New Zealand inventory of dioxin emissions to air, land and water, and reservoir sources

Organochlorines Programme
Ministry for the Environment

March 2000

Authors

Simon J Buckland
Howard K Ellis
Patrick Dyke[1]

[1] PD Consulting, Lechlade, UK

Principal New Zealand consultants

Woodward-Clyde NZ Ltd

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Foreword

People around the world are concerned about organochlorine contaminants in the environment. Research has established that these persistent chemicals affect even the most remote regions of the world. Organochlorines, as gases or attached to dust, are transported vast distances by air and ocean currents – they have been found even in polar regions

Organochlorines are stored in body fat and accumulate through the food chain. Even a low level of emissions can build up over time into a significant risk to the health of people and animals, including birds and marine mammals.

This inventory of emissions focuses just on dioxins. Dioxins are unusual in that, while they result primarily from human activity, they are not produced intentionally. They are by-products of no known use, but are among the most toxic chemicals known.

Overseas, dioxin emissions are mainly generated by industry, particularly through combustion, waste incineration, and metal production and processing. In New Zealand, these same sources, together with uncontrolled landfill fires, are important contributors to our total dioxin emissions. However, relative to other industrialized countries, New Zealand has a comparatively fewer number of these industries, and they are also generally smaller. As a consequence, of the total mass of dioxins emitted, it is estimated that non-industrial sources emit roughly equal amounts to the atmosphere as arise from industrial sources.

Each of us generates dioxins during normal daily activities, some of which we would not think of as causing pollution. For example, domestic fireplaces burning wood or coal release dioxins, as does the backyard burning of domestic rubbish.

In releasing this inventory, we should acknowledge the steps that have already been taken by New Zealand industry to reduce dioxin emissions. The chlorinated chemicals, pentachlorophenol (PCP) and 2,4,5-T, both contained dioxins as impurities. PCP, widely used as a fungicidal and preservative treatment of timber, was voluntarily phased out by the timber industry in 1988 and is no longer used and the phenoxy herbicide 2,4,5-T is no longer manufactured or imported. Also, advances in pulp processing mean that elemental chlorine is no longer used in the manufacture of bleached paper. The inventory estimates present day emissions of dioxins, but we should bear in mind that the situation would look much worse without the earlier action by industry.

The inventory will help the Government identify priority actions to further reduce the emissions of dioxins in New Zealand. It is proposed that, as one component of an integrated organochlorines management plan, national environmental standards under the Resource Management Act be developed to control industrial emissions. But the standards need to be complemented by measures to reduce dioxin emissions from non-industrial sources.

The message from this inventory is that, if New Zealand as a whole is to reduce dioxin emissions below current levels, this is as much an individual responsibility as it is a corporate and industrial responsibility. Any genuine effort to minimise emissions relies on commitments from everybody, both at work and at home.

Denise F Church

Denise Church
Chief Executive

Disclaimer

The information contained in this report has been prepared with the aim of assessing the magnitude of PCDD and PCDF emissions in New Zealand from industrial, non-industrial and reservoir sources, as well as from natural events. While the Ministry for the Environment has taken all reasonable care in collecting the activity statistics and emission factor data for each source, and in processing this information into PCDD and PCDF emission estimates, it does not warrant the correctness, completeness or usability of the information or emission estimates provided, and further disclaims all liability whatsoever for any consequences that might result from the use of the information or emission estimates.

This publication

This publication is the final Ministry for the Environment report on the "New Zealand inventory of dioxin emissions to air, land and water, and reservoir sources". It has been prepared following extensive consultation with industry sectors that have been identified as PCDD and PCDF emitters. Consultation has also occurred with other key stakeholders. This consultation has ensured that industry specific process data, including industry and other privately held data on PCDD and PCDF emissions in New Zealand, have been made available and incorporated into this report. The estimates of PCDD and PCDF emissions to air, land and water and reservoir sources have been made using the most up to date information available at the time of publication.

This report, and the emission estimates made, supersedes all previous reports prepared by Woodward Clyde (NZ) Ltd dated October 1997, December 1998 and September 1999, and the draft Ministry for the Environment report dated December 1999 that were circulated for review and comment.

Executive summary

ES.1 Methodology

This study provides a national inventory of polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF) emissions to air, land and water from known sources and estimates the quantity of PCDDs and PCDFs present within reservoir sources. The reference date for this inventory is 1998.

The basic methodology used to assemble the inventory was similar to other countrywide inventory compilations that have been carried out overseas. For each identified PCDD and PCDF source, an annual estimate of emissions was derived as the product of an activity statistic and an emission factor where sufficient information was available. Source activity statistics were chosen that related to the throughput of fuel, the tonnes of material manufactured or a similar measure, and an emission factor was generated based on average emissions (to air, land or water) per unit of activity.

The current study was carried out in three distinct phases. Phase I was a desk top study to assess emissions based on currently available data; Phase II was a limited source testing phase to provide additional data for those sectors where it was considered the available data were inadequate; and Phase III was the development of this national inventory of PCDD and PCDF emissions and releases from Phases I and II.

Sources of PCDDs and PCDFs to the environment for which annual estimates of emissions and releases have been attempted were:

Incineration and combustion processes:

Clinical, pathological and quarantine waste incineration, hazardous waste incineration, wastewater solids incineration, crematoria, power generation, industrial (including agricultural) and domestic coal burning, industrial and domestic wood burning, domestic waste burning, land transport and uncontrolled fires.

Manufacturing and production processes:

Cement and lime manufacturing, ferrous and non-ferrous metal production, glass production and pulp and paper production.

Miscellaneous activities:

Used oil use and disposal, cigarette smoking, use of halogenated pesticides, landfills and wastewater treatment.

Historic activity sites that will constitute reservoir sources:

Historic pesticide manufacturing, historic use of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), timber treatment and historic pentachlorophenol (PCP) use, coal gasification.

Certain sources found in inventories for other countries, for example, municipal solid waste incineration and vinyl chloride manufacture, were not considered in the current study since they are not carried out in New Zealand.

Wherever possible, New Zealand derived emission factors were used for the emissions estimate. For some sectors, however, either no New Zealand factors were available, or the New Zealand data were judged inadequate for all conditions that may occur. In these cases, emission factors from the published literature were adopted. To gauge the certainty of each estimate, high, medium and low certainty rankings have been applied to the activity statistic and the emission factor used. These rankings were based on expert knowledge of each industry and the appropriateness and applicability of the emission factors (e.g. New Zealand based factors or overseas factors taken from the literature).

Extensive consultation was undertaken throughout this inventory compilation. This included consultation with industry as well as government agencies and non-governmental organisations. The inclusive approach that was followed for the participation of industry has enabled privately held data to be incorporated into the study, and has ensured that, where available, accurate activity statistics for industrial processes were used for the annual emission estimates.

All emission estimates to air and releases to land and water, and the quantity of PCDDs and PCDFs present in reservoir sources are reported as international toxic equivalents (I-TEQ). These estimates include half limit of detection (LOD) values for non-detected PCDD and PCDF congeners.

ES.2 Emissions to air

The inventory includes estimated emissions to air from industrial and non-industrial (effectively domestic) sources, as well as natural sources such as forest fires. Industrial sources are generally characterised as point source emissions (e.g. a single point of emission from an industrial facility), whereas non-industrial sources are characterised by a large number of small point source or diffuse emissions (e.g. multiple emissions from home heating appliances in a residential area).

The estimates of emissions from industrial and non-industrial sources (including natural sources) are summarised in Table ES.1, along with an assessment of the certainty for each estimate made. The total annual emission to air for 1998 was estimated to be in the range 14 – 51 g I-TEQ. A relative ranking of the sources with respect to the magnitude of their emissions is presented in Figure ES.1. This ranking is based on the upper bounds of the emission estimate range for each source shown in Table ES.1. A similar ordering of sources is obtained if the ranking is made using the mid-point of the emissions estimate range.

ES.2.1 Industrial sources

The major industrial emitters of PCDDs and PCDFs to air were identified as uncontrolled landfill fires (10 – 15 g I-TEQ yr^{-1}), followed by industrial and agricultural coal combustors (0.034 – 4.0 g I-TEQ yr^{-1}), clinical, pathological and quarantine waste incinerators (0.38 – 3.5 g I-TEQ yr^{-1}) and industrial wood combustors (0.85 – 2.4 g I-TEQ yr^{-1}).

For landfill fires, there is considerable uncertainty in the magnitude of the estimate made, both with respect to the quantity of waste that is consumed during a fire and the PCDD and PCDF emission factors. However, it is clear that landfill fires do occur at an unacceptable rate in New Zealand, and, given the nature of the waste in landfills and the uncontrolled conditions under which combustion occurs, elevated PCDD and PCDF emissions can be expected.

The combustion of coal in the industrial and agricultural sector is characterised by a large number of appliances that, individually, have comparatively low emissions, but collectively make this the second largest industrial source. In contrast, the combustion of coal at New Zealand's only coal fired power station had an upper emission estimate that was, at 0.11 g I-TEQ yr^{-1}, approximately 40 times lower than those for the industrial and agricultural sector.

Table ES.1 PCDD and PCDF emissions to air [1]

Source	Annual emission estimate (g I-TEQ yr^{-1})	Certainty [2]	Section
Incineration and combustion processes			
Clinical, pathological and quarantine waste incineration	0.38 – 3.5	M, M	4
Hazardous waste incineration	0.00054 – 0.0039	H, H	5
Wastewater solids incineration	0.009	H, L	6
Crematoria	0.0080 – 0.45	H, L	8
Power generation	0.059 – 0.11	H, M	9
Industrial, commercial and agricultural coal combustion			
Industrial and commercial appliances	0.032 – 3.8	H, M	10
Agricultural appliances	0.0017 – 0.20	H, L	10
Domestic coal burning	0.36 – 0.59	H, L	11
Industrial wood combustion			
Wood processing wastes	0.28 – 1.2	M, M	12
Contaminated wood wastes	0.57 – 1.2	M, L	12
Domestic wood burning	0.71 – 8.7	H, L	13
Domestic waste burning	0.54 – 6.4	L, L	14
Land transport			
Unleaded petrol	0.010 – 0.59	H, L	15
Diesel	0.10 – 0.57	H, L	15
Uncontrolled fires			
Forest, scrub and grass fires	0.080 – 1.1	L, L	16
Structure fires	0.27 – 2.7	L, L	16
Vehicle fires	0.10 – 0.14	L, L	16
Manufacturing and production processes			
Cement and lime manufacture			
Cement manufacture	0.10 – 0.65	H, M	17
Lime manufacture	0.0030 – 0.16	H, L	17
Iron and steel production			
Primary steel production	0.10	H, H	18
Secondary steel production	0.017 – 0.063	H, H	18
Non-ferrous metal production	0.10 – 1.3	L, L	19
Aluminium production			
Secondary aluminium production	0.0091 – 1.8	M, L	20
Glass production	0.00024 – 0.0038	H, L	21
Pulp and paper production (black liquor recovery boilers)	0.033 – 0.045	H, M	22
Miscellaneous activities			
Cigarette smoking	0.00029 – 0.0084	H, L	23
Used oil use and disposal	0.00068 – 0.024	L, L	24
Landfills			
Landfill gas (fugitive emissions)	0.077 – 0.086	L, L	26
Landfill gas (flared and combusted in engines)	0.0013 – 0.077	M, L	26
Landfill fires	10 – 15	L, L	26
Total annual estimate of emissions to air for 1998	**14 – 51**		

1. Sources presented in this table are listed in the sequence of incineration and combustion processes, manufacturing and production processes and miscellaneous activities. No interpretation should be read into the significance of this order with respect to the magnitude of these source emissions and the risks that these emissions may pose.
2. Certainty rankings are presented as *activity statistic ranking, emission factor ranking.* H = High certainty; M = Medium certainty; L = Low certainty. See Section 3.3.

