-15	1,6E-17	9,4E-16	4,8E-08	1,2E-08	1,3E-14	3,8E-17	4,8E-16	2,7E-10	6,5E-11	9,5E-10	1,9E-15	4,3E-16
Sulfur dioxide	7446-09-5	NPI													
Sulfuric acid	7664-93-9	NPI													
TCDD	1746-01-6	NPI	3,1E-07	8,7E-10	5,2E-08	6,2E-01		3,1E-07	9,5E-10	3,4E-08	6,2E-01		6,8E-05	4,4E-11	2,8E-10
Tetrachloroethylene	127-18-4	NPI	2,1E-13	4,0E-14	1,1E-13	8,7E-08	1,7E-06	2,0E-13	4,0E-14	1,1E-13	5,3E-08	1,0E-06	2,9E-09	5,1E-14	1,0E-13
Toluene	108-88-3	NPI	8,1E-15	8,6E-18	8,7E-16	6,5E-10	1,4E-08	8,9E-15	1,0E-17	6,7E-16	2,7E-11	5,9E-10	3,1E-10	1,8E-16	5,7E-16
toluene-2,4-diisocyante	584-84-9	NPI	1,4E-13	1,8E-16	1,8E-15			1,5E-13	2,1E-16	1,3E-15			1,4E-10	3,1E-16	1,0E-15
Total Nitrogen		NPI													
Total Phosphorus		NPI													
Total Volatile Organic Compounds		NPI													
Trichloroethylene	79-01-6	NPI	1,8E-14	1,7E-16	2,5E-15	4,2E-09		1,8E-14	1,8E-16	2,2E-15	4,6E-10		4,0E-10	1,4E-15	2,1E-15
Vinyl chloride	75-01-4	NPI				1,1E-07	1,7E-07				4,3E-09	6,5E-09			
Xylene mixture (m-xylene,	1330-20-7	NPI	5,8E-15	1,2E-17	6,2E-16	5,3E-10	1,8E-08	7,1E-15	1,7E-17	4,2E-16	9,8E-12	3,3E-10	3,7E-10	5,6E-16	3,8E-16
zinc (ZnII)	7440-66-6	NPI	1,5E-10	4,6E-09	3,1E-09		1,2E-04	9,7E-11	4,9E-09	2,5E-09		1,3E-04	8,4E-10	5,6E-11	6,5E-31
2,2-DPA	75-99-0	pesticide	2,5E-11	9,4E-16	9,4E-13		1,9E-07	6,7E-12	9,9E-16	7,3E-13		3,3E-08	4,6E-10	5,5E-16	3,1E-14
2,4,5-T (bromide)	93-76-5	pesticide	1,2E-09	3,8E-15	1,0E-11		5,8E-07	1,1E-10	5,1E-15	8,0E-12		2,9E-07	8,9E-09	6,1E-15	5,4E-18
2,4-D	94-75-7	pesticide	1,4E-10	4,7E-17	5,3E-12		8,9E-08	1,1E-11	1,4E-16	5,5E-12		2,1E-08	9,1E-10	1,1E-16	1,2E-20
acrolein	107-02-8	pesticide	4,4E-10	4,3E-13	4,5E-11		1,1E-04	4,8E-10	6,5E-13	2,8E-11		1,3E-06	2,5E-07	9,4E-13	2,3E-11
agridex	88650-63-9	pesticide													
aldicarb	116-06-3	pesticide	1,2E-07	7,2E-13	1,5E-09		1,9E-06	1,0E-08	4,5E-13	2,4E-09		2,4E-07	7,3E-07	4,0E-12	1,6E-12
amitraz	33089-61-1	pesticide	2,5E-11	2,6E-14	7,1E-13		2,7E-07	4,1E-11	1,1E-13	2,5E-13		4,0E-08	1,5E-07	3,0E-13	3,3E-14
amitrole	61-82-5	pesticide	3,1E-10	1,4E-15	1,7E-11	3,1E-07	6,6E-07	3,5E-11	1,7E-15	2,2E-11	1,4E-07	2,5E-07	1,6E-09	1,7E-15	1,0E-18
atrazine	1912-24-9	pesticide	9,4E-08	1,6E-12	3,0E-10	3,9E-08	9,1E-08	6,5E-09	9,8E-13	2,9E-10	1,6E-08	1,5E-08	7,3E-07	1,2E-11	2,6E-18
azinphos-methyl	86-50-0	pesticide	3,5E-08	2,3E-14	5,6E-10		4,9E-07	2,0E-09	1,6E-13	1,7E-10		3,4E-08	1,4E-06	3,9E-13	2,4E-14
benomyl	17804-35-2	pesticide	3,7E-10	6,6E-15	3,1E-12		1,2E-08	9,1E-11	9,8E-15	1,8E-12		1,0E-09	2,1E-08	5,4E-15	2,0E-18
bensulfuron-Me	83055-99-6	pesticide					8,7E-08					1,4E-08			
bifenthrin	82657-04-3	pesticide	2,8E-09	3,4E-12	3,2E-10		2,9E-07	3,1E-09	5,0E-12	1,4E-10		3,1E-07	2,0E-06	1,1E-12	4,9E-13
bitertanol	55179-31-2	pesticide	1,3E-09	1,0E-13	1,4E-11		1,7E-07	3,7E-10	1,3E-13	9,2E-12		2,9E-08	6,7E-08	7,4E-14	2,0E-19
bromacil	314-40-9	pesticide	6,3E-10	1,5E-15	6,4E-12			5,0E-11	2,5E-15	5,7E-12			4,4E-09	4,8E-15	8,4E-17
bromocide	82657-04-3	pesticide	2,8E-09	3,4E-12	3,2E-10		2,9E-07	3,1E-09	5,0E-12	1,4E-10		3,1E-07	2,0E-06	1,1E-12	4,9E-13
bromoxynil	1689-84-5	pesticide	7,5E-09	1,9E-13	2,1E-11		2,8E-07	8,7E-10	2,2E-13	1,3E-11		5,1E-08	9,3E-08	4,0E-13	2,7E-15
bupirimate	41483-43-6	pesticide	2,6E-09	4,0E-15	1,7E-11			1,0E-10	7,2E-15	6,4E-12			6,2E-08	6,7E-14	1,2E-14
butroxydim	138164-12-2	pesticide													
captan	133-06-2	pesticide	1,5E-10	3,8E-17	5,7E-12	2,1E-10	1,9E-08	8,6E-12	3,6E-16	9,9E-13	1,2E-12	6,0E-11	8,8E-09	7,6E-17	2,4E-17
carbaryl	63-25-2	pesticide	3,0E-09	3,3E-16	4,0E-11	6,1E-08	3,4E-07	1,8E-10	2,0E-15	1,8E-11	2,7E-08	2,6E-08	4,2E-08	1,9E-15	3,8E-16
carbofuran	1563-66-2	pesticide	6,3E-08	8,4E-14	4,1E-10		6,0E-07	4,2E-09	1,4E-13	3,6E-10		8,7E-08	4,9E-07	5,6E-13	3,7E-14
chlordane	57-74-9	pesticide	2,8E-11	1,8E-12	1,2E-11	1,9E-05	4,0E-05	3,2E-11	2,4E-12	7,4E-12	2,3E-05	5,3E-05	1,8E-08	1,5E-13	1,5E-13
chlorfenapyr	122453-73-0	pesticide													
chlorfenvinphos	470-90-6	pesticide	6,9E-08	2,8E-13	3,3E-10		1,5E-05	4,5E-09	4,8E-13	1,8E-10		2,3E-06	9,3E-07	2,3E-12	1,1E-13
chlorfluazuron	71422-67-8	pesticide													
chlorothalonil	1897-45-6	pesticide	1,8E-10	2,9E-12	6,6E-12	2,2E-09	3,8E-07	1,8E-10	2,9E-12	6,3E-12	1,0E-09	1,7E-07	1,2E-07	2,5E-12	5,2E-12
chlorpyriphos	2921-88-2	pesticide	2,6E-09	4,4E-14	3,2E-11		4,0E-07	2,5E-09	1,1E-13	1,1E-11		1,2E-07	5,0E-06	3,6E-13	3,4E-12
clethodim	99129-21-2	pesticide													
clopyralid	1702-17-6	pesticide	6,3E-10	4,5E-15	2,3E-11			8,1E-11	4,6E-15	2,7E-11			3,2E-09	5,9E-15	1,9E-14
cyanazine	21725-46-2	pesticide	4,9E-09	1,4E-14	2,2E-11		1,6E-06	3,3E-10	2,3E-14	1,4E-11		4,7E-08	4,7E-08	8,2E-14	3,7E-24
cypermethrin	52315-07-8	pesticide	4,5E-06	8,9E-11	2,2E-07		1,0E-06	1,2E-06	9,6E-11	1,9E-07		8,5E-07	9,6E-05	6,2E-11	2,6E-09
deltamethrin	52918-63-5	pesticide	2,3E-10	8,8E-13	5,4E-12		1,3E-07	3,1E-10	1,4E-12	2,2E-12		2,2E-08	3,9E-07	3,9E-13	6,0E-14
diazionon	333-41-5	pesticide	5,6E-09	4,7E-14	2,4E-11		1,2E-06	5,8E-10	1,2E-13	9,7E-12		4,5E-07	8,8E-07	2,0E-12	8,3E-13
dichlorvos	62-73-7	pesticide	8,8E-11	5,0E-15	1,8E-12	6,6E-07	7,6E-06	4,4E-11	6,4E-15	9,8E-13	1,6E-08	1,3E-07	1,5E-08	6,7E-16	1,4E-14
dicofol	115-32-2	pesticide	9,8E-11	4,0E-13	4,4E-12	3,6E-07	8,2E-06	8,8E-11	6,4E-13	2,0E-12	3,0E-07	3,9E-06	2,0E-08	8,4E-14	1,4E-17
difenoconazole	119446-68-3	pesticide	2,4E-09	2,4E-13	2,7E-11			6,6E-10	3,2E-13	1,7E-11			1,2E-07	2,2E-13	1,4E-17
diflubenzuron	35367-38-5	pesticide	5,9E-08	1,5E-12	4,3E-10		8,9E-08	1,0E-08	2,2E-12	2,3E-10		2,1E-08	2,5E-06	2,7E-12	1,0E-13
diflufenican	83164-33-4	pesticide	2,2E-12	1,1E-15	2,1E-14			1,6E-12	1,3E-15	1,2E-14			4,6E-10	5,4E-16	1,4E-16
dimethipin	55290-64-7	pesticide					1,5E-07					1,3E-08			
dimethoate	60-51-5	pesticide	2,2E-08	3,2E-14	1,2E-10		2,5E-07	1,4E-09	3,5E-14	9,9E-11		8,3E-08	1,8E-07	2,4E-13	3,2E-14
diquat	2764-72-9	pesticide	1,0E-08	6,9E-14	1,4E-10		6,9E-06	1,2E-09	8,3E-14	1,2E-10		1,1E-06	7,4E-08	8,1E-14	6,7E-16