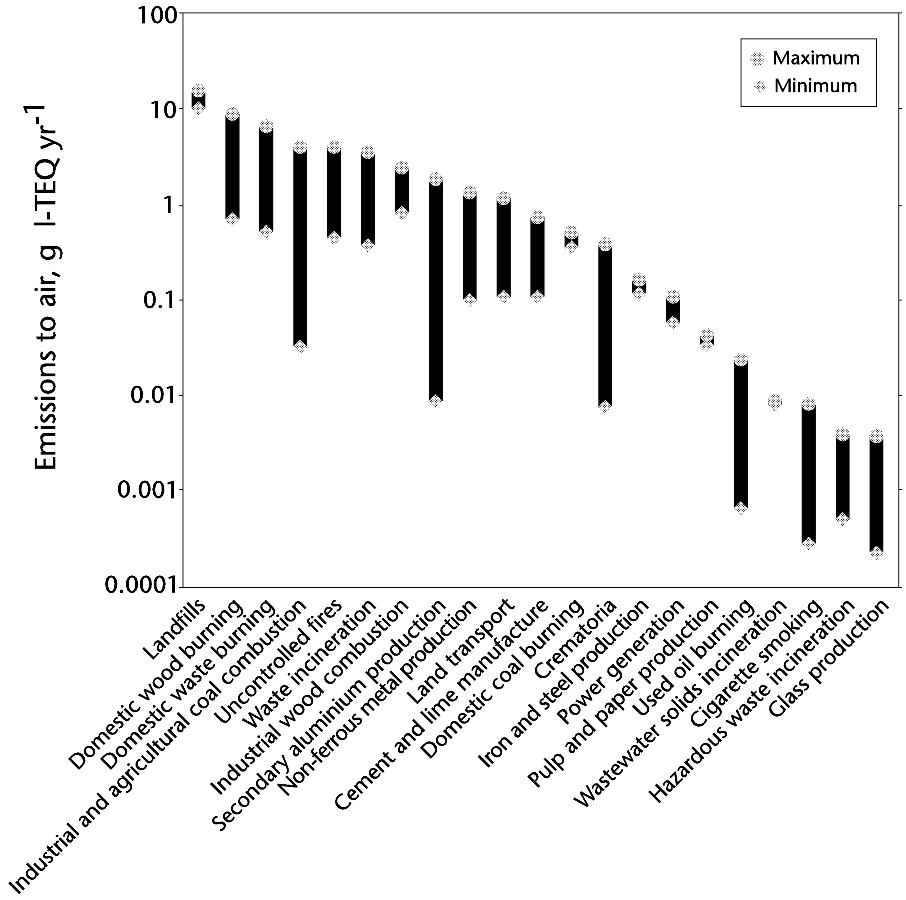

Figure ES.1 PCDD and PCDF emissions to air

The industrial combustion of wood (primarily bark and wood processing waste) is also characterised by multiple units having comparatively low emissions. The exception to this is where treated or "contaminated" wood waste is burnt, which, based on overseas emission factor data, can lead to a marked increase in emissions. The inventory has assumed that 10% of all wood waste burnt in the industrial sector is "contaminated".

Clinical, pathological and quarantine waste incineration was assessed separately for facilities for which there were New Zealand test data (5 incinerators burning approximately 9,200 tonne yr^{-1}) and facilities for which there were no emission test data (19 incinerators burning approximately 3,800 tonne yr^{-1}). The tested incinerators, which represent regionally based facilities, had emission estimates between 0.14 – 1.2 g I-TEQ yr^{-1}. The non-tested incinerators, which were generally older units that had poor emission controls and/or were assumed to be less well operated, had estimated emissions between 0.24 – 2.3 g I-TEQ yr^{-1}. With the exception of one incinerator that had state of the art pollution control equipment, the emission factors for the New Zealand waste incinerators were comparable to data from the United Kingdom for poorly operated and controlled plants. The principle reason New Zealand's emissions from this source are lower than comparative estimates that have been made from overseas inventories for waste incinerators is the much lower volume of waste that is incinerated in New Zealand. The total upper estimate for this sector, of 3.5 g I-TEQ yr^{-1}, would appear to be at the low end of a previous indicative estimate undertaken in 1992, which is consistent with the closure of many of the old hospital waste incinerators during the 1990s.

The upper bound of PCDD and PCDF emissions from the approximately 40 crematoria in New Zealand was estimated to be 0.45 g I-TEQ yr^{-1}, or approximately 0.01 g I-TEQ per crematorium.

The steel industry has been estimated to emit approximately 0.12 – 0.16 g I-TEQ yr^{-1} from primary and secondary steel production. The low level of emissions for primary steel production in New Zealand (0.10 g I-TEQ yr^{-1}) compared to emissions from other countries where steel manufacturing has been identified as a major source is because the steel is produced from iron sand using the direct reduction process. There are no sinter plants in New Zealand, which have been associated with high PCDD and PCDF emissions overseas.

Higher emission estimates have been made for non-ferrous metal production. Thus, non-ferrous metal (excluding aluminium) producers have been assessed to emit approximately 1.3 g I-TEQ yr^{-1} as an upper estimate, while secondary aluminium production has an upper estimate of 1.8 g I-TEQ yr^{-1}. No estimate could be made for emissions from New Zealand's sole primary aluminium smelter as no test data was available for this plant, and overseas studies have not reported emission factors for this industry.

Cement manufacture is primarily undertaken at two major plants, each producing around 500,000 tonnes of product per year. One plant burns used oil as an auxiliary fuel. Emissions from this plant have been extensively tested and the upper range of emissions was estimated at 0.12 g I-TEQ yr^{-1}. Emissions from the second plant were estimated using overseas emission factor data. The total upper estimate of emissions from cement manufacture was estimated to be 0.65 g I-TEQ yr^{-1}. Lime manufacture is primarily undertaken at four plants, which collectively produce approximately 151,000 tonnes per year. The upper range of emissions from lime manufacture was estimated to be 0.16 g I-TEQ yr^{-1}.

Other processes identified as emitting PCDDs and PCDFs to air had low emissions compared to these sources. Thus landfill gas fugitive emissions and gas flared and combusted in engines had upper estimates of emissions that were below 0.1 g I-TEQ yr^{-1}. Even smaller upper bound estimates, at less than 0.05 g I-TEQ yr^{-1}, were obtained for hazardous waste incineration (1 plant in New Zealand), wastewater solids incineration (1 plant), glass production (1 major plant) and black liquor recovery (4 boilers) from bleached kraft pulp production.

The flaring of gas and oil condensates from the exploration and production testing of oil and gas wells has been found to emit PCDDs and PCDFs to air. However, insufficient information was available to enable an estimate of emissions from this source to be made.

ES.2.2 Non-industrial and natural sources

The assessment of emissions from non-industrial and natural sources was particularly problematic, and resulted in low certainty for all of the estimates made. In every case, this was because the certainty of the emission factors used was low. For uncontrolled fires and non-industrial emissions, the certainty of the activity statistic was also low. Notwithstanding this uncertainty, three of the top five ranked emitters to air were non-industrial sources, namely domestic wood burning, domestic waste burning and uncontrolled fires (forest, scrub and grass fires, structure fires and vehicle fires). Collectively these three sources accounted for between 10 – 40% of the total PCDD and PCDF release to air based on the lower and upper bound estimates of emissions.

Domestic wood burning for space heating was estimated to contribute 0.71 – 8.7 g I-TEQ yr^{-1}. The significance of wood burning as a source of PCDDs and PCDFs to air has been shown by ambient air monitoring in a number of residential areas of New Zealand, where elevated winter PCDD and PCDF concentrations were measured compared to summer concentrations.

Domestic waste burning was estimated to emit 0.54 – 6.4 g I-TEQ yr^{-1}. Although there is some uncertainty in the quantity of waste burnt, domestic waste burning, especially in rural areas, is known to occur. It is believed that domestic waste burning is of lesser significance in urban areas.

The use of coal as a domestic fuel for space heating also represents an important source of PCDDs and PCDFs based on an upper estimate of 0.59 g I-TEQ yr^{-1}. Its lower emissions, and ranking as a source, compared to domestic wood burning can be explained on the basis of the relative quantities of each fuel burnt (around 63,000 tonne yr^{-1} for coal and 713,000 tonne yr^{-1} for wood).

Uncontrolled fires, particularly forest, scrub and grass fires (estimated emission range of 0.080 – 1.1 g I-TEQ yr^{-1}) and structure fires (0.27 – 2.7 g I-TEQ yr^{-1}) were also identified as significant sources of PCDD and PCDF emissions in New Zealand. These estimates were, however, compromised by the lack of reliable data on the amount of material that is actually burnt in these fires (particularly for structure fires) and the lack of specific emission factors for these sources.

Total PCDD and PCDF emissions from land transport (unleaded and diesel fuels) were estimated at just over 1 g I-TEQ yr^{-1} as an upper range estimate. This compares with a previous estimate from 1992 of approximately 5 g I-TEQ yr^{-1} for vehicles fuelled by leaded petrol. The current lower emission estimate is consistent with the removal of leaded petrol as a fuel for New Zealand's vehicle fleet.

ES.3 Releases to land

Activities and processes that produce a solid waste stream have been assessed for the magnitude of their PCDD and PCDF release to land. The results from those sectors where an estimate of releases could be made are summarised in Table ES.2. The total annual release to land for 1998 was estimated in the range 26 – 54 g I-TEQ. Based on the upper bounds of the emission estimates, a relative ranking of the sources is presented in Figure ES.2.

For most of the sources assessed, there was medium to high certainty for the activity statistic used to estimate the release. However, for all sectors except primary and secondary steel production, pulp and paper production in bleached kraft mills and wastewater treatment, the emission factor used had a low certainty.

The inventory shows that the residues and solid waste streams from several combustion processes represent a major contributor of PCDDs and PCDFs to land. Thus, collectively, ash from domestic and industrial wood combustion, and ash and gas scrubbing residues from clinical, pathological and quarantine waste incineration account for approximately 30% of the total release to land based on the upper bound estimates made.

Similarly, releases from the metallurgical industry were also important, particularly for secondary metal production. For the aluminium sector, releases ranged from 0.0017 g I-TEQ yr^{-1} for primary aluminium production to 6.8 g I-TEQ yr^{-1} for secondary aluminium production. The estimated release from secondary steel production, at 1.4 g I-TEQ yr^{-1}, was also higher than for primary steel production estimated at 0.67 g I-TEQ yr^{-1}. Based on limited data, the numerous small foundries involved in non-ferrous metal operations were estimated to release approximately 2.2 g I-TEQ yr^{-1} of PCDDs and PCDFs to land as an upper estimate.

Table ES.2 PCDD and PCDF releases to land [1]

Source	Annual release estimate (g I-TEQ yr^{-1})	Certainty [2]	Section
Incineration and combustion processes			
Clinical, pathological and quarantine waste incineration	0.43 – 3.2	M, L	4
Hazardous waste incineration	$0.25 \times 10^{-6} – 85 \times 10^{-6}$	H, L	5
Wastewater solids incineration	0.024	M, L	6
Power generation	0.0016 – 0.12	H, L	9
Industrial, commercial and agricultural coal combustion			
Industrial and commercial appliances	0.00045 – 0.30	M, L	10
Agricultural appliances	0.000023 – 0.016	M, L	10
Domestic coal burning	0.00072	M, L	11
Industrial wood combustion			
Wood processing wastes	0.0012 – 0.017	M, L	12
Contaminated wood wastes	0.33 – 1.9	M, L	12
Domestic wood burning	0.48 – 9.7	M, L	13
Domestic waste burning	5.7	L, L	14
Manufacturing and production processes			
Cement and lime manufacture			
Cement manufacture	1.3×10^{-5} – 1.4	H, L	17
Lime manufacture	5.0×10^{-6} – 0.15	M, L	17
Iron and steel production			
Primary steel production	0.67	H, M	18
Secondary steel production	1.4	H, M	18
Non-ferrous metal production	0.19 – 2.2	L, L	19
Aluminium production			
Primary aluminium production	0.0017	H, L	20
Secondary aluminium production	0.67 – 6.8	L, L	20
Pulp and paper production			
Bleached kraft mills	0.56	H, M	22
Non-kraft mills (paper recycling)	0.0050	M, L	22
Miscellaneous activities			
Used oil use and disposal	0.012 – 0.53	L, L	24
Use of halogenated pesticides	0.13 – 0.15	H, L	25
Landfills [3]			
Residential solid waste	8.9	H, L	26
Industrial solid waste	11.1	H, L	26
Wastewater treatment	0.61 – 5.2	M, M	27
Total annual estimates of releases to land for 1998	**26 – 54**		

1. Sources presented in this table are listed in the sequence of incineration and combustion processes, manufacturing and production processes and miscellaneous activities. No interpretation should be read into the significance of this order with respect to the magnitude of these source releases and the risks that these releases may pose.
2. Certainty rankings are presented as *activity statistic ranking, emission factor ranking.* H = High certainty; M = Medium certainty; L = Low certainty. See Section 3.3.
3. Landfills are themselves not a direct source of PCDDs and PCDFs to land. The annual release estimate made for this sector represents the quantity of PCDDs and PCDFs that are deposited each year via residential and industrial waste to the already existing PCDD and PCDF reservoir within landfills. For an estimate of the PCDD and PCDF reservoir within landfills see Table ES.4.