(0.45 versus 0.12). The median characterisation factors for the marine ecotoxicity are extremely low for all emission compartments due to high dilution in the seawater compartment. Emissions to air (urban and rural) and soil (agricultural and industrial) lead to similar median characterisation factors for the terrestrial environment, underlying the potential importance of air emissions for this toxicity impact category.

There is a large variation in environmental conditions, such as rainfall, across Australia. For instance, rainfall varies from over 2000 mm yr^{-1} in the equatorial regions to less than 200 mm yr^{-1} in the deserts. The variability reflects the different climatic zones characteristic of Australia: equatorial, tropical, subtropical, desert, grassland and temperate. As USES-LCA 2.0 is a generic multimedia fate and exposure model, it is not capable of including spatial variability within Australia in the calculation of the characterisation factors. Therefore, average Australian-wide figures have been used. Spatial explicit models, such as the ones developed for (parts of) North America and Europe [27,34,36,43], may be modified for this purpose.

The 95th percentile characterisation factors for each of the emission compartments for carcinogenics and non-carcinogenics are high and range from 10^{-4} to 10^{-2} yr kg^{-1}. These high values are associated with metals such as cadmium, arsenic and mercury but also TCDD as a surrogate for dioxins and furans. The application of USES-LCA 2.0 to metals needs to be considered with care as no attempt has been made to

CFhum-carc yr/kg freshwate	CFhum-noncarc yr/kg freshwater	CFfw day/kg seawater	CFsw day/kg seawater	CFter day/kg seawater	CFhum-carc yr/kg seawater	CFhum-noncarc yr/kg seawater	CFfw day/kg agrisoil	CFsw day/kg agrisoil	CFter day/kg agrisoil	CFhum-carc yr/kg agrisoil	CFhum-noncarc yr/kg agrisoil	CFfw day/kg industsoil	CFsw day/kg industsoil	CFter day/kg industsoil	CFhum-carc yr/kg industsoil	CFhum-noncarc yr/kg industsoil
	5,6E-06					6,9E-09					6,2E-08					9,0E-08
	8,3E-07	7,4E-29	1,8E-07	2,2E-27		3,4E-05	1,5E-09	3,9E-10	8,2E-10		2,1E-07	1,5E-08	3,9E-09	1,7E-08		8,0E-07
	3,2E-10	4,9E-17	7,3E-16	1,0E-17		3,5E-14	2,9E-12	1,7E-17	3,4E-12		1,3E-10	4,4E-11	1,8E-17	2,7E-12		1,7E-10
4,7E-03	5,1E-02	3,2E-27	8,6E-07	1,4E-26	2,2E-02	2,4E-01	1,7E-08	5,4E-08	1,0E-08	1,4E-03	1,5E-02	5,1E-08	1,7E-07	8,4E-09	4,2E-03	4,6E-02
5,2E-09	1,2E-10	2,7E-15	6,4E-14	9,7E-17	5,8E-11	1,4E-11	2,0E-13	1,9E-17	1,8E-12	2,2E-10	3,4E-11	3,4E-12	2,5E-17	1,8E-12	1,5E-10	3,3E-11
1,5E-02		8,5E-10	6,8E-09	9,3E-11	1,7E-03		2,6E-07	4,4E-11	1,5E-07	3,0E-02		1,2E-06	4,4E-11	1,5E-07	2,9E-02	
5,3E-08	9,8E-07	8,4E-14	4,0E-13	4,6E-14	2,2E-08	4,3E-07	7,2E-12	2,7E-14	4,0E-11	3,6E-08	6,9E-07	4,2E-11	2,8E-14	4,0E-11	3,6E-08	6,9E-07
5,0E-11	6,2E-10	5,4E-16	6,7E-15	4,0E-17	1,6E-12	3,5E-11	8,0E-14	5,2E-18	1,2E-12	1,5E-11	3,1E-10	1,1E-12	5,8E-18	1,2E-12	1,4E-11	3,0E-10
		1,2E-14	4,1E-15	9,7E-17			1,9E-13	1,0E-16	1,5E-13			1,9E-12	1,1E-16	1,5E-13		
6,9E-10		5,5E-15	4,0E-14	6,7E-16	1,4E-10		1,4E-12	1,2E-16	8,4E-12	3,7E-10		8,2E-12	1,5E-16	8,4E-12	3,4E-10	
8,8E-09	9,0E-08				2,2E-09	3,3E-09				4,8E-09	3,0E-08				4,4E-09	2,3E-08
6,6E-11	4,6E-10	1,1E-15	1,9E-14	6,5E-17	1,6E-12	5,2E-11	7,8E-14	8,5E-18	1,1E-12	6,4E-12	1,7E-10	1,3E-12	1,0E-17	1,1E-12	5,2E-12	1,7E-10
	8,6E-07	3,3E-31	9,1E-09	1,0E-28		1,4E-04	7,7E-11	5,1E-12	5,0E-10		1,5E-05	7,9E-10	5,2E-11	1,0E-08		1,0E-06
	1,3E-08	5,3E-15	2,7E-15	5,8E-16		2,6E-11	1,4E-11	3,7E-16	4,4E-12		1,2E-08	1,7E-10	4,6E-16	2,7E-12		1,4E-08
	5,2E-08	8,5E-20	3,0E-14	6,0E-21		6,7E-13	2,2E-10	1,5E-16	3,2E-11		2,6E-09	3,1E-09	2,1E-15	2,2E-11		1,8E-08
	1,2E-08	1,4E-23	1,6E-15	7,1E-24		2,0E-16	3,7E-11	4,3E-18	3,1E-11		8,0E-10	4,5E-10	5,2E-17	1,6E-11		5,8E-09
	3,8E-06	4,1E-11	8,0E-12	2,4E-12		1,1E-07	3,4E-09	3,5E-13	2,0E-08		7,7E-07	5,1E-08	4,8E-13	1,6E-08		1,3E-06
	4,9E-06	1,8E-13	5,9E-12	4,2E-14		7,1E-10	5,0E-08	2,7E-13	1,7E-08		4,4E-07	5,2E-07	2,8E-12	5,5E-09		3,5E-06
	1,2E-06	1,3E-12	1,1E-11	7,7E-15		2,8E-09	1,4E-10	1,7E-14	2,5E-11		9,8E-09	1,0E-09	1,9E-14	2,5E-11		1,4E-08
7,2E-08	1,2E-07	2,9E-20	8,7E-15	1,8E-20	1,0E-13	1,7E-13	9,8E-11	1,1E-16	1,0E-10	8,5E-09	1,4E-08	1,1E-09	1,1E-15	3,8E-11	4,7E-08	8,0E-08
1,3E-07	1,3E-07	3,6E-19	1,5E-11	1,6E-20	4,7E-11	4,5E-11	2,5E-08	4,3E-13	1,9E-09	5,1E-09	4,9E-09	3,2E-07	5,4E-12	1,0E-09	5,8E-08	5,6E-08
	1,0E-07	3,8E-15	5,7E-12	3,3E-16		1,2E-12	7,6E-09	2,4E-15	2,1E-09		1,1E-09	1,2E-07	3,5E-14	2,1E-09		9,4E-09
	1,4E-09	1,0E-18	6,4E-14	2,0E-20		6,1E-15	4,4E-11	1,1E-17	4,7E-12		3,5E-12	7,0E-10	1,8E-16	4,6E-12		4,6E-11
	2,2E-08					3,5E-13					7,7E-10					8,0E-09
	2,3E-07	1,9E-12	1,1E-10	8,7E-14		3,0E-10	4,7E-09	5,0E-14	1,9E-09		7,1E-09	2,5E-08	6,1E-14	1,8E-09		5,8E-09
	2,2E-07	2,4E-19	5,9E-13	6,0E-21		2,4E-11	1,7E-10	1,8E-16	1,8E-11		1,1E-09	2,5E-09	2,7E-15	1,7E-11		8,1E-09
		1,4E-17	2,4E-14	1,6E-18			1,4E-10	1,6E-16	2,9E-11			1,9E-09	2,1E-15	1,7E-11		
	2,3E-07	1,9E-12	1,1E-10	8,7E-14		3,0E-10	4,7E-09	5,0E-14	1,9E-09		7,1E-09	2,5E-08	6,1E-14	1,8E-09		5,8E-09
	7,5E-08	6,4E-15	9,9E-13	9,6E-17		1,6E-11	1,0E-09	4,6E-15	4,5E-11		1,0E-09	1,6E-08	7,0E-14	3,8E-11		1,3E-08
		3,6E-15	3,5E-13	2,2E-16			1,1E-09	1,4E-15	1,5E-10			1,7E-08	1,8E-14	1,1E-10		
1,1E-11	2,5E-10	1,1E-18	1,3E-14	1,2E-19	1,1E-17	2,7E-16	1,9E-11	6,9E-19	8,4E-12	4,8E-14	1,1E-12	5,8E-10	5,8E-18	2,3E-11	7,1E-13	1,6E-11
1,8E-08	1,7E-08	9,4E-18	3,1E-14	9,5E-19	1,7E-14	1,5E-14	4,3E-10	2,1E-17	9,9E-11	3,0E-10	2,8E-10	8,1E-09	3,7E-16	1,1E-10	3,5E-09	3,3E-09
	1,1E-06	6,1E-15	2,0E-12	5,2E-16		4,0E-11	1,6E-08	1,9E-14	2,3E-09		3,9E-08	2,1E-07	2,4E-13	1,4E-09		4,8E-07
1,0E-06	2,4E-06	3,0E-12	3,0E-11	7,4E-13	2,5E-06	5,9E-06	6,1E-11	5,6E-13	8,9E-11	5,4E-06	1,3E-05	3,0E-10	5,6E-13	8,9E-11	5,2E-06	1,2E-05
	1,8E-05	6,8E-14	7,1E-12	2,7E-15		2,8E-09	1,3E-08	3,5E-14	1,2E-09		4,5E-07	2,0E-07	5,0E-13	9,4E-10		3,8E-06
9,1E-10	1,5E-07	2,0E-11	5,1E-12	6,8E-13	1,1E-10	1,9E-08	1,5E-10	1,4E-12	1,4E-10	5,0E-10	8,7E-08	1,0E-09	1,4E-12	1,3E-10	5,1E-10	8,7E-08
	7,6E-07	2,8E-12	5,6E-12	1,3E-14		1,4E-10	5,3E-09	3,4E-14	8,0E-10		4,3E-08	6,1E-08	4,0E-14	9,3E-10		4,8E-08
		1,2E-15	2,0E-14	4,0E-16			2,0E-10	4,6E-16	1,0E-10			2,1E-09	4,0E-15	3,7E-11		
	2,7E-07	1,8E-25	3,0E-13	7,7E-27		5,3E-12	8,3E-10	1,4E-15	7,2E-11		5,4E-09	1,2E-08	2,2E-14	5,4E-11		7,0E-08
	1,7E-07	2,9E-10	5,1E-10	4,6E-11		2,2E-10	1,7E-06	2,2E-11	4,9E-07		1,3E-06	2,2E-05	3,2E-11	3,8E-07		1,9E-07
	4,5E-09	3,4E-12	4,7E-11	2,4E-14		2,5E-10	3,0E-10	5,1E-14	3,7E-11		8,4E-10	1,6E-09	5,2E-14	3,7E-11		8,4E-10
	3,2E-06	1,2E-12	6,4E-12	2,0E-14		1,2E-09	8,6E-09	5,1E-14	7,1E-10		1,7E-07	1,3E-07	3,3E-13	5,7E-10		5,8E-07
1,2E-08	3,3E-08	7,7E-15	5,5E-14	1,7E-16	2,7E-12	2,2E-11	5,2E-11	1,9E-15	1,7E-11	4,7E-09	3,8E-08	7,1E-10	1,9E-15	1,7E-11	5,0E-09	3,9E-08
1,6E-07	2,1E-06	3,8E-16	3,9E-12	8,7E-18	1,3E-09	1,7E-08	2,7E-11	1,3E-16	7,5E-12	1,1E-09	1,3E-08	2,0E-10	8,6E-16	7,4E-12	1,7E-09	2,1E-08
		2,2E-17	1,4E-12	5,9E-19			3,1E-10	5,8E-16	3,4E-11			4,4E-09	8,3E-15	3,3E-11		
	8,0E-08	1,2E-13	1,8E-11	2,6E-15		7,1E-12	9,1E-09	1,3E-14	9,4E-10		5,8E-10	1,4E-07	1,6E-13	8,9E-10		4,6E-09
		1,2E-15	8,7E-15	8,7E-18			5,3E-13	2,2E-17	6,6E-14			5,5E-12	2,7E-17	6,5E-14		
	4,9E-08					6,9E-14					5,7E-09					3,4E-08
	1,6E-07	5,3E-15	6,4E-13	3,8E-16		4,8E-13	6,2E-09	8,5E-15	7,4E-10		6,3E-09	8,1E-08	1,1E-13	4,3E-10		7,0E-08
	6,3E-07	1,3E-16	4,1E-13	1,2E-17		1,0E-11	1,9E-09	2,0E-15	3,3E-10		2,2E-08	2,6E-08	2,8E-14	2,2E-10		2,2E-07

(continued on next page)

account for metal speciation and metal bioavailability. The ecotoxicity of metals, such as copper and zinc, is strongly influenced by its speciation [8,26,38] but to date only copper speciation has been incorporated into an LCIA ecotoxicity model [39].

The ecotoxicological effect factors were calculated using the mean of log-transformed L(E)C50 values for various taxa from international ecotoxicity datasets [37]. The HC50 values do not specifically consider the ecotoxicity for Australian species unless already included. It would be preferable to use local data under local conditions but there is insufficient local data for all but a handful of chemicals. In general, Australian species are within the range of sensitivities of the overseas species for various toxicants [2,3].

3.2. Normalisation figures

The total contributions to each impact category are presented in Tables 6a and 6b differentiating between NPI industry emissions, NPI diffuse emissions and pesticide usage. NPI emissions determine carcinogenic and non-carcinogenic human toxicity and marine ecotoxicity normalisation scores, while pesticide usage causes more than 85% of freshwater

Table 5 (*continued*)

		characteri-sation factor	CFfw	CFsw	CFter	CFhum-carc	CFhum-noncarc	CFfw	CFsw	CFter	CFhum-carc	CFhum-noncarc	CFfw	CFsw	CFter
		unit	day/kg	day/kg	day/kg	yr/kg	yr/kg	day/kg	day/kg	day/kg	yr/kg	yr/kg	day/kg	day/kg	day/kg
		group	uair	uair	uair	uair	uair	rair	rair	rair	rair	rair	freshwater	freshwater	freshwater
dithianon	3347-22-6	pesticide	3,8E-08	4,5E-13	4,4E-10		1,9E-07	5,7E-09	5,0E-13	3,7E-10		3,6E-08	3,5E-07	6,5E-13	4,1E-15
diuron	330-54-1	pesticide	5,6E-08	2,3E-13	3,6E-10		2,3E-07	4,0E-09	3,4E-13	2,6E-10		1,6E-07	4,9E-07	1,4E-12	3,8E-21
dodine	2439-10-3	pesticide	1,0E-08	8,0E-16	2,2E-10		5,0E-09	7,3E-10	1,9E-15	2,1E-10		5,1E-10	6,5E-08	4,3E-15	1,8E-15
endosulfan	115-29-7	pesticide	8,5E-10	7,3E-14	5,8E-12		1,5E-06	1,0E-09	1,2E-13	2,7E-12		6,8E-08	9,9E-07	9,5E-14	3,4E-13
endothal	129-67-9	pesticide	3,9E-10	1,3E-15	2,3E-11			5,0E-11	1,5E-15	2,8E-11			1,9E-09	2,1E-15	6,9E-20
esfenvalerate	66230-04-4	pesticide	7,6E-07	5,1E-10	1,4E-08			3,6E-07	5,6E-10	1,1E-08			6,7E-05	4,8E-10	4,6E-10
ethephon	16672-87-0	pesticide	2,0E-10	1,1E-15	1,3E-11		2,6E-07	2,7E-11	1,2E-15	1,6E-11		1,2E-07	9,5E-10	1,0E-15	5,2E-20
fenitrothion	122-14-5	pesticide	1,4E-08	7,3E-14	8,4E-11		1,4E-06	1,2E-09	1,9E-13	3,0E-11		3,2E-07	6,1E-07	6,7E-13	4,4E-14
fenoxycarb	72490-01-8	pesticide	1,2E-10	8,0E-15	1,3E-12			5,0E-11	1,2E-14	7,2E-13			1,6E-08	4,7E-15	9,9E-18
fenthion	55-38-9	pesticide	7,5E-09	8,7E-14	5,2E-11		5,2E-07	1,0E-09	2,4E-13	1,8E-11		2,6E-07	1,4E-06	1,8E-12	4,9E-13
fipronil	120068-37-3	pesticide					4,7E-06					1,0E-06			
fluazifop-p-butyl	79241-46-6	pesticide	2,3E-10	2,3E-14	2,2E-12			9,3E-11	3,2E-14	9,5E-13			5,9E-08	5,1E-14	3,2E-14
fluometuron	2164-17-2	pesticide													
flupropanate	756-09-2	pesticide													
glyphosate	1071-83-6	pesticide	3,3E-11	1,4E-16	2,2E-13		4,2E-08	6,8E-12	1,1E-15	8,6E-14		7,2E-09	3,1E-09	1,8E-15	1,9E-22
haxainone	51235-04-2	pesticide	1,3E-08	1,7E-14	1,4E-10		4,3E-08	9,2E-10	3,3E-14	1,5E-10		3,4E-09	8,9E-08	9,7E-14	4,8E-17
hetpachlor	76-44-8	pesticide	6,1E-13	1,2E-16	1,5E-14	1,3E-06	4,2E-07	1,0E-12	3,2E-16	7,0E-15	2,7E-08	3,6E-09	1,5E-07	1,6E-14	2,0E-15
hexachlorobenzene	118-74-1	pesticide	8,1E-11	6,5E-11	3,7E-11	1,3E-05	9,5E-06	8,0E-11	6,5E-11	3,7E-11	1,2E-05	8,3E-06	4,6E-08	5,1E-11	2,8E-11
imazethapyr	81335-77-5	pesticide					6,9E-09					1,1E-09			
ioxynil	2961-62-8	pesticide	3,1E-09	2,1E-14	2,3E-10			5,6E-10	2,1E-14	2,7E-10			1,4E-08	2,5E-14	5,2E-24
lindane	58-89-9	pesticide	1,2E-08	1,8E-12	1,2E-10	2,7E-07	9,9E-06	5,2E-09	2,2E-12	7,9E-11	1,8E-07	3,0E-06	1,2E-06	3,9E-12	2,0E-11
malathion	121-75-5	pesticide	3,9E-09	3,4E-14	8,9E-12		1,8E-08	4,4E-10	1,0E-13	2,6E-12		6,6E-10	3,6E-07	5,3E-13	8,1E-15
mancozeb	8018-01-7	pesticide	4,4E-11	2,2E-15	5,4E-13		2,2E-07	2,0E-11	5,0E-15	2,5E-13		7,3E-09	7,4E-09	1,9E-15	5,0E-20
MCPA	94-74-6	pesticide	2,4E-10	7,4E-16	2,1E-12		8,3E-07	1,9E-11	1,3E-15	1,5E-12		1,2E-07	2,0E-09	1,4E-15	4,9E-21
mepiquat	15302-91-7	pesticide													
metalaxyl	57837-19-1	pesticide	3,4E-10	1,5E-15	3,9E-12		2,7E-08	3,0E-11	1,4E-15	5,3E-12		1,9E-08	2,0E-09	6,6E-15	4,0E-16
metham sodium (dithiocarb	137-42-8	pesticide	7,0E-08	1,2E-13	2,9E-09			6,2E-09	1,7E-13	4,3E-09			3,8E-07	4,1E-13	8,3E-19
methamidophos	10265-92-6	pesticide	5,2E-08	1,5E-13	4,1E-10		1,1E-06	4,0E-09	2,1E-13	4,1E-10		8,4E-08	3,5E-07	6,9E-13	7,3E-16
methidathion	950-37-8	pesticide	1,9E-09	1,1E-15	2,5E-11	1,4E-07	2,6E-07	8,4E-11	4,7E-15	1,1E-11	1,2E-08	1,7E-08	3,1E-08	9,4E-15	3,4E-15