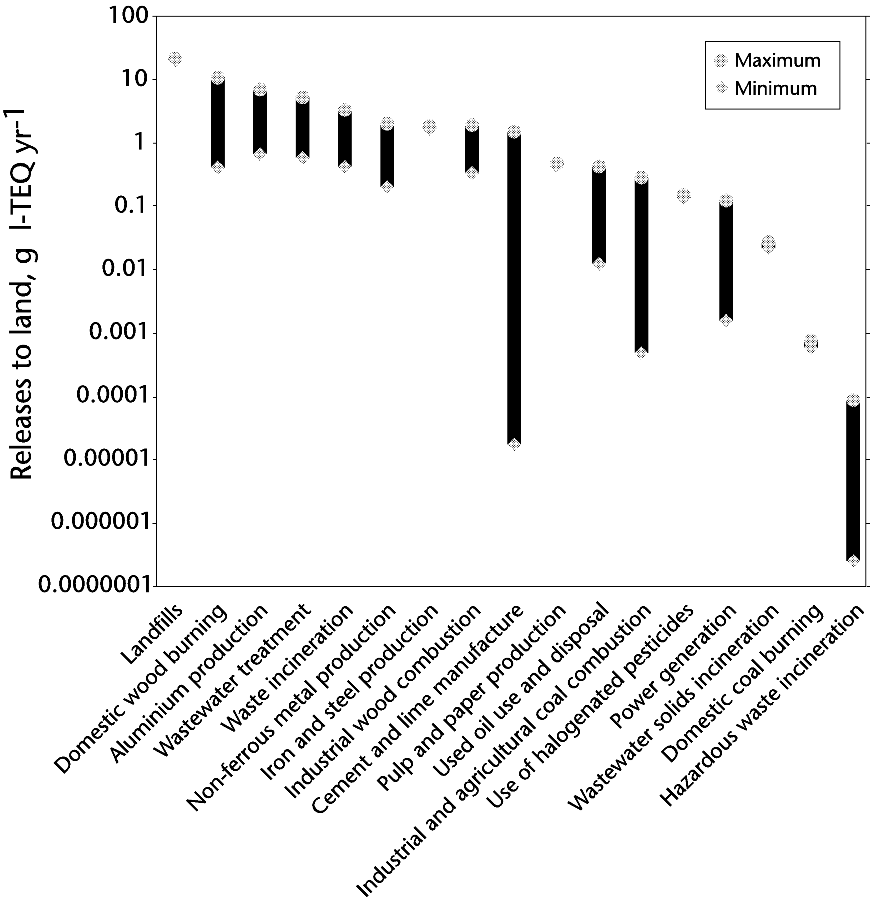

Figure ES.2 PCDD and PCDF releases to land

PCDDs and PCDFs in wastewater treatment plant solids were estimated in the range 0.61 – 5.2 g I-TEQ yr^{-1}, whilst approximately 20 g I-TEQ of PCDDs and PCDFs are released annually from domestic and industrial solid waste deposited in landfills.

PCDD and PCDF releases in solid waste streams from all other processes for which an annual estimate could be made were consistently below 1 g I-TEQ yr^{-1}. Insufficient information was available for the following sectors to make an estimate of annual releases to land, but all of these activities will release some PCDDs and PCDFs:

- Crematoria
- Domestic waste burning
- Uncontrolled fires (forest, scrub and grass fires, structure fires and vehicle fires)
- Cigarette smoking

Knowing the fate of solid waste streams is important to understand the potential exposures and risks PCDD and PCDF containing materials may represent to human and environmental health. Generally most incinerator ash is disposed of to landfill, as are dusts and fines from metallurgical production. In contrast, grate ash from industrial and agricultural coal combustion and slag from primary steel production is applied to land in some form. For wastewater treatment plant solids, there is a growing interest within the wastewater industry to beneficially reuse this material. Ultimately, this can be expected to result in wastewater treatment plant solids, and products produced from this material, being applied to land in increasing quantities.

ES.4 Releases to water

Estimates of PCDD and PCDF releases to water have been made only for those sources that could be readily identified as having a direct discharge to water. These covered discharges from primary steel production, pulp and paper production at bleached kraft mills, landfills and wastewater treatment. The total annual release for 1998 was estimated to be in the range 0.56 – 3.9 g I-TEQ (Table ES.3).

Table ES.3 PCDD and PCDF releases to water [1]

Source	Annual release estimate (g I-TEQ yr^{-1})	Certainty [2]	Section
Manufacturing and production processes			
Primary steel production	0.015	H, M	18
Pulp and paper production (bleached kraft mills)	0.20 – 0.35	H, M	22
Miscellaneous activities			
Landfills			
From annual refuse placed	0.00074 – 0.0093	L, M	26
From the reservoir	0.0083 – 0.95	L, M	26
Wastewater treatment	0.34 – 2.6	M, L	27
Total annual estimate of releases to water for 1998	**0.56 – 3.9**		

1. Sources presented in this table are listed in the sequence of manufacturing and production processes and miscellaneous activities. No interpretation should be read into the significance of this order with respect to the magnitude of these source releases and the risks that these releases may pose.
2. Certainty rankings are presented as *activity statistic ranking, emission factor ranking.*
H = High certainty; M = Medium certainty; L = Low certainty. See Section 3.3.

The major contributor to this release, at approximately 60 – 65%, was the wastewater treatment sector. This is believed to be due to the types of treatment applied to wastewater effluent and the relatively high solids content of the discharge. Current industry improvements in wastewater treatment processes are likely to see this level of release to water decrease in the future.

The reservoir present within landfills gave an upper release estimate in leachate of 0.95 g I-TEQ yr^{-1}. This, however, does not necessarily reflect the level of PCDD and PCDF release to water, as the leachate may be re-circulated back through the landfill, or there may be contaminant absorption onto solids and land before the leachate enters water. In addition, it should be noted that the wide variation in concentrations measured for New Zealand landfill leachate means the estimated release range is much larger and has greater uncertainty than other estimates made for releases to water.

Pulp and paper production, which historically has been considered to be a major source of PCDDs and PCDFs to the environment, was found to be a minor source in the current study. New Zealand's two bleached kraft mills were estimated to contribute less than 10% of the total release to water, based on the upper estimate of emissions made. A higher contribution, at 35%, is derived if the lower bound ranges of emissions are used. However, this is likely to be overly conservative, as the 1998 monitoring data from one of the mills did not detect any PCDDs or PCDFs in the effluent discharge, with the lower bound release range (0.20 g I-TEQ yr^{-1}) being derived solely by assuming non-detected congeners were present at half the LOD. Reductions in this source are consistent with measures taken to reduce formation during the bleaching process.

For primary steel production, no PCDDs or PCDFs were measured in the discharge. The estimate of release to water of 0.015 g I-TEQ yr^{-1} was made solely by assuming that non-detected congeners were present at half the LOD.

Other processes and activities that have been addressed in this inventory for their emissions to air and releases to land have also been evaluated for releases to water. For some of these sectors there may be no aqueous waste stream. For others, a process may involve an aqueous waste stream, but there are no releases to water. In these instances, it can be concluded that there are no direct releases of PCDDs and PCDFs to water. These sectors are:

- Clinical, pathological and quarantine waste incineration
- Hazardous waste incineration
- Domestic coal burning
- Domestic wood burning
- Domestic waste burning
- Land transport
- Cement and lime manufacture
- Cigarette smoking.

For a number of other sectors, releases of PCDDs and PCDFs may occur, but no estimates of the magnitude of these releases have been made in the current inventory due to insufficient information. These sectors are:

- Wastewater solids incineration
- Power generation
- Industrial and agricultural coal combustion
- Industrial wood combustion
- Uncontrolled fires
- Secondary steel production
- Non-ferrous metal production
- Aluminium production
- Pulp and paper production at non-kraft mills (via recycled paper)
- Used oil use and disposal.

In addition, the following sectors may also contribute diffuse PCDD and PCDF releases to water via site run-off.

- Pulp and paper production at bleached kraft mills via release from the reservoir within waste dumps
- Timber treatment sites that have historically used PCP via release from the reservoir in contaminated areas
- Gasworks sites via the release from the reservoir in contaminated areas.

Again, insufficient information is available to assess the magnitude of these releases, although for pulp and paper production and gasworks sites, any release is likely to be very small to negligible.

ES.5 Reservoir sources

A reservoir source is one in which previously formed PCDDs and PCDFs may be released, thereby contributing to contamination of the wider environment. While the potential exposure pathways and the resulting environmental significance of reservoir sources are uncertain, they can pose an ongoing risk to the environment and to human health.

A summary of the quantity of PCDDs and PCDFs estimated to be present in reservoir sources that are assessed in the current inventory is given in Table ES.4.

Table ES.4 PCDD and PCDF reservoirs [1]

Source	Reservoir (g I-TEQ)	Certainty [2]	Section
Manufacturing and production processes			
Pulp and paper production (bleached kraft mills)	24	M, M	22
Miscellaneous activities			
Landfills	500	M, L	26
Historic activities			
Historic use of 2,4,5-T	620 – 860 [3]	M, M	29
Timber treatment and historic pentachlorophenol use			
NaPCP for antisapstain treatment	80	L, L	30
PCP in oil for preservative use	230	M, M	30
Coal gasification	0.028 – 6.4	L, M	31
Total estimate of reservoir source	**1,450 – 1,700**		

1. Sources presented in this table are listed in the sequence of manufacturing and production processes, miscellaneous activities and historic activities. No interpretation should be read into the significance of this order with respect to the magnitude of these reservoirs and the risks that these reservoirs may pose.
2. Certainty rankings are presented as *activity statistic ranking, emission factor ranking.* H = High certainty; M = Medium certainty; L = Low certainty. See Section 3.3.
3. Reservoir estimate for 2,3,7,8-TCDD.

The inventory considers only reservoirs of PCDDs and PCDFs from certain industrial activities. Generally these reservoirs represent sites of localised contamination in which levels of PCDDs and PCDFs are elevated compared to typical ‘background’ levels that might be found in the wider general environment. Such reservoirs include wastes from pulp and paper production at bleached kraft mills, contaminated soil and other wastes at PCP timber treatment sites and old gasworks sites, and refuse within landfills.

An estimate of the reservoir from the historic use of 2,4,5-T is also made. However, this reservoir represents a diffuse reservoir, as the contamination is distributed across the land surface of New Zealand where 2,4,5-T would have been applied. A reservoir consisting of wastes from the historic manufacture of 2,4,5-T also exists, but a lack of data has meant that it has not been possible to make any estimate of the size of this reservoir in the current study.

Generally, there is considerable uncertainty in the activity statistic and the emission factor used to determine the size of each reservoir. Although a single estimate of the reservoir is given for most of the sources considered (as opposed to a range), this is primarily due to the lack of available data upon which to calculate an estimate range. The single estimates that are reported in this inventory should not be interpreted as being the definitive PCDD and PCDF burden within these reservoirs. In general, the reservoir estimates are likely to be even more uncertain than the estimates of emissions to air and releases to land and water already presented.

Notwithstanding these uncertainties, it would appear that the reservoirs associated with the historic usage of PCP and 2,4,5-T, and with refuse within landfills, are markedly higher than the reservoirs from pulp and paper production at bleached kraft mills and the gasification of coal.

The use of PCP in the timber industry has been estimated to have led to a PCDD and PCDF input of between 1.2 – 10.2 kg I-TEQ into the New Zealand environment. Of this, only 310 g I-TEQ can be estimated as being present within contaminated soil at timber treatment sites.

Similarly, it has been estimated that between 2.71 – 3.38 kg of 2,3,7,8-TCDD has been distributed on the land surface of New Zealand from the historic use of 2,4,5-T. Over time, there will have been some loss and degradation of this contaminant, with the reservoir currently being estimated in the range 620 – 860 g 2,3,7,8-TCDD.

With the exception of reservoirs from pulp and paper production and landfills, the size of these reservoirs is not expected to increase (excluding any refinement of the current estimates). This is because both PCP and 2,4,5-T are no longer used in New Zealand, and coal gasification is no longer undertaken. In the case of pulp and paper production, the size of the reservoir has been conservatively estimated to increase at a rate of 0.56 g per year and for landfills at a rate of approximately 20 g per year (cf. Table ES.2). The magnitude of these increases assumes that there is no degradation of the PCDDs and PCDFs already present within the reservoir.

The presence of PCDDs and PCDFs in soil and sediment within the general environment also constitutes a reservoir of these contaminants. The origin of these contaminants in soil will primarily have arisen from industrial and non-industrial emissions to air (for example from waste incinerator and industrial boiler emissions, domestic fuel burning and historic leaded fuel automobile emissions) and subsequent deposition, as well as from the discharge to land of solid material containing PCDDs and PCDFs. Similarly, the origin of these contaminants in sediment will primarily have arisen from their release to water and subsequent deposition. These abiotic compartments represent diffuse reservoirs, and, as a consequence, assessing the magnitude of such reservoirs is particularly problematic. Although these reservoirs are not considered in the current inventory, their significance to the total PCDD and PCDF burden within reservoirs in New Zealand should not be underestimated.

ES.6 Conclusions

The assembly of an inventory such as this is clearly reliant on available and accurate data for emissions to air, land and water. In this context, the current assessment has estimated the total amount of PCDDs and PCDFs released to air, land and water in New Zealand in 1998 to be approximately 41 – 109 g I-TEQ.

Although this inventory contains uncertainties on the range of emissions presented, the overall and composite pattern of PCDD and PCDF emissions is believed to be accurate. This pattern indicates that industrial combustion processes, including waste incineration and landfill fires, non-industrial sources, primarily domestic wood and waste burning, and uncontrolled fires represent potentially the largest source of PCDD and PCDF emissions to air in New Zealand. Releases to land are of comparable magnitude as emissions to air, whereas releases to water are much less.

Estimating reservoir sources is problematic. Therefore only reservoirs associated with certain industrial activities have been considered, which primarily represent sites of localised contamination. Diffuse reservoirs also exist in the form of PCDDs and PCDFs bound-up within soil and sediment throughout the general environment, but these have not been considered in this inventory.

To refine the current estimates would require further assessment of individual sectors involving the collection of additional data. Better estimates from landfill fires and other uncontrolled combustion sources, domestic wood and waste burning and non-ferrous metallurgical production, are some of the more important sources where the collection of further data is warranted.

A direct comparison of the current New Zealand inventory with other country inventories is not straightforward, due to differences in the methodologies applied and variability in the characteristics of each source and industry sector assessed. Nevertheless, compared to the limited number of country studies that have been undertaken, New Zealand’s contribution to global emissions is toward the low end of the spectrum reported. In northern hemisphere countries, emissions from the industrial sector were dominant, at least before stringent emissions controls were enforced. In New Zealand, industrial and non-industrial sources contribute roughly equivalent amounts. This is consistent with the relatively modest level of industrial development in New Zealand, and consequently, non-industrial sources are not over-shadowed.