methomyl	16752-77-5	pesticide	1,2E-07	1,2E-12	6,0E-10		1,3E-06	1,1E-08	8,7E-13	6,7E-10		9,8E-07	7,2E-07	5,0E-12	8,0E-14
methoxychlor	72-43-5	pesticide	3,5E-11	1,3E-15	1,2E-11		6,7E-08	4,5E-11	3,1E-15	5,0E-12		9,8E-09	6,1E-08	5,0E-16	4,6E-14
metiram	9006-42-2	pesticide	1,2E-08	7,8E-14	1,2E-09		7,4E-08	2,2E-09	7,9E-14	1,4E-09		1,5E-08	5,1E-08	9,5E-14	3,1E-20
metolachlor	51218-45-2	pesticide	2,4E-08	2,1E-13	1,1E-10		3,6E-08	1,3E-09	1,8E-13	5,8E-11		9,8E-09	4,0E-07	2,6E-12	6,5E-13
metribuzin	21087-64-9	pesticide	3,4E-14	1,5E-16	8,0E-15		5,1E-08	3,9E-14	2,2E-16	5,1E-15		7,0E-10	4,0E-08	1,7E-13	4,9E-15
metsulfuron-Me	74223-64-6	pesticide	3,6E-07	2,3E-12	6,7E-09		5,2E-08	5,2E-08	2,6E-12	6,2E-09		7,3E-09	2,2E-06	2,2E-12	1,3E-18
mirex	2385-85-5	pesticide	1,3E-12	8,0E-13	4,5E-13	1,8E-04	5,1E-04	1,3E-12	8,1E-13	4,2E-13	1,8E-04	5,0E-04	1,1E-09	4,6E-14	1,6E-14
molinate	2212-67-1	pesticide	1,8E-11	1,3E-15	1,8E-13		4,1E-06	1,0E-11	2,4E-15	8,3E-14		1,2E-07	8,0E-09	2,8E-15	1,2E-14
monocrotophos	2157-98-4	pesticide													
NAA	86-87-3	pesticide	2,7E-11	4,2E-17	4,0E-13			1,8E-12	1,2E-16	2,2E-13			3,4E-10	1,0E-16	6,1E-17
oleyl alcohol	143-28-2	pesticide													
paraquat	4685-14-7	pesticide	1,2E-09	2,5E-15	4,9E-11		5,1E-07	1,2E-10	3,6E-15	7,8E-11		6,8E-08	6,5E-09	7,1E-15	6,1E-19
parathion, methyl	56-38-2	pesticide	8,0E-10	1,0E-13	9,6E-12		2,9E-07	3,9E-10	3,3E-13	3,1E-12		4,9E-08	6,8E-07	1,1E-12	2,1E-14
pendimethalin	40487-42-1	pesticide	7,9E-10	1,0E-13	8,6E-12		9,9E-09	1,6E-10	1,8E-13	2,5E-12		1,7E-09	1,1E-07	5,2E-13	2,0E-13
pentachlorophenol	87-86-5	pesticide	6,4E-11	3,2E-15	5,8E-12	3,2E-07	5,3E-07	5,0E-11	3,9E-15	2,7E-12	1,8E-07	1,3E-07	1,1E-08	2,2E-16	1,1E-16
permethrin	52645-53-1	pesticide	5,4E-09	1,1E-11	8,2E-11		4,1E-08	4,5E-09	1,3E-11	5,5E-11		8,9E-09	1,6E-06	4,3E-12	1,3E-12
picloram	1918-02-1	pesticide	1,5E-09	1,0E-14	6,6E-11		2,8E-08	2,5E-10	1,0E-14	7,3E-11		6,8E-09	7,0E-09	1,3E-14	8,6E-19
primicarb	23103-98-2	pesticide	1,1E-09	1,8E-15	1,3E-11		1,4E-08	6,6E-11	3,5E-15	8,5E-12		3,5E-09	1,1E-08	1,7E-14	1,1E-15
profenofos	41198-08-7	pesticide	1,5E-08	8,2E-13	1,5E-10		6,6E-07	4,7E-09	2,3E-12	4,8E-11		7,2E-08	3,3E-06	3,6E-12	5,2E-14
propaquizafop	111479-05-1	pesticide	1,1E-09	1,9E-13	1,6E-11			6,3E-10	2,2E-13	1,2E-11			1,4E-07	8,3E-14	1,8E-18
protmetryn	7287-19-6	pesticide	1,0E-08	6,1E-14	5,6E-11		2,8E-08	8,0E-10	1,3E-13	2,3E-11		1,2E-08	2,6E-07	4,9E-13	5,5E-14
sethoxydim	74051-80-2	pesticide	6,9E-11	4,3E-16	5,6E-13		7,9E-09	1,3E-11	3,9E-15	2,1E-13		9,2E-10	6,4E-09	7,0E-15	2,9E-18
simazine	122-34-9	pesticide	1,5E-08	4,0E-14	1,2E-10		6,1E-07	1,1E-09	4,8E-14	1,3E-10		1,4E-07	1,1E-07	2,7E-13	5,2E-19
s-methoprene	40596-69-8	pesticide	3,9E-12	3,9E-15	7,4E-14		7,4E-09	6,7E-12	1,2E-14	2,9E-14		2,0E-09	1,6E-08	1,9E-14	2,5E-15
spinosad	168316-95-8	pesticide													
sulfometuron-Me	74222-97-2	pesticide	1,4E-11	6,6E-17	6,9E-13			2,3E-12	7,4E-17	7,6E-13			6,8E-11	6,6E-17	5,0E-21
tebufenozide	112410-23-8	pesticide	8,4E-10	2,1E-14	6,4E-12		7,4E-08	1,4E-10	4,8E-14	2,4E-12		2,8E-08	5,9E-08	1,1E-13	3,1E-15
tebuthiuron	34014-18-1	pesticide	7,8E-08	3,7E-13	1,3E-09		1,8E-07	8,0E-09	4,6E-13	1,3E-09		3,8E-08	4,6E-07	5,0E-13	2,2E-14
temephos	3383-96-8	pesticide	3,9E-11	4,6E-14	5,4E-13			5,0E-11	7,8E-14	1,7E-13			8,0E-08	3,0E-14	1,4E-16
thiabendazole	148-79-8	pesticide	2,7E-09	4,2E-15	2,0E-11		3,7E-08	1,7E-10	9,8E-15	1,5E-11		1,1E-08	2,4E-08	2,6E-14	4,8E-17
thidiazuron	51707-55-2	pesticide	2,6E-09	1,4E-14	7,3E-11			3,8E-10	1,7E-14	7,3E-11			1,4E-08	1,6E-14	3,7E-18
thiobencarb	28249-77-6	pesticide	1,1E-09	2,1E-14	7,2E-12		9,2E-07	1,7E-10	3,4E-14	3,2E-12		1,1E-07	8,7E-08	9,6E-14	1,0E-13
thiram	137-26-8	pesticide	3,8E-08	1,0E-13	3,0E-10		3,1E-07	8,2E-09	1,1E-13	1,7E-10		1,3E-07	8,2E-07	1,1E-13	3,6E-12
tralkoxydim	87820-88-0	pesticide													
triallate	2303-17-5	pesticide	1,6E-10	1,6E-13	6,6E-13		1,7E-07	1,3E-10	3,0E-13	2,9E-13		2,0E-08	1,5E-07	1,1E-12	1,9E-13
trichlopyr	55335-06-3	pesticide	3,1E-09	1,7E-14	2,7E-11			2,9E-10	2,3E-14	2,0E-11			2,6E-08	2,8E-14	2,7E-15
trifluralin	1582-09-8	pesticide	2,3E-12	6,9E-15	8,3E-14	4,3E-09	8,0E-08	3,8E-12	2,2E-14	3,6E-14	6,0E-10	8,2E-09	4,3E-08	2,1E-13	2,2E-14
trisulfuron	82097-50-5	pesticide	2,4E-07	2,1E-12	3,5E-09		3,4E-06	3,5E-08	2,3E-12	3,2E-09		4,7E-07	1,5E-06	2,8E-12	5,4E-17
zineb	12122-67-7	pesticide	4,1E-09	9,0E-14	1,7E-11	2,2E-08	2,7E-07	4,8E-10	9,8E-14	1,1E-11	1,5E-08	8,8E-08	4,4E-08	1,9E-13	1,2E-14
ziram	137-30-4	pesticide	8,0E-08	9,7E-14	1,4E-09	1,8E-08	3,5E-08	5,9E-09	1,6E-13	1,8E-09	4,1E-09	2,4E-09	5,2E-07	5,6E-13	1,5E-13

and 49% of terrestrial ecotoxicity normalisation scores despite the underestimate in total use. The pesticides that dominate the freshwater ecotoxicity normalisation are atrazine (52%), metham sodium (34%) and simazine (9%). For terrestrial ecotoxicity, metham sodium (84%) is the dominant pesticide with copper compounds (from industrial emissions) contributing 40% towards the total. The normalisation includes 13 of the 250 pesticides imported or manufactured in Australia and therefore will underestimate the total toxicity [4].

Two total figures are supplied for marine ecotoxicity: (1) pesticides and all NPI substances; and (2) pesticides and NPI substances excluding essential metals (Cr, Cu, Co, Mo, Mn, Ni, Se, Zn). There is negligible difference between the two totals. Exclusion of essential metals from marine ecotoxicity is consistent with the Declaration of Apeldoorn on LCIA of non-ferro metals in which it is stated that characterisation factors for toxicity in oceans of essential metals should be set at zero. The Declaration claims that the ocean is deficient in many essential metals and accumulation of trace amounts of metals from industrial sources is unlikely to have a detrimental effect [13].

Marine ecotoxicity is dominated by fluoride emissions (99%), mostly originating from air emissions from aluminium smelters and coal-burning electricity plants and water emissions from sewerage treatment plants. Fluoride is not