In this context, a strategy to reduce PCDD and PCDF emissions would need to address emissions from both industrial and non-industrial sources.

National environmental standards would be appropriate for controlling emissions to air and releases to land from industrial point sources such as waste incineration, wood and coal combustion, and certain manufacturing processes. The most appropriate measures to control industrial PCDD and PCDF releases to water and to minimise emissions from smaller industrial as well as non-industrial sources are less obvious and require careful consideration. In addition to a regulatory approach based on emissions limits, the need to develop and disseminate information and educational material on the sources of PCDDs and PCDFs and ways to reduce their emissions to the environment would appear to be justified.

Inherent to the planning of a PCDD and PCDF reduction strategy would be to identify means by which its effectiveness could be monitored. This could, in part, be achieved by a 5 yearly review and update of this inventory.

Whilst this inventory has been based on the assessment of emissions from individual sources, it is important to note that there is no clear evidence showing that the emissions of PCDDs and PCDFs from known sources correlate proportionally with general population exposures. Although the emissions inventory shows the relative contribution of the various sources to total emissions, it cannot be assumed that these sources make the same relative contributions to human exposures. General population exposures to PCDDs and PCDFs are primarily through the diet, and in particular from the consumption of meats, dairy products and fish. It is quite possible that the major sources of PCDDs and PCDFs in food may not be those sources that represent the largest fractions of total emissions in New Zealand as estimated in the current inventory. To better understand the potential for human exposure, the location of individual sources relative to agricultural areas also needs to be considered.

The findings of this inventory will be evaluated as part of the Organochlorines Management Plan, for which public comment will be sought during the year 2000.

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Environmental consultants
Greenpeace, representing environmental and conservation organisations
Industry and industry associations
Non-governmental organisations

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1 New Zealand Organochlorines Programme

1.1 Introduction

In 1995, the Ministry for the Environment commenced a national Organochlorines Programme to characterise the extent of contamination of the New Zealand environment by selected organochlorine contaminants, and establish risk-based environmental acceptance criteria for these substances. The organochlorines that are the focus of this programme are:

- The polychlorinated dibenzo-p-dioxins (PCDDs) and the polychlorinated dibenzofurans (PCDFs). These are often referred to generically as 'dioxins', but throughout this report, the PCDD and PCDF nomenclature is used;
- Polychlorinated biphenyls (PCBs);
- Organochlorine pesticides including DDT, aldrin, dieldrin and chlordane;
- Chlorophenols, in particular pentachlorophenol (PCP).

1.2 Scope and objectives of this inventory

To assist in the development of risk-based acceptance criteria for PCDDs and PCDFs, an estimate has been made of the current emissions to air, releases to land and water and reservoir sources of these contaminants in New Zealand. This national inventory was to be undertaken in the broadest sense possible, addressing not just industrial point source emissions, but emissions from non-industrial (effectively domestic) activity and where possible from uncontrolled activities such as natural and accidental fires.

The present study has capitalised on the experience of other countries that have undertaken countrywide estimates of PCDD and PCDF emissions. Where justified, a desk top analysis of the New Zealand scene was supplemented by the sampling and analysis of carefully selected sources, particularly in areas where the existing data were considered to be inadequate or likely to differ from other country data. From the rigorous review of these data, and by involving industry directly in the project, every effort has been made to compile a national inventory of PCDD and PCDF emissions, releases and reservoir sources that fairly reflects our best estimates. However, as with any inventory of this type, there will always be uncertainties and limitations in the results, and this must be borne in mind when interpreting the data.

The objectives of this inventory were to:

1. Estimate the ongoing PCDD and PCDF emissions to air in New Zealand;
2. Estimate the ongoing PCDD and PCDF releases to land and water in New Zealand;
3. Identify those sources considered to be most significant with respect to the magnitude of their emissions or releases, distinguishing between industrial and non-industrial sources;
4. Identify reservoir sources that may pose an ongoing risk, and estimate the quantity of PCDDs and PCDFs present within these reservoirs.
5. Detail the major uncertainties and limitations within the current inventory, and identify areas where additional data may reduce the uncertainties of the emission estimates made.

The Organochlorines Programme

The Organochlorines Programme was initiated in response to a recognition of the need to minimise industrial emissions of PCDDs and PCDFs to air and water, clean-up sites contaminated with organochlorine residues and manage the safe disposal of waste stocks of organochlorine chemicals such as the PCBs and persistent pesticides. The Organochlorines Programme is consistent with current international concerns on persistent organic pollutants (UNEP, 1997).

The Organochlorines Programme as a whole comprises the study of environmental and human levels of organochlorine substances; the development of an inventory of ongoing PCDD and PCDF emissions; and the estimation of the risk posed by these substances. The integration of these and other components of the Organochlorines Programme is shown in Figure 1.1. The outcomes from the overall programme will be:

- National environmental standards for PCDDs and PCDFs and where necessary environmental guidelines or standards for PCBs, organochlorine pesticides and chlorophenols;
- Identified clean-up technologies that can safely and effectively destroy organochlorine wastes;
- An integrated management strategy for PCDDs, PCDFs and other organochlorine contaminants and wastes in New Zealand;
- Identification of issues for the phase-out of organochlorines;
- Informed public input to Government decisions on the management of organochlorines in the New Zealand environment.

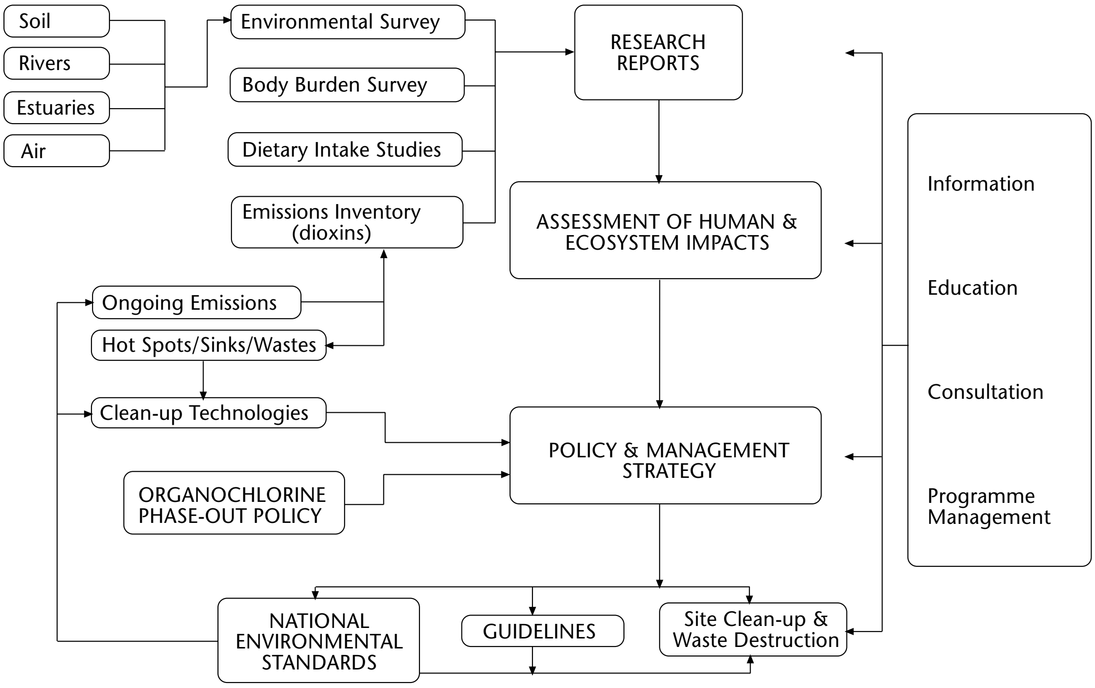


Figure 1.1 Overview of the New Zealand Organochlorines Programme

1.3 Previous New Zealand inventory

The current study is the first national assessment of PCDD and PCDF sources undertaken in New Zealand. A tentative inventory of selected sources has previously been reported, that estimated the quantities of PCDDs and PCDFs released to the environment from the following source activities (Bingham, 1992):

- Production and use of chlorinated phenols;
- Combustion of organic material;
- Bleaching of organic material with chlorine-containing oxidising agents.

Sources were ranked into the following emission bands:

"Minor"	< 2 g I-TEQ yr^{-1}
"Medium"	2 – 20 g I-TEQ yr^{-1}
"Major"	> 20 g I-TEQ yr^{-1}.

The findings reported by Bingham (1992) are detailed in the following Sections.

1.3.1 Production and use of chlorinated phenols

Pentachlorophenol

The most significant use of PCP and its sodium pentachlorophenate (NaPCP) salt was in the timber industry. Prior to 1988, the maximum annual usage of NaPCP for antisapstain control has been estimated at 200 tonnes (Shaw, 1990). The four NaPCP antisapstain formulations marketed in New Zealand were found to have an average PCDD and PCDF concentration of 0.9 mg I-TEQ kg^{-1} (Bingham, 1991). On this basis, Bingham (1992) estimated that the NaPCP formulation used in the timber industry accounted for 180 g I-TEQ yr^{-1}.

Bingham (1992) also reported that at the height of its use, application of PCP as a permanent preservative probably occurred at a rate of 100 tonnes per year, and therefore estimated that this source would account for 90 g I-TEQ yr^{-1}. On this basis, Bingham (1992) ranked PCP and NaPCP use in the timber industry as a "major" source of PCDDs and PCDFs. An estimation of reservoir sources at contaminated timber treatment sites is presented in Section 30 of this report.

The non-timber related applications of PCP/NaPCP have been reviewed by Shaw (1990). This report identifies PCP use in New Zealand in the following areas:

- As a slimicide in pulp and paper production. Shaw (1990) noted that this practice had ceased some 10 years previously;
- For the control of algae and moss;
- As a soil and timber sterilant in mushroom culture.

Bingham (1992) estimated that 0.43 tonnes of PCP was used on an annual basis for the control of algae and moss. On the basis of a PCDD and PCDF concentration for one mossicide formulation of 0.92 mg kg^{-1}, the release from this source was estimated as 0.4 g I-TEQ yr^{-1}. Similarly, a conservative estimate of mushroom industry usage was given as 2 tonnes per year. Assuming the NaPCP formulation was the same as that used in the timber industry (0.9 mg I-TEQ kg^{-1}), Bingham

(1992) estimated the contribution from this source as 1.8 g I-TEQ yr^{-1}. Collectively, NaPCP use as a mossicide and soil and timber sterilant in the mushroom industry were ranked as a “minor” source of PCDDs and PCDFs (Bingham, 1992).

2,4,5-Trichlorophenoxyacetic acid

During the period of 2,4,5-T manufacture in New Zealand, a high temperature liquid waste incinerator was operated at the manufacturing site. From 1975 to 1979, 538 tonnes of waste containing about 5.7 kg of TCDD (2,3,7,8-TCDD and other congeners) was destroyed on site. Based on routine stack monitoring, the mass emissions to air were estimated at less than 1.2 g TCDD over this 3½ year period, or < 0.34 g TCDD yr^{-1} (Pilgrim *et al.*, 1990). From April to August 1985, 56.5 tonnes of liquid waste containing 71.8 g of TCDD was incinerated. The mass emission to air was estimated at less than 0.017 g (Pilgrim *et al.*, 1990). This liquid waste incinerator no longer operates.

A solid waste incinerator was installed at the site in 1981. During the period July 1983 to March 1986, it has been estimated that the total mass of TCDD emitted to air from this incinerator was 0.0082 g for the 1,887 hours of incinerator operation (Pilgrim *et al.*, 1990). Current emissions from the operation of this solid waste incinerator are presented in Section 5 of this report.

1.3.2 Combustion of organic materials

From PCDD and PCDF measurements undertaken at two regional waste incineration facilities and one hospital incinerator, emissions to air of 0.94 g I-TEQ yr^{-1} were estimated for these three facilities. On the basis of this data, Bingham (1992) estimated that medical and quarantine waste incineration was a “medium” source of PCDDs and PCDFs in New Zealand. Current emissions from clinical, pathological and quarantine waste incineration are presented in Section 4 of this report.

A vehicle study undertaken in New Zealand determined an emission factor of 39 pg I-TEQ km^{-1} for a car fuelled on leaded petrol and driven through a standard urban driving cycle (Bingham *et al.*, 1989a,b; Bingham, 1992). Assuming similar emissions for all cars in New Zealand, Bingham (1992) estimated the total emissions to be approximately 5 g I-TEQ yr^{-1}. Motor vehicle emissions were assigned a “medium” ranking. Current emissions from land transport are presented in Section 15 of this report.

The Bingham (1992) inventory also considered PCDD and PCDF emissions from New Zealand’s only base-load coal fired power station. It ranked coal combustion for electricity generation as a “minor” source of PCDDs and PCDFs in New Zealand. Current emissions from coal fired power generation are presented in Section 9 of this report.

Miscellaneous combustion sources, such as domestic waste burning, bonfires, backyard incineration, coal and wood fuelled domestic fires and stoves, and burn-offs of forest and scrub were all identified as likely PCDD and PCDF emission sources (Bingham, 1992). Similarly, based on overseas data, the metallurgical industry, in particular metal reclamation and scrap steel furnaces were noted as being potential major sources. Although there were insufficient data at the time to make a detailed estimate, Bingham (1992) ranked miscellaneous combustion processes as “probably a major source” in New Zealand.