CFhum-carc	CFhum-noncarc	CFfw	CFsw	CFter	CFhum-carc	CFhum-noncarc	CFfw	CFsw	CFter	CFhum-carc	CFhum-noncarc	CFfw	CFsw	CFter	CFhum-carc	CFhum-noncarc
yr/kg	yr/kg	day/kg	day/kg	day/kg	yr/kg	yr/kg	day/kg	day/kg	day/kg	yr/kg	yr/kg	day/kg	day/kg	day/kg	yr/kg	yr/kg
r	freshwater	seawater	seawater	seawater	seawater	seawater	agrisoil	agrisoil	agrisoil	agrisoil	agrisoil	indussoil	indussoil	indussoil	indussoil	indussoil
	8,3E-08	1,4E-15	2,3E-12	8,8E-17		4,4E-12	7,0E-09	1,3E-14	7,9E-10		2,4E-09	1,0E-07	1,9E-13	5,7E-10		2,4E-08
	1,8E-07	1,5E-22	3,8E-12	9,6E-24		1,7E-11	1,1E-08	3,1E-14	1,5E-09		4,9E-09	1,6E-07	4,4E-13	1,0E-09		5,8E-08
	2,5E-09	1,0E-17	3,1E-14	2,9E-18		2,6E-16	2,8E-09	1,8E-16	9,9E-10		1,4E-10	3,8E-08	2,5E-15	7,9E-10		1,5E-09
	1,9E-07	1,3E-12	2,9E-12	3,4E-15		9,0E-11	5,9E-10	1,9E-14	5,9E-11		1,1E-08	5,0E-09	2,1E-14	6,8E-11		1,2E-08
		2,2E-21	1,0E-14	1,3E-21			1,2E-10	1,3E-16	9,8E-11			1,3E-09	1,4E-15	3,4E-11		
		1,9E-09	2,6E-09	5,8E-11			2,2E-07	4,3E-11	2,5E-08			2,6E-06	5,8E-11	2,4E-08		
	4,8E-08	1,6E-21	5,2E-15	9,6E-22		6,7E-14	6,1E-11	6,7E-17	5,6E-11		5,6E-09	6,4E-10	7,0E-16	2,0E-11		3,3E-08
	5,2E-07	3,7E-14	3,8E-12	9,0E-16		3,9E-11	3,0E-09	4,2E-15	3,0E-10		5,8E-09	4,7E-08	5,3E-14	2,8E-10		4,2E-08
		1,5E-17	9,9E-14	2,1E-19			1,7E-11	5,5E-18	2,3E-12			2,4E-10	7,4E-17	2,2E-12		
	3,3E-06	6,9E-13	9,8E-12	1,2E-14		5,0E-10	6,5E-09	2,9E-14	7,5E-10		5,2E-08	1,0E-07	1,5E-13	7,0E-10		2,7E-07
	6,3E-06					6,8E-09					1,0E-07					7,3E-07
		9,9E-14	5,5E-13	1,0E-15			9,5E-11	1,9E-15	1,1E-11			1,2E-09	2,9E-15	1,1E-11		
	1,7E-09	2,9E-23	1,6E-14	3,6E-25		1,7E-15	5,4E-12	3,2E-18	5,2E-13		3,3E-12	7,8E-11	4,6E-17	5,0E-13		4,4E-11
	1,1E-08	5,5E-18	4,9E-13	8,8E-19		7,2E-14	3,5E-09	3,8E-15	9,1E-10		5,5E-10	4,4E-08	4,8E-14	4,8E-10		5,2E-09
5,7E-06	4,5E-07	7,5E-15	1,2E-12	5,2E-17	4,9E-10	5,0E-11	8,7E-12	1,5E-16	3,4E-12	1,5E-08	1,9E-09	7,3E-11	1,6E-16	3,4E-12	1,6E-08	1,9E-09
1,4E-05	8,7E-06	6,3E-11	7,4E-11	3,2E-11	1,1E-05	7,6E-06	1,4E-10	3,2E-11	4,6E-10	6,7E-06	4,4E-06	1,1E-09	3,3E-11	4,5E-10	6,4E-06	4,3E-06
	1,9E-09					4,5E-14					5,6E-11					5,8E-10
		2,2E-25	8,5E-14	1,1E-25			9,8E-10	1,8E-15	6,1E-10			1,0E-08	1,9E-14	1,8E-10		
3,4E-07	5,4E-06	4,7E-11	1,3E-11	7,2E-13	1,7E-09	2,9E-08	9,9E-09	8,5E-13	1,2E-09	7,2E-08	1,2E-06	1,3E-07	1,2E-12	1,1E-09	1,0E-07	1,7E-06
	6,4E-09	3,2E-14	2,6E-12	1,9E-16		4,0E-13	9,3E-10	1,9E-15	3,8E-11		2,2E-11	1,5E-08	2,3E-14	3,6E-11		2,8E-10
	3,9E-09	8,9E-20	5,1E-14	1,1E-21		7,1E-15	6,2E-12	1,6E-18	9,3E-13		3,7E-12	8,1E-11	2,1E-17	9,2E-13		4,3E-11
	2,3E-07	1,0E-22	1,0E-14	8,4E-24		4,3E-12	4,3E-11	2,9E-17	7,4E-12		7,5E-09	6,2E-10	4,2E-16	5,3E-12		7,1E-08
	1,3E-08	5,7E-17	1,5E-14	1,0E-17		2,7E-13	1,1E-10	3,7E-16	2,9E-11		1,0E-09	1,2E-09	4,1E-15	1,2E-11		8,3E-09
		2,2E-20	2,1E-12	1,5E-20			2,5E-08	2,7E-14	2,5E-08			2,6E-07	2,8E-13	8,7E-09		
	9,3E-07	1,5E-16	2,2E-12	1,5E-17		2,2E-12	1,3E-08	2,6E-14	2,3E-09		4,0E-08	1,7E-07	3,3E-13	1,2E-09		4,5E-07
7,0E-08	9,3E-08	4,1E-16	1,5E-13	5,4E-17	5,0E-13	6,6E-13	5,6E-10	2,3E-16	1,5E-10	2,0E-09	2,7E-09	8,4E-09	2,6E-15	1,1E-10	1,9E-08	2,5E-08
	9,1E-07	3,7E-14	6,6E-12	2,3E-15		1,3E-11	3,3E-08	2,3E-13	3,4E-09		4,6E-08	3,9E-07	2,7E-12	1,6E-09		4,9E-07
	3,9E-09	2,7E-15	1,2E-13	3,0E-16		6,3E-13	1,2E-10	2,9E-16	2,0E-10		1,1E-09	7,4E-10	3,0E-16	1,9E-10		9,6E-10
	2,1E-08	9,8E-22	3,2E-13	6,3E-22		4,7E-14	3,9E-09	7,3E-15	3,3E-09		3,7E-09	4,0E-08	7,4E-14	8,9E-10		1,7E-08
	2,0E-08	5,3E-13	4,6E-12	2,4E-14		5,3E-12	1,1E-08	8,4E-14	9,6E-10		1,8E-09	1,5E-07	9,9E-13	6,2E-10		8,1E-09
	3,3E-09	1,5E-14	4,9E-12	2,0E-15		2,9E-10	1,3E-10	7,8E-16	5,5E-10		1,1E-09	5,8E-10	2,7E-15	5,6E-10		9,7E-10
	4,5E-09	1,8E-19	1,1E-11	2,1E-20		4,7E-14	7,2E-08	6,9E-14	1,3E-08		1,9E-10	9,4E-07	9,2E-13	7,8E-09		1,9E-09
9,4E-06	2,6E-05	3,5E-13	2,8E-12	1,3E-13	5,4E-05	1,5E-04	2,3E-12	3,4E-13	1,0E-12	7,7E-05	2,1E-04	9,3E-12	3,4E-13	1,0E-12	7,6E-05	2,1E-04
	3,2E-07	3,0E-14	4,7E-14	2,4E-16		3,5E-10	2,4E-11	9,6E-16	5,0E-12		4,7E-08	3,6E-10	1,0E-15	4,7E-12		5,8E-08
		7,9E-18	1,6E-15	9,9E-19			5,3E-12	2,7E-18	1,6E-12			8,2E-11	2,5E-17	1,2E-12		
	6,1E-08	1,7E-20	3,5E-14	1,1E-20		8,5E-14	4,5E-10	4,9E-16	4,3E-10		7,7E-09	4,6E-09	5,1E-15	1,4E-10		4,4E-08
	2,6E-07	2,0E-13	1,5E-11	1,6E-15		9,7E-11	9,5E-10	4,8E-15	1,3E-10		1,6E-09	9,5E-09	1,9E-14	1,0E-10		4,0E-09
	1,3E-07	1,4E-12	3,6E-12	2,1E-14		1,9E-10	4,6E-10	3,4E-14	4,0E-11		1,4E-09	1,3E-08	1,1E-13	1,4E-10		1,5E-08
1,1E-08	7,0E-09	1,4E-18	2,1E-14	7,5E-20	9,9E-14	6,6E-14	1,7E-11	1,2E-18	1,3E-11	1,0E-10	7,1E-11	1,3E-10	1,1E-17	1,3E-11	5,2E-10	3,6E-10
	4,3E-08	2,3E-11	1,0E-10	2,8E-13		1,1E-10	1,5E-09	3,5E-13	2,0E-10		1,3E-09	1,2E-08	3,8E-13	2,0E-10		5,7E-10
	7,7E-09	5,9E-20	4,3E-14	1,8E-20		3,4E-14	4,1E-10	7,6E-16	1,6E-10		6,3E-10	4,5E-09	8,3E-15	6,2E-11		5,0E-09
	2,3E-08	1,8E-16	7,1E-14	2,2E-17		1,7E-13	2,8E-10	4,3E-16	6,6E-11		7,1E-10	3,8E-09	5,8E-15	4,5E-11		7,6E-09
	9,7E-07	2,4E-13	4,6E-11	2,5E-15		1,9E-10	4,4E-09	8,8E-15	5,3E-10		3,3E-09	5,4E-08	6,4E-14	5,3E-10		1,6E-08
		2,3E-18	1,0E-12	4,4E-20			1,9E-10	1,2E-16	2,3E-11			2,5E-09	1,5E-15	2,4E-11		
	4,0E-08	4,8E-14	2,0E-12	1,4E-15		5,0E-12	2,1E-09	5,2E-15	2,0E-10		6,5E-10	3,3E-08	6,3E-14	1,8E-10		5,2E-09
	3,1E-08	6,0E-18	6,6E-14	1,0E-19		4,1E-12	1,2E-11	1,3E-17	1,3E-12		1,3E-10	1,7E-10	1,8E-16	1,3E-12		8,0E-10
	4,1E-07	1,0E-20	7,5E-13	1,2E-21		1,1E-11	4,3E-09	1,1E-14	8,2E-10		2,6E-08	5,2E-08	1,3E-13	4,3E-10		2,0E-07
	5,6E-08	9,0E-14	7,4E-13	3,9E-16		6,4E-11	1,2E-11	1,2E-15	1,8E-12		3,2E-10	8,6E-11	1,3E-15	1,8E-12		5,0E-10
		2,5E-22	3,3E-16	8,1E-23			3,9E-12	3,8E-18	1,7E-12			4,3E-11	4,2E-17	6,8E-13		
	1,8E-07	6,9E-15	7,0E-13	1,2E-16		3,9E-11	1,7E-10	4,5E-16	1,8E-11		1,1E-09	2,4E-09	4,7E-15	1,8E-11		7,4E-09
	1,5E-08	2,6E-15	2,5E-12	4,1E-16		1,0E-13	1,9E-08	2,1E-14	5,2E-09		8,3E-10	2,3E-07	2,5E-13	2,7E-09		7,4E-09
		5,1E-15	3,2E-12	1,8E-17			2,9E-11	6,3E-17	3,4E-12			1,8E-10	1,2E-16	3,4E-12		
	3,1E-08	1,1E-17	1,3E-13	8,9E-19		5,9E-13	5,5E-10	6,0E-16	8,8E-11		9,8E-10	7,8E-09	8,5E-15	6,1E-11		1,0E-08
		3,5E-19	7,9E-14	6,7E-20			5,9E-10	6,4E-16	1,7E-10			7,2E-09	7,9E-15	8,7E-11		
	2,5E-07	1,2E-13	5,6E-13	2,2E-15		9,1E-11	5,6E-10	5,3E-15	6,0E-11		1,8E-08	8,9E-09	1,4E-14	5,4E-11		4,0E-08
	6,2E-08	2,7E-13	4,0E-13	5,8E-15		4,4E-12	7,9E-09	1,0E-14	5,7E-10		1,2E-08	1,4E-07	2,9E-14	7,9E-10		2,3E-08
	3,9E-07	1,5E-11	8,2E-12	3,3E-14		3,4E-09	2,6E-10	1,3E-13	2,3E-11		9,4E-09	3,5E-09	1,5E-13	2,3E-11		1,7E-08
		7,3E-16	1,4E-13	5,0E-17			5,7E-10	6,7E-16	8,5E-11			8,1E-09	8,9E-15	5,9E-11		
2,6E-08	3,5E-07	1,1E-12	6,1E-12	1,0E-14	3,8E-10	5,1E-09	3,8E-11	1,1E-14	2,8E-11	7,7E-10	1,0E-08	4,3E-10	1,3E-14	2,8E-11	5,5E-10	7,4E-09
	2,8E-07	1,2E-17	9,5E-12	1,1E-18		8,2E-12	4,8E-08	9,0E-14	6,7E-09		1,2E-08	6,3E-07	1,2E-12	4,0E-09		1,2E-07
6,2E-09	3,5E-08	1,7E-14	4,3E-13	4,0E-16	6,0E-13	3,6E-12	6,2E-10	3,1E-15	3,9E-11	1,7E-10	9,7E-10	9,5E-09	4,0E-14	3,1E-11	1,4E-09	7,9E-09
1,8E-08	9,9E-09	9,1E-15	2,8E-12	2,7E-15	4,4E-14	2,5E-14	2,9E-08	3,2E-14	1,2E-08	1,4E-09	7,7E-10	3,2E-07	3,5E-13	5,1E-09	1,1E-08	6,1E-09

CF = characterisation factor, fw = freshwater, sw = seawater, ter = terrestrial, hum-carc = human carcinogenic, hum-noncarc = human non-carcinogenic, uair = urban air, rair = rural air, agrisoil = agricultural soil, indussoil = industrial soil.

considered a toxicant for ecosystem protection in the Australian and New Zealand Water Quality Guidelines for Fresh and Marine Water Quality [3]. Despite its low toxicity ($HC50 = 125\ mg\ L^{-1}$), when coupled with its long term stability in the marine environment and large anthropogenic emissions ($8500\ t\ yr^{-1}$) there is a high marginal risk in terms of potentially affected fraction of species. Essential metals contribute approximately 1% to the total where included. After fluoride, the next largest contributors to marine ecotoxicity (excluding essential metals) are the metals beryllium and arsenic. The major source of beryllium in the marine environment is atmospheric fallout from the combustion of fossil fuels. Air emissions from gold and copper mining and lead and zinc smeltering are the primary sources of arsenic emissions.