1.3.3 Bleaching of organic material with chlorine-containing oxidising agents

Bleached kraft pulp production was by far the principal source of PCDDs and PCDFs in New Zealand arising from the use of chlorine-containing oxidising agents (Bingham, 1992). Based on a study of these contaminants in effluent from one kraft mill (Campin *et al.*, 1991), the bleaching of wood pulp was ranked as a "medium" source of PCDDs and PCDFs.

1.4 Content of this report

The remainder of this report is structured as follows:

Section 2 provides some background information on PCDDs and PCDFs, including information on their toxicity and sources, as well as standard means of reporting PCDD and PCDF concentrations through the use of toxic equivalent factors.

Section 3 provides details on the methodology followed for this inventory.

Sections 4 to 31 report the derivation of annual estimates of PCDD and PCDF emissions to air, releases to land and water and PCDD and PCDF reservoirs for individual processes/activities. These sources are presented in order of the following categories:

1. Incineration and combustion processes;
2. Manufacturing and production processes;
3. Miscellaneous current day activities;
4. Historic activities that constitute reservoir sources.

Section 32 presents a summary of the PCDD and PCDF annual emission estimates made. Here data are tabulated for emissions to air, land and water and reservoir sources on a sector by sector basis. The activity statistic and emission factors that were used to derive each emission estimate are also tabulated to allow for a rapid appraisal of the data.

Section 33 compares the New Zealand inventory estimates with data from other countrywide inventories that have been reported.

Section 34 appraises the uncertainties and data gaps within the current study.

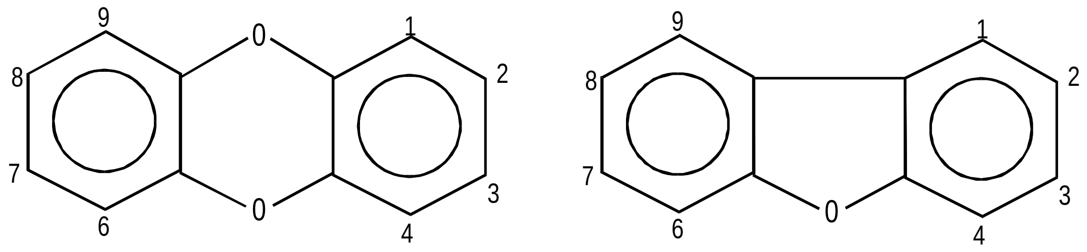
Section 35 lists the units and abbreviations used.

Section 36 lists the references cited in this report.

2 Background information on PCDDs and PCDFs

2.1 Structure and composition

The PCDDs and PCDFs are two groups of aromatic compounds having the basic structures shown in Figure 2.1.



Dibenzo-p-dioxin

Dibenzofuran

Figure 2.1 Structures of dibenzo-p-dioxin and dibenzofuran

Both groups of chemicals may have up to eight chlorine atoms attached at carbon atoms 1 to 4 and 6 to 9. Each individual compound resulting from this is referred to as a congener. Each specific congener is distinguished by the number and position of chlorine atoms around the aromatic nucleus. In total, there are 75 possible PCDD congeners and 135 possible PCDF congeners. Groups of congeners with the same number of chlorine atoms are known as homologues. The number of congeners in each homologue group is shown in Table 2.1.

2.2 Toxicity

Congeners containing 1, 2 or 3 chlorine atoms are thought to be of no toxicological significance. However, the 17 congeners with chlorine atoms substituted in the 2,3,7,8-positions are thought to pose a risk to human and environmental health. Toxic responses include dermal toxicity, immunotoxicity, carcinogenicity, and adverse effects on reproduction, development and endocrine functions. Of the 17 congeners, the most toxic, and widely studied, congener is 2,3,7,8-TCDD. Increasing substitution from 4 to 8 chlorine atoms generally results in a marked decrease in potency.

Toxic equivalents

In environmental media, the PCDDs and PCDFs occur as complex mixtures of congeners. To enable a complex, multivariate dataset to be reduced to a single number, a system of toxic equivalents (TEQs) has been developed. The toxic equivalents method is based on the available toxicological and *in vitro* biological data, and knowledge of structural similarities among the PCDDs and PCDFs, to generate a set of weighting factors, each of which expresses the toxicity of a particular PCDD or PCDF congener in terms of an equivalent amount of 2,3,7,8-TCDD. Multiplication of the concentration of a PCDD or PCDF congener by this toxic equivalents factor (TEF) gives a corresponding 2,3,7,8-TCDD TEQ concentration. The toxicity of any mixture of PCDDs and PCDFs, expressed as 2,3,7,8-TCDD, is derived by summation of the individual TEQ concentrations. This is reported as the ‘Total TEQ’ for a mixture.

Table 2.1 Homologues and congeners of PCDDs and PCDFs

Abbreviation	Homologue name	No. of possible congeners	No. of possible 2,3,7,8-chlorinated congeners
MCDD	Monochlorodibenzo-p-dioxin	2	0
DiCDD	Dichlorodibenzo-p-dioxin	10	0
TrCDD	Trichlorodibenzo-p-dioxin	14	0
TCDD	Tetrachlorodibenzo-p-dioxin	22	1
PeCDD	Pentachlorodibenzo-p-dioxin	14	1
HxCDD	Hexachlorodibenzo-p-dioxin	10	3
HpCDD	Heptachlorodibenzo-p-dioxin	2	1
OCDD	Octachlorodibenzo-p-dioxin	1	1
MCDF	Monochlorodibenzofuran	4	0
DiCDF	Dichlorodibenzofuran	16	0
TrCDF	Trichlorodibenzofuran	28	0
TCDF	Tetrachlorodibenzofuran	38	1
PeCDF	Pentachlorodibenzofuran	28	2
HxCDF	Hexachlorodibenzofuran	16	4
HpCDF	Heptachlorodibenzofuran	4	2
OCDF	Octachlorodibenzofuran	1	1

Although a number of toxic equivalents schemes have been developed, the most widely adopted system to date is that proposed by the North Atlantic Treaty Organization, Committee on Challenges to Modern Society (NATO/CCMS), known as the International Toxic Equivalents Factor (I-TEF) scheme (Kutz *et al*., 1990). This approach assigns a TEF to each of the 17 toxic 2,3,7,8-chlorinated PCDDs and PCDFs (Table 2.2). The remaining non 2,3,7,8-chlorinated congeners are considered biologically inactive and are assigned a TEF of zero.

Table 2.2 Toxic equivalents factors for PCDDs and PCDFs

PCDD and PCDF congener	I-TEF (Kutz *et al*., 1990)	WHO-TEF (humans/mammals) (Van den Berg *et al*., 1998)
2,3,7,8-TCDD	1	1
1,2,3,7,8-PeCDD	0.5	1
1,2,3,4,7,8-HxCDD	0.1	0.1
1,2,3,6,7,8-HxCDD	0.1	0.1
1,2,3,7,8,9-HxCDD	0.1	0.1
1,2,3,4,6,7,8-HpCDD	0.01	0.01
OCDD	0.001	0.0001
2,3,7,8-TCDF	0.1	0.1
1,2,3,7,8-PeCDF	0.05	0.05
2,3,4,7,8-PeCDF	0.5	0.5
1,2,3,4,7,8-HxCDF	0.1	0.1
1,2,3,6,7,8-HxCDF	0.1	0.1
2,3,4,6,7,8-HxCDF	0.1	0.1
1,2,3,7,8,9-HxCDF	0.1	0.1
1,2,3,4,6,7,8-HpCDF	0.01	0.01
1,2,3,4,7,8,9-HpCDF	0.01	0.01
OCDF	0.001	0.0001

The I-TEF scheme has recently been revised and expanded through the auspices of the World Health Organization (WHO) to provide TEF values for humans and wildlife (Van den Berg *et al*., 1998). Thus WHO-TEFs are now available for humans/mammals (Table 2.2), fish and birds.

2.3 Sources

PCDDs and PCDFs are not produced intentionally, but are released to the environment from a variety of industrial discharges, combustion processes and as a result of their occurrence as unwanted by-products in various chlorinated chemical formulations.

Historically the manufacture and use of chlorinated aromatic chemicals have been major sources of PCDDs and PCDFs in the environment. Most notable examples include the wood preservative and biocide PCP, 2,4,5-trichlorophenoxy acetic acid (2,4,5-T) and the PCBs.

Other processes, such as the production of chlorine-bleached pulp, have led to environmental contamination by PCDDs and PCDFs, as well as the trace contamination of pulp and paper products.

Combustion processes are recognised as being another important source of PCDDs and PCDFs. Most thermal reactions which involve the burning of chlorinated organic or inorganic compounds appear to result in the formation of these substances. PCDDs and PCDFs have been detected in emissions from the incineration of various types of wastes, particularly municipal, medical and hazardous wastes, from the production of iron and steel and other metals, including scrap metal reclamation, from fossil fuel plants, domestic coal and wood fires, and automobile engines (especially when using leaded fuels) as well as accidental fires. An extensive review of PCDD and PCDF sources has been published by Fiedler *et al*. (1990), and more recently by the United States Environmental Protection Agency (US EPA, 1998).

Although natural, non-anthropogenic, combustion sources (like forest fires) have probably always been a source of PCDDs and PCDFs, the background levels associated with the pre-industrial processes (before the 1930s/1940s) are found to be negligible when compared to those resulting from more recent industrial activities (Kjeller *et al*., 1991; Beurskens *et al*., 1993; Jones and Alcock, 1996).

Tighter Government regulations, improved industrial processes and the use of modern pollution control equipment have resulted in a lowering of PCDD and PCDF emissions from known industrial sources in many countries. However, it is unlikely that a complete elimination of these contaminants will be possible due to uncontrolled releases, such as forest fires and other accidental fires.

2.4 Countrywide inventories

A number of countries have reported countrywide inventories for PCDDs and PCDFs, primarily for emissions to air, but also, in a few cases, releases to land and water. These include inventories for European countries, reviewed by LUA (1997), Canada (Environment Canada, 1999), the United States (US EPA, 1998), Japan (Hiraoka and Okajima, 1994; MITI, 1998) and Australia (EPG, 1998). Some of these inventories are discussed further in Section 33 in a comparison with the inventory data from the current study.

A summary of countrywide inventories has recently been published (UNEP, 1999).

3 Assessment of PCDD and PCDF sources

PCDDs and PCDFs may be released directly to air, land or water from industrial and non-industrial activities, as well as natural events such as forest fires. They may also be present in products or materials, including waste materials, and enter the environment during the use and/or disposal of these materials.

This project was designed to quantify releases of PCDDs and PCDFs to all environmental media and to examine the issue of reservoir sources. The relative contribution of the different sources to the exposure of a population or ecosystem is not necessarily indicated by the simple source strength, as the fate and behaviour of PCDDs and PCDFs in the environment plays a very important role in mediating between releases and exposure.

In aiming to reduce general population exposures, most attention has historically focused on controlling levels of PCDDs and PCDFs released from the use of chlorinated chemicals (such as PCP and 2,4,5-T) and on controlling releases to air and water. Direct releases to land and into landfills are generally thought to contribute much less to exposure.

3.1 Methodology

The methodology followed in this inventory was typical of other inventory compilations for these compounds and was based on the emission factor approach. To estimate annual emissions from a source, an activity statistic is generated and multiplied by an emissions factor.

Annual emission (g TEQ yr^{-1}) = Activity (tonne yr^{-1}) x Emission factor (g TEQ $tonne^{-1}$)

Activity statistics are chosen that relate to the throughput of fuel, the tonnes of material manufactured or a similar measure, and an emission factor is generated that shows average emissions (to air, land or water) per unit of activity. For any source that may be characterised by a large number of (often small) emitters, the activities of the individual emitters are grouped into a single source category, and an activity statistic is applied across the group.

It should be noted that in an inventory of this nature, there is considerable uncertainty in the factors controlling emission of PCDDs and PCDFs and great variation can be found in emission factors depending on a number of features of the processes of interest. Implicit in the activity statistic approach, and the grouping of source categories, is the assumption that facilities with similar design and operating conditions should have similar PCDD and PCDF release potential. This, however, is not always the case. A range of emission factors can therefore be used to indicate some of the variation expected, and certainty rankings can be applied to indicate the certainty of any estimate made. This is discussed further in Section 3.3.

The compilation of the inventory was carried out in three phases, namely:

Phase I	A desk top study to assess emissions based on currently available data;
Phase II	A limited source testing programme to provide additional data;
Phase III	The development of a national inventory of PCDD and PCDF emissions from Phases I and II.

3.1.1 Phase I

Phase I comprised a desktop study to:

1. Identify potential PCDD and PCDF emission sources in New Zealand. This was to include a consideration of industrial, non-industrial and natural sources, as well as environmental reservoirs such as waste dumps, landfills and contaminated soils;
2. Collect and collate existing available PCDD and PCDF emission data;
3. Derive an appropriate (interim) PCDD and PCDF emission factor from international data;
4. Estimate, where possible, the national PCDD and PCDF emissions from each source, using the emission factor;
5. Rank each PCDD and PCDF source according to likely mass emissions and/or significance. The ranking should include the number of operations in New Zealand, the PCDD and PCDF emission potential, and whether the New Zealand discharges were likely to be significantly different from overseas discharges.

The basic outline for the project was modelled on the inventory studies carried out in the United Kingdom for emissions to air (HMIP, 1995) and releases to land and water (Environment Agency, 1997). The initial screening of potential processes for assessment was based on those processes reported in the United Kingdom studies. Incorporating local specialist knowledge to reflect local circumstances ensured that emissions and releases were only calculated for those activities carried out in New Zealand. For example, municipal waste incineration in poorly controlled and operated combustors has been identified internationally as a major source of PCDDs and PCDFs. However, there are no municipal waste incinerators that operate in New Zealand. Similarly, other international inventories generally cover emissions from industries such as chlorine and vinyl chloride production as well as pesticide production. Vinyl chloride is not manufactured in New Zealand, nor does any pesticide manufacturing occur. These processes have therefore not been included in this New Zealand inventory.

On completion of the Phase I report a peer review was carried out to access industry and other stakeholder expertise and also to involve international expertise. This ensured that the report reflected current practice in New Zealand and also had the benefit of recent developments in the science and in particular in the generation of emissions factors that might be appropriate in a New Zealand setting.

3.1.2 Phase II

Phase II of the study was to carry out testing for those sources it was considered important to quantify but for which no or minimal New Zealand data were available. The sources were selected drawing on the results of the ranking process from Phase I, the peer review and other input from stakeholders.

3.1.3 Phase III

In this report, which comprises Phase III of the study, the data from Phase I and Phase II have been brought together and a national inventory has been developed. The inventory is presented process by process, with emissions to air, releases to land and water, and reservoirs for each process/activity presented in individual sections of the report.

The emission factors used to derive the national inventory are based on either test results carried out in New Zealand (either as part of Phase II or already existing New Zealand data) or factors reported in the literature from international studies. This is discussed further in Section 3.3. The derivation of the appropriate emission factor is described in each section.

3.2 PCDD and PCDF emissions and releases

3.2.1 Emissions to air

PCDDs and PCDFs may be emitted to air by a number of processes. As noted in Section 2.3, important sources include the incineration of wastes, thermal processing of metals and combustion of fuels. Releases due to evaporation are not generally assessed as part of an inventory study.

The formation of PCDDs and PCDFs in thermal processes is complex and many factors are important. The material being burned, the combustion conditions, the composition of the particulates generated and the design and operation of boilers and pollution controls can all exert a large influence over the formation of PCDDs and PCDFs. The final emissions may be strongly influenced by the "end-of-pipe" pollution control system that may capture or destroy PCDDs and PCDFs. The control of emissions from waste incineration processes has been well studied and excellent control can be achieved. Releases from other processes have been less intensely studied but effective controls are becoming available. For any generic thermal process or fuel type there will be a wide range of PCDD and PCDF emissions.

Emissions to air can also occur when contaminated sites are subject to scouring by wind and material is carried off-site. Information is not available on the significance of this in New Zealand, and this is not assessed in the inventory.

Use of fuel consumption data

Discharges to air from most large industrial operations are characterised through a direct approach to determine fuel use, operation time and other parameters to give an estimate of actual emissions. For New Zealand, one of the largest contributor groups (in terms of the number of discharges) was the small to medium sized boilers. In many cases, while there were no data available on the number or sizes of these sources, fuel consumption data was available. Pro-rating of data from existing inventories and other available survey data provided a basis for establishing the fuel use in these units, and hence the emissions, on a national basis.

Domestic combustion sources were also difficult to quantify in the New Zealand context. Similarly, however, detailed fuel consumption information was available for New Zealand's largest (Auckland) and third largest (Christchurch) cities. These data were extrapolated to other centres, with appropriate correction factors to account for the different heating patterns for each region. As a check, the total estimated fuel consumption was available from the Ministry of Commerce.

3.2.2 Releases to land and water

A large number of industrial and non-industrial processes are thought to release PCDDs and PCDFs to land or water (Environment Agency, 1997).

There is a concern when considering releases to land and water that there will be "double counting" of some PCDDs and PCDFs. For example, some PCDDs and PCDFs present in a stormwater discharge or in domestic refuse are likely to have come from an air emission source and the stormwater or refuse simply accumulates them and is a transport vector. At times there is no way of identifying the original source of the PCDDs and PCDFs. For the purposes of the inventory this was not problematic since the task was to identify direct releases to the environment and not to assess pathways and fate.

In the case of stormwater, because this medium was considered to be a transport mechanism rather than a PCDD and PCDF source per se, estimates of its PCDD and PCDF loadings have not been included in this inventory.

There have been few attempts overseas to quantify releases to land and water and the uncertainty is even greater than that for emissions to air. This should be borne in mind when considering the results of this inventory.

3.2.3 Reservoirs

Reservoirs are materials or places that contain previously formed PCDDs and PCDFs. The inventory considers only reservoirs from certain industrial activities. These generally represent sites of localised contamination in which the levels of PCDDs and PCDFs are elevated compared to typical ‘background’ levels that might be found in the wider general environment. For such reservoirs, there is the potential for the redistribution and circulation of the contaminants into the wider environment to occur. While the potential exposure pathways and the resulting environmental significance of these reservoir sources are uncertain, they can pose an ongoing risk to the environment and to human health.

In addition, the presence of PCDDs and PCDFs bound within soils and sediments throughout the general environment may be considered a diffuse reservoir. However, no estimate is made of the magnitude of these reservoirs in the current study.

3.3 Uncertainty

For many of the major industries in New Zealand, there is a reasonable amount of data available on PCDD and PCDF emissions to air. Much less data are, however, available for these industries on concentrations in solid or liquid waste streams that may be released to land or water. For the majority of the smaller industrial plants, there are almost no PCDD and PCDF data available for any of the process streams. This lack of industry or process specific data is problematic in trying to derive a national emission estimate for a particular source. A further uncertainty is that, for some industrial processes, a wide range of equipment is in use, operating with varying inputs and in a range of operating conditions. As a consequence, in many instances it is not possible to reliably predict the emissions from different plant configurations and operational conditions. However, activity/production data are almost always available and are generally of good quality.

For non-industrial sources, there is considerable difficulty in estimating emissions due to the lack of data, the widely varying conditions and the uncontrolled nature of these emissions. Activity statistics for such processes are also imperfect, and are often derived from secondary indicators.

3.3.1 New Zealand specific data and international data

For each source category, representative emission factors were sought using New Zealand specific data and international emission data. As noted previously, emission testing as part of Phase II (primarily on air discharges) was carried out for those sources it was considered important to quantify but for which no or minimal New Zealand data were available. In general, for those sources where the New Zealand data were limited but for which there was consistency between these data and the international emission factors, then the international emission factors were used to derive an annual emission estimate. The reasoning behind this was that it was considered the international data would be more representative of the diversity of operational facilities within that sector than test data from a limited number of sources.

The exception to this approach was where:

1. There were only a few processes within a specific industry sector (e.g. hazardous waste incineration [1 plant], coal combustion at power stations [1 plant], cement manufacturing [2 major plants], primary steel production [1 plant], secondary steel production [1 plant] and bleached kraft pulp production [2 plants]), and reliable New Zealand emission test data were available, or
2. Most of the activity occurred at a few major facilities (e.g. clinical, pathological and quarantine waste incineration) and reliable New Zealand emission test data were available.

In these instances, the New Zealand emission factors have been used to calculate the annual PCDD and PCDF emissions. For other activities, including estimating releases from landfills and wastewater treatment, and reservoirs from the historic use of PCP and 2,4,5-T, New Zealand specific data have also been used.

The principal sources of international data on emissions of PCDDs and PCDFs that were used in this inventory were:

- *A Review of Dioxin Emission in the UK* (HMIP, 1995), referred to herein as the **UK Review**, which addressed emissions to air. The emission factors used in the UK Review were based on a wide range of sources including extensive surveys conducted in Europe and information from around the world. This reference provided a useful compilation of emission factors for known sources in the mid 1990s;
- *A Review of Dioxin Releases to Land and Water in the UK* (Environment Agency, 1997), referred to herein as the **UK Land and Water Review**, which focussed primarily on releases to land and water;
- *The Inventory of Dioxin Sources in the United States* (US EPA, 1998), referred to herein as the **US Inventory**, which focussed primarily on emissions to air. This draft report provided an extensive review of available emission factors.

The derivation of the emission factors used to calculate an annual estimate of releases for each source is described in the relevant sections.

3.3.2 Range of emission factors used

Since the factors influencing the emissions from particular processes are complex and emissions vary considerably, it was deemed potentially misleading to derive single values for annual releases. Wherever possible, a range of estimated releases was therefore calculated using a range of emission factors. The application of a range of emission factors is consistent with other countrywide inventories, such as that reported in the UK Review. This inventory identified a range of measured emission factors, frequently spanning an order of magnitude. The presentation of a range of emissions is also consistent with the objectives of the current study.

3.3.3 Certainty rankings

No source considered in this inventory has been comprehensively studied (e.g. had its emissions measured under all conditions over an extended period) and therefore all estimates made are subject to uncertainty. This uncertainty will apply to both the activity statistic and the emission factor used to derive the estimate of emissions. To provide a qualitative indication of the certainty of each estimate, the following certainty rankings have been assigned:

‘High’ certainty (H)

‘Medium’ certainty (M)

‘Low’ certainty (L)

The certainty ranking is assigned on the basis of available data, including a consideration of data quality, expert judgement and knowledge of the industry sectors and a broad knowledge of emission factors. In addition, the following general principles were adopted:

Activity statistic

- If the statistic was actual industry-compiled data (e.g. the amount of waste burnt, or product manufactured), or was derived from comprehensive surveys, an ‘H’ certainty ranking was assigned;
- If limited industry or survey data were available, or the data were modified to account for confounding factors, then an ‘M’ certainty ranking was applied;
- If there was no data available, and the level of activity was based on expert judgement and/or modelled data, then an ‘L’ certainty ranking was assigned.

Emission factor

- If extensive industry specific New Zealand emission monitoring data were available to derive emission factors, an ‘H’ certainty ranking was assigned;
- If a limited amount of New Zealand emission monitoring data was available, and the emission factors derived compare well with overseas emission factors, an ‘M’ certainty ranking was assigned;
- If there were no New Zealand emission monitoring data available, and the estimate of PCDD and PCDF emissions was based solely on overseas emission factors, then an ‘L’ certainty was assigned.

3.4 Units

Units of µg TEQ tonne^{-1} have been used for air emission factors, and (in general) ng TEQ kg^{-1} or pg TEQ L^{-1} have been used for land and water release factors or concentrations.

3.4.1 Toxic equivalents

All New Zealand specific PCDD and PCDF data presented in this inventory is reported as I-TEQ. Similarly, emission factors or media concentrations that were taken from the UK Review and the US Inventory were, for the most part, reported as I-TEQ. Therefore, throughout this inventory, all annual emission estimates made can be read as being I-TEQ unless otherwise stated.

3.4.2 Detection limits

When PCDD and PCDF measurements are carried out, there will be some cases where concentrations are below the analytical detection limits. In these cases three approaches may be taken to express a toxic equivalents result, namely:

- The non-detected values can be assumed to be present at the detection limit (ND=DL);
- The non-detected values can be assumed not to be present (i.e. their concentration is zero, [ND=0]);
- A value is set in between ND=DL and ND=0. Often this involves setting non-detect measurements to half the detection limit to avoid being over cautious (ND=DL) or potentially complacent (ND=0).

For data reported in the literature, it is often not clear what practice has been used to generate toxic equivalent results. Whilst this may contribute to the uncertainty in the estimates made, in many situations this is not critical, as most of the total toxic equivalents for a source is derived from measured PCDDs and PCDFs, with the non-detected PCDD and PCDF congeners contributing only a small fraction, if any, of the toxic equivalents. This is particularly the case with emissions to air, for example with waste incinerator emissions, or residues in solid wastes, for example ashes and sludges. For aqueous discharges, however, such as pulp and paper mill effluent, the non-detected values can contribute a significant portion of the total toxic equivalents.

For all New Zealand test data, including industry held data and the data obtained as part of Phase II, toxic equivalent levels and the resultant annual emission estimates are reported with non-detected values for PCDD and PCDF congeners having been set to half the detection limit.

3.5 Reference date

The reference date for this inventory is taken as the 1998 calendar year. The following, however, should be noted:

1. For a few sources, activity statistic data were not available for the reference year. To enable emission estimates to be made, the most recently available data from preceding years were therefore taken, and assumed to be representative of the source activity in 1998. For most PCDD and PCDF sources considered in this inventory, this is not likely to result in any increased uncertainty in the emission estimates made.
2. For the New Zealand emission factor data, concentrations of PCDDs and PCDFs in emissions to air and levels in solid and aqueous releases to land and water were primarily for samples collected between 1994 and 1999. Concentration data for a very few samples were collected prior to this. All Phase II sampling and analysis was undertaken in 1998.