Heavy metals and transition metals are the major contributors to the total human carcinogenic and non-carcinogenic impact categories on a national level. As (47%), Pb (9%), Mn (26%), Hg (6%) and Se (11%) are the main contributors to the total non-carcinogenic impact. The total carcinogenic

Table 6a
Australian total contribution to human and ecotoxicity impact categories on an absolute basis (divided by 20 million; units are in years)

Impact category	Contribution from			Total impact
	NPI (industry)	NPI (diffuse)	Pesticide usage	
Freshwater ecotoxicity	7.0 E−05	2.3 E−06	4.0 E−04	4.7 E−04
Marine ecotoxicity − all NPI	1.0 E−01	7.2 E−4	3.9 E−8	1.0 E−01
Marine ecotoxicity − excluding essential metals	1.0 E−01	6.6 E−04	3.9 E−08	1.0 E−01
Terrestrial ecotoxicity	1.6 E−04	1.4 E−05	1.6 E−04	7.6 E+03
Human toxicity (carcinogenic)	3.6 E+03	4.1 E+03	1.5 E−02	
Human toxicity (non-carcinogenic)	2.0 E+04	5.3 E+03	1.6 E−01	

impact category is dominated by Cd (84%) with smaller contributions from Co (12%). The diffuse contributions to both impact categories are large: 53% to the human carcinogen impact category and 33% to the human non-carcinogen impact category. The only organic compound to make a large contribution to diffuse total human carcinogenic impact category on a national level is formaldehyde (2%), which is a consequence of domestic solid fuel burning. Note that metal figures do not account for speciation.

Approximately 90% of the diffuse contribution to the human carcinogen impact category can be attributed to metals associated with dust emissions during truck transportation on unpaved roads in Western Australia (Pilbara and Bunbury airsheds). The metals are based on the weight fraction of different toxic metals commonly found in roadside dust and the amount of dust suspended through road transportation activities. The diffuse component for human non-carcinogens is also mostly due to metals in dust from unpaved roads in the same airsheds. Future NPI estimates of diffuse emissions from roads are likely to be modified in light of recent calls to update the ‘Emission estimation technique manual for aggregated emissions from paved and unpaved roads’ [32] to include new equations, a default moisture content of 1% and typical Australian data for road silt contents [40]. These modifications could affect the dominance of road emissions as a major source of human toxicity in Australia.

Table 6b
Australian total contribution to human and ecotoxicity impact categories on per capita basis (divided by 20 million; units are in years)

Impact category	Contribution by source			Total impact
	Industry	Diffuse	Pesticide usage	
Freshwater ecotoxicity	3.5 E−12	1.2 E−13	2.0 E−11	2.4 E−11
Marine ecotoxicity − all NPI	5.1 E−09	3.6 E−11	1.0 E−15	5.2 E−09
Marine ecotoxicity − excluding essential metals	5.1 E−09	3.6 E−11	1.9 E−16	5.2 E−09
Terrestrial ecotoxicity	7.8 E−12	7.2 E−13	8.1 E−12	1.7 E−11
Human toxicity (carcinogenic)	1.8 E−04	2.0 E−04	7.6 E−10	3.8 E−4
Human toxicity (non-carcinogenic)	9.8 E−04	4.9 E−04	7.8 E−09	1.5 E−03

The sources of diffuse impact in highly urban environments are quite different to the Pilbara and Bunbury airsheds and reflect a greater importance of organic contaminants. For example, in the Sydney−Newcastle−Wollongong airshed the major carcinogenic contributing substances are Cr (28%, mostly from lawn mowing), Co (52%, mostly from lawn mowing), benzene (8%, mostly from motor vehicles) and PAHs (8%, mostly from domestic solid fuel burning). The major non-carcinogenic contributing substances are Pb (78%, mostly from lawn mowing), toluene (7%, mostly from motor vehicles) and xylene (8%, mostly from motor vehicles).

The data allow identification of those industries that contribute significantly to the total national impact. The use of pesticides in agriculture accounts for 85% of the national freshwater ecotoxicity normalisation score and 49% of the terrestrial ecotoxicity normalisation score. Pesticide use in agriculture therefore plays a critical role in Australia’s total ecotoxicity impact. The contribution is likely to be much greater, if usage figures were expanded from 13 to 250 chemicals. However, this requires that usage figures become available, i.e. for all chemicals with an annual usage of 1 t or more. According to our model calculations, therefore, efforts to minimise overapplication, undertake crop rotations, use of bio-fumigants, development of pest resistant crops, or substitution with less environmentally harmful chemicals will lower Australia’s ecotoxicity impact. Marine ecotoxicity is dominated by air emissions from industry, in particular from aluminium smelters, coal-burning electricity plants and water emissions from sewerage treatment plants. The two human toxicity impact categories are dominated by the inhalation of dust contaminated with metals. There is a large diffuse contribution (mainly from road dust) with the remainder of the impact from industry. Of the 106 industry sectors considered in this analysis, the majority of industry related human toxicity impacts are caused by only a handful of industry sectors, such as non-ferrous metal ores (mining), basic non-ferrous metals and products (manufacturing) and electricity supply (see Table 7). For the year 2002/2003 the total impacts have been determined on a continent basis without consideration of regional climatic variations. Future normalisation data releases should investigate the feasibility of combining NPI emissions with regional (climate) specific characterisation factors.

4. Conclusions

The USES-LCA 2.0 model, developed for west European conditions, was modified for the Australian environment and population. The adapted model was used to calculate characterisation factors for 38 human carcinogenic and 68 human non-carcinogenic substances (in terms of the marginal change in cumulative population-based risk and potential impacts

Table 7
Identification of industry sectors contributing more than 10% to the national industry and total (industry + diffuse + pesticide) impact

Impact category	Industry code and description after ABS		Contribution to 'industry only' emissions (%)	Contribution to total emissions (%)
Freshwater ecotoxicity	2702	Manufacturing: Basic non-ferrous metals and products	28	<10
	3601	Electricity supply	28	<10
	1302	Mining: Non-ferrous metal ores	12	<10
	3701	Water supply; sewerage and drainage services	12	<10
Marine ecotoxicity	3601	Electricity supply	33	33
	2702	Manufacturing: Basic non-ferrous metals and products	25	25
	3701	Water supply; sewerage and drainage services	13	13
	2602	Ceramic products	11	11
Terrestrial ecotoxicity	2702	Manufacturing: Basic non-ferrous metals and products	65	20
	1302	Mining: Non-ferrous metal ores	16	<10
Human toxicity (carcinogenic)	1302	Mining: Non-ferrous metal ores	70	33
	2702	Manufacturing: Basic non-ferrous metals and products	16	<10
Human toxicity (non-carcinogenic)	1302	Mining: Non-ferrous metal ores	44	29
	2702	Manufacturing: Basic non-ferrous metals and products	26	17
	3601	Electricity supply	12	<10

(DALYs) per kilogram) as well as characterisation factors for freshwater, terrestrial and marine ecotoxicity of 100 substances (in terms of marginal change in potentially affected fraction of species). The substances chosen reflect reportable substances under the National Pollutant Inventory (NPI) scheme and commonly used pesticides in Australian agriculture. The normalisation results provide up-to-date information for human toxicity and ecotoxicity for Australia, which uses actual emission and pesticides' usage data. The normalisation data presented here can be considered to be a lower limit estimate of the actual impact to the Australian population and environment since only larger emitters have to report under the current NPI scheme and only 13 pesticides are included in the assessment. Nevertheless, the total toxicity estimates reflect major industry emissions, diffuse air emissions for many Australian cities (including motor vehicles) and usage figures for commonly used pesticides in Australian agriculture. Further work is required to obtain a more comprehensive assessment of pesticide use and dust emissions and the there is a need to develop a regionally specified fate and exposure model for Australia.

Acknowledgement

Financial support from the Cooperative Research Centre for Waste Management and Pollution Control (Project 04-6003) is gratefully acknowledged.