   It is assumed that these concentration data reflect the current level of emissions to air and releases to land and water. However, it is recognised that the older the data, the more invalid this assumption may be, and therefore the greater the uncertainty in the emission estimates made. As a consequence, greater emphasis has been placed on the use of the most currently available New Zealand data and, in the case of overseas emission factors, the most recently published data in the international literature.
3. More recent information is continually becoming available on activity statistics. For example, the 1998/99 National Landfill Census is shortly to be published by the Ministry for

the Environment. This will provide more up to date data on landfill activities (such as the number of operational landfills, the quantities of waste landfilled and the frequency of landfill fires) with which to assess PCDD and PCDF emissions and releases associated with landfill operations in New Zealand. Similarly, additional emission factors will continue to become available, both in New Zealand and internationally. This inventory should therefore be periodically updated on the basis of additional data becoming available.

3.6 Consultation

The study was conducted in a way that ensured the active participation of all the stakeholder groups. For the Organochlorines Programme, the Ministry for the Environment has established a Consultative Group consisting of representatives from central and local government, industry, professional bodies, and environment and conservation groups. Regular meetings and briefings were held with the Consultative Group throughout the duration of this particular study.

In addition, a meeting of all representatives from industry sectors covered in this inventory, including representatives from the waste incineration, metallurgical, pulp and paper, timber, wastewater treatment and landfill sectors, was held early on in the process. Subsequent follow-up meetings and discussions were held with each industry sector on a one on one basis.

As part of their active environmental management programmes, many of New Zealand’s major industries already monitor their processes for PCDDs and PCDFs. Such industries therefore hold considerable data on PCDD and PCDF concentrations in their emissions to air and releases to land and water. The consultation programme that was followed for this inventory, and the inclusive approach for the participation of industry, has enabled private data held by industry to be made available to the current study. In addition, this consultation has ensured that, where available, accurate and reliable activity statistics (e.g. production data, fuel use etc.) have been used to derive the annual emission estimates.

4 Clinical, pathological and quarantine waste incineration

4.1 Emissions to air

By international standards, there are no large-scale incinerators in New Zealand. There are, however, known to be 24 smaller incinerators currently in operation, most of which burn a combination of general hospital waste along with pathological and quarantine waste. Because of the range of wastes that these incinerators handle, there has been no further separation into more specific waste categories for the purpose of deriving emission estimates.

The majority of the New Zealand incinerators have capacities between 100 – 500 kg hr^{-1}. Two incinerators have capacities approaching 1,000 kg hr^{-1}. The total quantity of waste incinerated in 1998 was approximately 13,000 tonnes, of which 9,200 tonnes was incinerated in five regional facilities.

Since the mid 1990s, extensive PCDD and PCDF emission testing has been undertaken on the five larger incinerators that act as regional facilities for the disposal of waste. All five incinerators have both primary and secondary combustion chambers. The two largest units (1,000 and 750 kg hr^{-1} capacity) have gas scrubbing equipment, and reported stack emission concentrations of 0.040 – 0.070 ng I-TEQ Nm^{-3} (10% oxygen) and 1.4 – 13.7 ng I-TEQ Sm^{-3}. These correspond to emission factors of 0.37 – 0.58 µg I-TEQ $tonne^{-1}$ and 16.6 – 164 µg I-TEQ $tonne^{-1}$ respectively. The other three units (300 – 500 kg hr^{-1} capacity), which do not have any gas scrubbing, reported stack emission concentrations of 0.73 – 51.4 ng I-TEQ Sm^{-3}, 3.4 – 5.2 ng I-TEQ Sm^{-3} and 1.5 – 13.4 ng I-TEQ Sm^{-3}. These correspond to emission factors of 35.0 – 617 µg I-TEQ $tonne^{-1}$, 40.6 – 62.5 µg I-TEQ $tonne^{-1}$ and 17.4 – 161 µg I-TEQ $tonne^{-1}$ respectively. Over all five incinerators, the emission factors ranged from 0.37 – 617 µg I-TEQ $tonne^{-1}$. These emission factors are comparable to the ranges derived by the UK Review of 20 – 200 µg I-TEQ $tonne^{-1}$ for a "new" plant and 120 – 480 µg I-TEQ $tonne^{-1}$ for an "old" plant (HMIP, 1995). Annual PCDD and PCDF emissions from each of these incinerators were assessed separately, as shown in Table 4.1. The total emission from the five regional incinerators is estimated to be in the range 0.14 – 1.2 g I-TEQ yr^{-1}.

The remaining 19 incinerators, which are primarily dual chambered units, vary in size between 10 – 500 kg hr^{-1}, and collectively dispose of about 3,800 tonnes of waste per year. The effectiveness of the after burner on these facilities is considered to be highly variable. For some of the smaller units, reliable annual throughput data were not available, and therefore an estimation of throughput was made from the nominal capacity by assuming a 40 hour week, 50 week per year operation.

No PCDD or PCDF emission data are available for these 19 incinerators. Because they are typically older style units that have poor emission controls and/or are assumed to be less well operated, an emission factor range of 62.5 – 617 µg I-TEQ $tonne^{-1}$, based on the top end emission factors from the New Zealand test data for plants without gas scrubbing, has been used. On this basis, the total emission from the incinerators without measured PCDD and PCDF data is estimated to be in the range 0.24 – 2.3 g I-TEQ yr^{-1}.

National emission estimate

PCDD and PCDF emissions from the incineration of clinical, pathological and quarantine waste are summarised in Table 4.1. The total annual emission from this source is estimated to be in the range 0.38 – 3.5 g I-TEQ yr^{-1}.

Table 4.1 PCDD and PCDF emissions from clinical, pathological and quarantine waste incineration

Source	Waste incinerated (tonne yr^{-1})	Emission factor (µg I-TEQ $tonne^{-1}$)	Annual emission range (g I-TEQ yr^{-1})
Incinerators with measured emissions			
Incinerator A (with gas scrubbing)	4,000	0.37 – 0.58	0.0015 – 0.0023
Incinerator B (with gas scrubbing)	2,500	16.6 – 164	0.042 – 0.41
Incinerator C (without gas scrubbing)	950	35.0 – 617	0.033 – 0.59
Incinerator D (without gas scrubbing)	1,250	40.6 – 62.5	0.051 – 0.078
Incinerator E (without gas scrubbing)	500	17.4 – 161	0.0087 – 0.081
Incinerators without measured emissions	3,800	62.5 – 617	0.24 – 2.3
Total	13,000		0.38 – 3.5

In comparison with this current estimate, a previous study has ranked medical and quarantine waste incinerators as a medium (2 – 20 g I-TEQ yr^{-1}) source of PCDDs and PCDFs in New Zealand (Bingham, 1992). However, since this earlier study, many of the old hospital waste incinerators have ceased operation, with the waste now being incinerated in regional facilities. These are the facilities for which measured emission data are available, and which have been used in this inventory. The 1998 estimate of emissions would therefore be expected to be at the bottom end of, or lower than, the estimate made by Bingham (1992), as the current study shows. However, it should be noted that the total quantity of waste that is now incinerated is thought to be markedly greater than the waste quantities incinerated in the early 1990s.

Certainty

Activity statistic	M
Emission factor	M

The activity statistic is assigned a 'medium' certainty ranking because there is uncertainty over the quantity of wastes burned in the smaller incinerators. The emission factor is assigned a 'medium' certainty ranking because emission measurements have been undertaken on the larger regional incinerators, but none on the smaller plants that combust about a third of the total volume of clinical, pathological and quarantine waste incinerated in New Zealand.

4.2 Releases to land

Of the 24 waste incinerators burning clinical, pathological and quarantine waste, only two have emission control equipment. One facility (Incinerator A in Table 4.1) has a water based quench cooler followed by activated carbon and lime injection, then a fabric filter. The second facility (Incinerator B) has a gas to air heat exchanger, activated carbon and lime injection, fabric filter, quench cooler with a wet absorption tower. Collectively, these two incinerators burn approximately 6,500 tonnes per year. Using United Kingdom figures for scrubber residues per tonne of waste (40 kg $tonne^{-1}$ for wet scrubbers and 80 kg $tonne^{-1}$ for dry scrubbers; Environment Agency, 1997), a combined solids and sludge production of 90 kg dry weight (DW) $tonne^{-1}$ of waste was assumed (assuming that most solid matter is collected in the dry part). For all plants, a grate ash rate of 150 kg tonne^{-1} was assumed (Environment Agency, 1997). For the 22 incinerators with no gas scrubbing, there are no other ash streams produced.

There are no New Zealand data for PCDDs and PCDFs in grate ash, although industry data for a plant that operates in the United Kingdom and that has a system almost identical to one of the larger New Zealand incinerators (Incinerator B in Table 4.1) reported a concentration of 4,000 ng I-TEQ kg^{-1}. The UK Land and Water Review quotes a range of 15 – 300 ng I-TEQ kg^{-1} for grate ash. For the current inventory, a concentration range of 15 – 300 ng I-TEQ kg^{-1} is applied to estimate releases from grate ash, although, it should be noted that by excluding the higher 4,000 ng I-TEQ kg^{-1} concentration, this may underestimate current releases.

The only available New Zealand data for PCDDs and PCDFs in gas scrubbing residues is a concentration of 10,000 ng I-TEQ kg^{-1} for spent lime that was obtained from a single test. It is unknown how representative this concentration data is. The UK Land and Water Review report concentrations of 680 ng I-TEQ kg^{-1} for wet scrubbers and 1,800 – 4,500 ng I-TEQ kg^{-1} for dry scrubbers (Environment Agency, 1997). As spent lime represents only one component of the total gas scrubbing residues, an emission factor range of 680 – 4,500 ng I-TEQ kg^{-1} based on the United Kingdom data is adopted for this study. However, it should be noted that use of the New Zealand data for spent lime would markedly increase the upper estimate of releases made from gas scrubbing residues.

National release estimate

PCDD and PCDF releases in solid waste from clinical, pathological and quarantine waste incinerators are summarised in Table 4.2. The total annual release from this source is estimated to be in the range 0.43 – 3.2 g I-TEQ yr^{-1}.

Table 4.2 PCDD and PCDF releases to land from clinical, pathological and quarantine waste incineration

Ash type	Waste incinerated (tonne yr^{-1})	Ash production (kg tonne^{-1})	Total ash (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Gas scrubbing residues	6,500	90	585	680 – 4,500	0.40 – 2.6
Grate ash	13,000	150	1,950	15 – 300	0.029 – 0.59
Total					0.43 – 3.2

The majority of grate ash, and the ash and sludge from the incinerators with gas scrubbing equipment, is believed to go to landfill.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a ‘medium’ certainty ranking because the quantities of grate ash and gas scrubbing residues have been estimated from the quantities of waste incinerated, based on generation rates reported in the UK Land and Water Review. The emission factor is assigned a ‘low’ certainty ranking because concentration measurements have been based solely on United Kingdom data.

4.3 Releases to water

At the incinerator with the water based quench cooler, the water is evaporated prior to lime and activated carbon addition. At the incinerator with a heat exchanger, the aqueous waste stream is tapped off from the wet absorption tower when the HCl concentration is approximately 8%. This acid solution is used as a neutralisation agent, with the resultant salt plus water being mixed with solid waste and deposited to landfill. There is therefore no direct liquid discharge from these two incinerators.

There is also believed to be no discharges to water from the 22 incinerators that do not have scrubbing of the gaseous waste stream.

Any leaching of PCDDs and PCDFs from the ash residues that are deposited in landfills will be accounted for in the estimate of releases to water from landfill leachate (see Section 26).

5 Hazardous waste incineration

5.1 Emissions to air

New Zealand has only one relatively small hazardous waste incinerator. This is a fixed hearth, two chamber unit. Waste material is loaded, in a batch process, into the primary chamber where it is ignited at temperatures between 850 – 900 °C. The combustion gases enter the second chamber where they are fully combusted under controlled oxygen and high temperature (> 1,100 °C) conditions. There is no scrubbing of the gas stream prior to release to air.

The incinerator is used for the incineration of waste material generated in the formulation and packaging of agrichemicals, in the destruction of redundant stocks of agrichemicals and the disposal of any leachate collected from the Waireka Landfill. The Waireka Landfill contains waste from the now ceased manufacture of phenoxy herbicides (see Section 28). In 1998, approximately 302 tonnes of waste was incinerated at this facility.

PCDD and PCDF emission testing is carried out twice per year on the air discharge from the incinerator. Since 1996, concentrations in the stack emission have been measured in the range 0.0031 – 1.26 ng I-TEQ Sm^{-3} (mean emission of 0.170 ng I-TEQ Sm^{-3}). These emissions, which are dependent on the type of waste incinerated, correspond to emission factors ranging from 0.09 – 179 µg I-TEQ $tonne^{-1}$, as shown in Table 5.1. Because of this wide variation in emission factors, and the regular testing programme undertaken at this facility, an annual emission has been estimated for each waste stream using the specific emission factors for each type of waste. The overall minimum emission has then been derived by summing the individual minimum emissions for each waste stream. The overall maximum emission has been similarly derived.

National emission estimate

PCDD and PCDF emissions from this hazardous waste incinerator are summarised in Table 5.1. The annual emission from this source is estimated to be in the range 0.00054 – 0.0039 g I-TEQ yr^{-1}.