References

[1] Airservices Australia. Map series: visual terminal charts; 1999.
[2] ANZECC (Australian and New Zealand Environment and Conservation Council) and ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand). Australian and New Zealand guidelines for fresh and marine water quality. In: Aquatic ecosystems – rationale and background information, vol. 2. Canberra: ANZECC and ARMCANZ; 2000 [chapter 8].
[3] ANZECC (Australian and New Zealand Environment and Conservation Council) and ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand). Australian and New Zealand guidelines for fresh and marine water quality. In: The guidelines, vol. 1. Canberra: ANZECC and ARMCANZ; 2000 [chapters 1–7].
[4] Australian Academy of Technological Sciences and Engineering (AATSE). Pesticide use in Australia. Parkville, Vic.: ATSE; 2002 (www.atse.org.au).
[5] Australian Bureau of Statistics. Census of population and housing: Australia in profile – a regional analysis 2001. Cat no. 2032.0. Canberra: ABS; 2001.
[6] Australian Bureau of Statistics. Australian national accounts: input–output tables – electronic publication, Cat no. 5209.0.55.001. Canberra: ABS; 2004.
[7] Bare JC, Norris GA, Pennington DW, McKone T. TRACI - the tool for the reduction and assessment of chemical and other environmental impacts. Journal of Industrial Ecology 2002;6:49–78.
[8] De Schamphelaere KAC, Janssen C. Bioavailability and chronic toxicity of zinc to juvenile rainbow trout (*Oncorhynchus mykiss*): comparison with other fish species and development of a biotic ligand model. Environmental Science and Technology 2004;38:6201–9.
[9] EC. European union system for the evaluation of substances 2.0 (EUSES 2.0); 2004.
[10] FAO. Food and Agriculture Organisation of the United Nations, statistical databases; 2005.
[11] Guinée JB, Headings R, Van Oers LFCM, Van de Meent D, Vermeire T, Rikken M. USES: uniform system for the evaluation of substances. Inclusion of fate in LCA characterisation of toxic releases. Applying USES 1.0. International Journal of Life Cycle Assessment 1996;1:133–8.
[12] Guinee JB, de Koning A, Pennington DW, Rosenbaum R, Hauschild M, Olsen SI, et al. Bringing science and pragmatism together – a tiered approach for modelling toxicological impacts in LCA. International Journal of Life Cycle Assessment 2004;9:320–6.
[13] Heijungs R, de Koning A, Ligthart R, Koerenromp R. Improvement of LCA characterization factors and LCA practice for metals. Apeldoorn: TNO; August 2004.
[14] Hertwich EG, Pennington DW, Bare J. Introduction. In: Udo de Haas HA, et al., editors. Life cycle impact assessment: striving towards best practice. Pensacola, FL, USA: SETAC; 2002.
[15] Hertwich EG, Pease WS, McKone TE. Evaluating toxic impact assessment methods: what works best? Environmental Science and Technology 1998;32:A138–44.
[16] Huijbregts MAJ, Struijs J, Goedkoop M, Heijungs R, Hendriks JA, van de Meent D. Human population intake fractions and environmental fate factors for toxic pollutants in Life Cycle Impact Assessment. Chemosphere 2005;61(10):1495–504.
[17] Huijbregts MAJ, Rombouts LJA, Ragas AMJ, Van de Meent D. Human-toxicological effect and damage factors for life cycle impact assessment

of carcinogenic and non-carcinogenic chemicals. Integrated Environmental Assessment and Management 2005;1(3):181–244.
[18] Huijbregts MAJ, Lundie S, McKone TE, Van de Meent D. Geographical scenario uncertainty in generic fate and exposure factors of toxic pollutants for life-cycle impact assessment. Chemosphere 2003;51:501–8.
[19] Huijbregts MAJ, Breedveld L, Huppes G, De Koning A, Van Oers L, Suh S. Normalisation figures for environmental life-cycle assessment: the Netherlands (1997/1998a), Western Europe (1995) and the world (1990 and 1995). Journal of Cleaner Production 2003;11(7):737–48.
[20] Huijbregts MAJ, Guinée JB, Reijnders L. Priority assessment of toxic substances in LCA. Part III: export of potential impact over time and space. Chemosphere 2001;44:59–65.
[21] Huijbregts MAJ, Thissen U, Guinée JB, Jager T, van de Meent D, Ragas AMJ, et al. Priority assessment of toxic substances in life cycle assessment, I: calculation of toxicity potentials for 181 substances with the nested multi-media fate, exposure and effects model USES-LCA. Chemosphere 2000;41:541–73.
[22] Huijbregts MAJ, Thissen U, Jager T, van de Meent D, Ragas AMJ. Priority assessment of toxic substances in LCA. II: assessing parameter uncertainty and human variability in the calculation of toxicity potentials. Chemosphere 2000;41:575–88.
[23] International Organization for Standardization (ISO). ISO 14040 environmental management – life cycle assessment – life cycle impact assessment. Geneva: ISO; 2000.
[24] Itsubo N, Sakagami M, Washida T, Kokubu K, Inaba A. Weighting across safeguard subjects for LCIA through the application of conjoint analysis. International Journal of Life Cycle Assessment 2004;9:196–205.
[25] Jolliet O, Margni M, Charles R, Humbert S, Payet J, Rebitzer G, et al. IMPACT 2002+ – a new life cycle impact assessment methodology. International Journal of Life Cycle Assessment 2003;8:324–30.
[26] Kramer KJM, Jak RG, van Hattum B, Hoofman RN, Zwolsman JJG. Copper toxicity in relation to surface water-dissolved organic matter: biological effects to *Daphnia magna*. Environmental Toxicology and Chemistry 2004;23:2971–80.
[27] MacLeod M, Woodfine DG, Mackay D, McKone T, Bennet D, Maddalena R. BETR North America: a regionally segmented multimedia contaminant fate model for North America. Environmental Science and Pollution Research 2001;8(3):156–63.
[28] MacLeod M, Bennett D, Perem M, Maddalena RL, McKone TE, Mackay D. Dependence of intake fraction on release location in a multi-media framework: a case study of four contaminants in North America. Journal of Industrial Ecology 2004;8(3):89–102.
[29] Margni M, Rossier D, Crettaz P, Jolliet O. Life cycle impact assessment of pesticides on human health and ecosystems. Agriculture Ecosystems and Environment 2002;93:379–92.
[30] Murray CJL, Lopez AD. The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. In: Global burden of disease and injury series, vol. I. USA: Harvard School of Public Health, World Bank, World Health Organisation; 1996. 990 pp.
[31] Murray CJL, Lopez AD. Global health statistics: a compendium of incidence, prevalence and mortality estimates for over 200 conditions. In: Global burden of disease and injury series, vol. II. USA: Harvard School of Public Health, World Bank, World Health Organisation; 1996. 906 pp.
[32] National Pollutant Inventory (NPI). Emissions estimation technique manual for aggregated emissions from paved and unpaved roads. Environment Australia: Canberra; 1999.
[33] National Pollutant Inventory (NPI). 2002–03 NPI facility data, National Pollutant Inventory (NPI), www.npi.gov.au; 2005.
[34] Pennington DW, Margni M, Amman C, Jolliet O. Multimedia fate and human intake modeling: spatial versus nonspatial insights for chemical emissions in Western Europe. Environmental Science and Technology 2005;39(4):1119–28.
[35] Pennington DW, Potting J, Finnveden G, Lindeijer E, Jolliet O, Rydberg T, et al. Life cycle assessment part 2: current impact assessment practice. Environment International 2004;30:721–39.
[36] Prevedouros K, McLeod M, Jones KC, Sweetman AJ. Modelling the fate of persistent organic pollutants in Europe: parameterization of a gridded distribution model. Environmental Pollution 2004;128:251–61.
[37] RIVM e-toxBase. National Institute for Public Health and the Environment. Bilthoven, The Netherlands: RIVM; 2004 [Download d.d 19-5-2004].
[38] Schubauerberigan MK, Dierkes JR, Monson PD, Ankley GT. pH-dependent toxicity of Cd, Cu, Ni, Pb and Zn to *Ceriodaphnia dubia*, *Pimephales promelas*, *Hyalella azteca* and *Lumbriculus variegatus*. Environmental Toxicology and Chemistry 1993;12:1261–6.
[39] Simonnin G, Payet J, Jolliet O. Use of the biotic ligand model for life cycle impact assessment on ecosystems. In: Proceedings of the SETAC EUROPE meeting, Prague, 2004; 2004.
[40] Sinclair Knight Merz (SKM). Improvement of NPI fugitive particulate matter emission estimation techniques, RFQ No. 0027/2004, SKM, Perth; 2005.
[41] Standards Australia/Standards New Zealand. Environmental management—life cycle assessment—life cycle impact assessment. Standards Australia/Standards New Zealand (AS/NZS ISO 14042:2001); 2001.
[42] Van de Meent D, Huijbregts MAJ. Calculating LCA effect factors from PAF-based ecotoxicological response functions. Environmental Toxicology and Chemistry 2005;24(6):1573–8.
[43] Webster Eva, Mackay Don, Di Guardo Antonio, Kane David, Woodfine David. Regional differences in chemical fate model outcome. Chemosphere 2004;55(10):1361–76.
[44] Bennett DH, McKone TE, Evans JS, Nazaroff WW, Margni MD, Jolliet O, et al. Defining intake fraction. Environmental Science and Technology 2002;36:206A–11A.