Table 5.1 PCDD and PCDF emissions from hazardous waste incineration

Waste stream	Waste incinerated (tonnes)	Emission factor [1] (µg I-TEQ $tonne^{-1}$)	Annual release range (g I-TEQ yr^{-1})
Waste 1	95	4.97 [2]	0.00047
Waste 2	19	0.09 – 6.9	0.0000017 – 0.00013
Waste 3	173	0.09 – 8.4	0.000016 – 0.0015
Waste 4	9	2.4 – 76.6	0.000022 – 0.00069
Waste 5	6	5.5 – 179	0.000033 – 0.0011
Total	302		0.00054 – 0.0039

1. Based on sampling conducted in 1996 through 1998.
2. Only one sampling round has been conducted (1998).

A previous estimate of emissions from this incinerator, summarised in Section 1.3 of this report, has been published by Pilgrim *et al.* (1990). During the period July 1983 to March 1986, it was estimated that the total amount of TCDD emitted to air was 0.0082 g. This is approximately 0.0032 g TCDD yr^{-1}, which falls within the range of emissions estimated in the current study. It should be noted, however, that the waste feed to the incinerator in the 1980s included solid wastes and sludges from the manufacture of chlorinated phenoxy herbicides. As such, the PCDD and PCDF TEQ concentration of this historic waste is likely to be markedly higher than the TEQ level of the wastes currently incinerated in this facility.

Certainty

Activity statistic	H
Emission factor	H

The activity statistic is assigned a 'high' certainty ranking because it is based on precise data for the amount of waste handled by this particular incinerator. The emission factor is also assigned a 'high' certainty ranking because it is based on regular emission monitoring that has been undertaken on the incinerator over the preceding three years.

5.2 Releases to land

Since 1996, the quantity of grate ash generated from the hazardous waste incinerator has been as follows: 1996 – 6.25 tonnes; 1997 – 4.00 tonnes; 1998 – 2.50 tonnes.

No PCDD and PCDF TEQ concentration data are available for this ash. However, the UK Land and Water Review quotes concentrations of 0.1 – 34 ng I-TEQ kg^{-1} for ash from chemical waste incinerators (Environment Agency, 1997), and these data have been used in this inventory.

National release estimate

PCDD and PCDF release in grate ash from hazardous waste incineration is summarised in Table 5.2. For 1998, the annual release from this source is estimated to be in the range 0.25 – 85 µg I-TEQ yr^{-1}.

Table 5.2 PCDD and PCDF releases from hazardous waste incineration

Source	Grate ash produced (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Hazardous waste incineration	2.50	0.1 – 34	0.25×10^{-6} – 85×10^{-6}

Prior to 1991, the grate ash was disposed of at the local community landfill. Currently the ash is stored onsite and has not been released to the environment. Using an average ash production rate of 4.25 tonnes per year (1996-98 data), since 1991, this represents a holding of 3.4 – 1,200 µg I-TEQ at the site.

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a 'high' certainty ranking because it is based on actual data for the amount of grate ash produced from this particular incinerator. The emission factor is assigned a 'low' certainty ranking because no New Zealand data are available on PCDD and PCDF TEQ concentrations in the ash. The concentration data used in the estimate made are taken from the UK Land and Water Review for chemical waste incinerators.

5.3 Releases to water

There are no releases to water from the operation of this hazardous waste incinerator.

6 Wastewater solids incineration

Only one wastewater solids (sewage sludge) incinerator operates in New Zealand, and PCDD and PCDF emissions from this source are considered below. The release of PCDDs and PCDFs from wastewater solids and wastewater effluent is discussed in Section 27.

6.1 Emissions to air

The wastewater solids incinerator is a fluidised bed incinerator that operates at a temperature of approximately 800 °C. The off gases are scrubbed, firstly in a high efficiency venturi scrubber followed by a packed tower caustic scrubber. The gases are then passed through a large soil/bark biofilter having an effective bed area of 2,400 m^2 and a bed depth of 900 mm.

The incinerator processes approximately 1,000 dry tonnes of wastewater solids per year.

No PCDD and PCDF concentration data are available on the gases emitted to air from the biofilter. Since the plant has a multistage gas scrubbing system, PCDD and PCDF emissions are expected to be low. The emission factor of 9 µg I-TEQ $tonne^{-1}$ quoted in the UK Review relating to well controlled sewage sludge incinerators (HMIP, 1995) was therefore adopted for this inventory.

National emission estimate

PCDD and PCDF emissions from the incineration of wastewater solids are summarised in Table 6.1. The annual emission is assessed as being 0.009 g I-TEQ yr^{-1}, which is likely to be a conservative upper estimate for this source.

Table 6.1 PCDD and PCDF emissions from wastewater solids incineration

Source	Wastewater solids incinerated (tonne yr^{-1})	Emission factor (µg I-TEQ $tonne^{-1}$)	Annual emission (g I-TEQ yr^{-1})
Wastewater solids incineration	1,000	9	0.009

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a ‘high’ certainty ranking because it is actual data for New Zealand's only sewage sludge incinerator. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand test data are available for this facility. The factors used are taken from international sources.

6.2 Releases to land

No information is available on the volume of ash produced from the incinerator. The UK Land and Water Review indicates that 430 kg of grate ash and 13 kg of electrostatic precipitator (ESP) ash is produced per tonne of dry waste (Environment Agency, 1997). Based on these production rates, this would equate to 430 tonnes of grate ash per annum, and, assuming the scrubbers and biofilter collect all the fly ash and the ESPs referred to in the UK Land and Water Review were 92.5% efficient, approximately 14 tonnes of fly ash per annum.

Similarly, no New Zealand data are available on PCDD and PCDF concentrations in the ash from this incinerator. The UK Land and Water Review quotes concentrations of 39 ng I-TEQ kg^{-1} in grate ash and 473 ng I-TEQ kg^{-1} in ESP ash from sewage sludge incinerators (Environment Agency, 1997), and these have been adopted here.

National release estimate

PCDD and PCDF releases in ash from wastewater solids incineration are summarised in Table 6.2. The total annual release from this source is estimated to be 0.024 g I-TEQ yr^{-1}.

Table 6.2 PCDD and PCDF releases to land from wastewater solids incineration

Ash type	Ash production (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release (g I-TEQ yr^{-1})
Grate ash	430	39	0.017
Fly ash	14	473	0.0066
Total	444		0.024

The grate ash residue from the incinerator is disposed of in a secure landfill. The fly ash is assumed to be collected by the scrubbers and biofilter.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a ‘medium’ certainty ranking because it is actual data for New Zealand's only sewage sludge incinerator, but there are assumptions on the amount of ash produced and collected. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand test data are available for this facility. The factors used are taken from international sources.

6.3 Releases to water

The liquid discharge from the caustic scrubber is recycled back to the wastewater treatment plant. No data are available on PCDD and PCDF concentrations in this waste stream and therefore no estimate of PCDD and PCDF release to water from this source is made.

7 Municipal solid waste incineration

Municipal solid waste incineration has been identified internationally as a significant source of PCDD and PCDF emissions. In most of the countrywide inventories that have been undertaken, municipal waste incineration has been assessed as the principal source of PCDD and PCDF emissions to air (LUA, 1997; UNEP, 1999).

In New Zealand, there are no municipal waste incinerators, with all residential and industrial solid waste that is collected going to landfills or being recycled. The disposal of residential and industrial solid waste in landfills is discussed in Section 26.

8 Crematoria

8.1 Emissions to air

There are 32 Crematoria Authorities in New Zealand, each with at least one crematorium within their governance (Chapman, 1999). Those Authorities that cover larger populations or geographical areas will likely have more than one crematorium, and, on this basis, there are estimated to be approximately 40 crematoria operating in New Zealand (Grooby, 1999). The majority of these crematoria are of the double chamber type. New Zealand guidelines require the primary chamber to be preheated to 800 – 900 °C before committal of the casket, with the afterburner chamber at a minimum of 800 °C (DoH, 1992a). There is a growing awareness among the operators of crematoria regarding contaminant emissions, resulting in a trend for plastic materials to be removed from the casket prior to cremation.

No information is formally collected nationally on the number of cremations carried out each year. However, the Funeral Directors Association of New Zealand has surveyed the operators of the country's crematoria and determined that there were approximately 15,900 cremations in 1998 (Grooby, 1999). This is approximately 61% of the 26,206 deaths in New Zealand in 1998 (Statistics NZ, 1999). This data has been confirmed using information from the Births, Deaths and Marriages registry that indicated the number of cremations between 59 – 63% of the deaths recorded (Clarke, 1999).

No PCDD and PCDF emission tests have been carried out on New Zealand crematoria. Bremmer *et al.* (1994) have reported results from two crematoria of 2.4 µg I-TEQ body^{-1} (where the flue gases were not cooled prior to discharge) and 4.9 µg I-TEQ body^{-1} (where the flue gases were cooled with ambient air prior to discharge). Both crematoria were fitted with afterburners that operated at 850°C. Bremmer *et al.* (1994) have also reported emissions from a third German crematorium of 28 µg I-TEQ body^{-1}, but no details were provided on the operational parameters for this installation. The US Inventory reported an average emission factor of 0.5 µg I-TEQ body^{-1} on the basis of three tests on a single crematorium (US EPA, 1998). Similarly, the UK Review identified a mean emission factor for crematoria up to 80 µg I-TEQ body^{-1}, but noted that this reflected older non "state of the art" plants (HMIP, 1995). More recent data from Japan reported emission factors between 0.45 – 63 µg TEQ body^{-1}, with a mean of 11 µg TEQ body^{-1} for ten crematoria studied (Takeda *et al.*, 1998). In this study, all crematoria had a secondary combustion chamber. The lowest emissions were observed for those crematoria with dust control and temperatures in excess of 850 °C. Markedly higher concentrations were found for those crematoria where a secondary combustion chamber was connected to three or four main combustion chambers.

For the current inventory, an emission factor range of 0.5 – 28 µg I-TEQ body^{-1} has been adopted based on a lower bound value from the US Inventory and an upper bound value from Bremmer *et al.* (1994). With the exception of the high United Kingdom value for older non "state of the art" crematoria, this emission factor range brackets all other mean PCDD and PCDF data sets.

National emission estimate

PCDD and PCDF emissions from crematoria are summarised in Table 8.1. The annual emission from this source is estimated to be in the range 0.0080 – 0.45 g I-TEQ yr^{-1}.

Table 8.1 PCDD and PCDF emissions from crematoria

Source	No. of cremations (bodies yr^{-1})	Emission factor (µg I-TEQ $body^{-1}$)	Annual emission range (g I-TEQ yr^{-1})
Crematoria	15,900	0.5 – 28	0.0080 – 0.45

Certainty

Activity statistic H

Emission factor L

The activity statistic is assigned a ‘high’ certainty ranking because the number of cremations has been determined from a survey of crematoria operators and this data is in good agreement with data from the Births, Deaths and Marriages registry. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand emissions test data are available. The factors used are taken from studies on overseas crematoria, and these studies have provided a wide range of emission factors depending upon the technology in place.

8.2 Releases to land

As noted in Section 8.1, there are approximately 15,900 cremations per year. Assuming an ash production rate of 4 kg per cremation (Grooby, 1999), this gives a total ash generation of approximately 64 tonnes per year.

Concentrations of PCDDs and PCDFs in crematoria ash are not known and there is therefore insufficient information on which to estimate an annual PCDD and PCDF release. Primarily, the ashes are either scattered, or interned in a memorial wall or garden.

9 Power generation

9.1 Emissions to air

Emissions to air from power generation arise from the combustion of fossil fuels. Fossil fuels used for this purpose in New Zealand are natural gas and coal. New Zealand's natural gas sources are effectively chlorine-free, and therefore it was assumed that there would be no or minimal PCDD and PCDF emissions from its use in power generation. However, this has not been demonstrated by actual emission testing. It should be noted that PCDDs and PCDFs have been measured in emissions from gas combustion plants overseas (Umweltbundesamt, 1994) although the data are highly uncertain and further investigation of this source is required.

There is only one coal fired power station, located in the Waikato Region, that currently operates in New Zealand. This inventory therefore only considers PCDD and PCDF emissions from power generation associated with coal usage at this facility.

Coal consumption

Total coal consumption in New Zealand was about 2.1 million tonnes in 1995 (MOC, 1997). Coal utilisation can be divided into the following general categories: power generation, steel production, cement manufacturing, industrial and commercial appliances, domestic appliances and agricultural appliances, as shown in Table 9.1 (MOC, 1997). It is assumed that coal use in 1998 was similar to this 1995 based data.

The total coal consumed for power generation in New Zealand was approximately 294,000 tonnes per year. Coal use and PCDD and PCDF emissions for the latter categories are discussed in subsequent Sections of this report.

Table 9.1 Coal use in New Zealand

Activity	Coal use	
	(tonne yr^{-1})	(%)
Steel production	693,000	33
Power generation	294,000	14
Cement manufacturing	210,000	10
Other industrial manufacturing	504,000	24
Commercial appliances	294,000	14
Domestic appliances	63,000	3
Agriculture appliances	42,000	2
Total	2,100,000	100

Emission factors

In 1998, two emission tests were carried out at New Zealand's only coal fired power station as part of Phase II for this inventory. These tests reported stack emission concentrations of 0.014 ng I-TEQ Sm^{-3} and 0.026 ng I-TEQ Sm^{-3}, which corresponds to an emission factor range of 0.2 – 0.36 µg I-TEQ $tonne^{-1}$. The first test was carried out at 100% load (243 MW electrical) and the second with a varying load between 75 and 96% full load (187 to 240 MW electrical); the fuel used was pulverised bituminous coal.

The UK Review reports emission factor data for coal fired power stations of 0.32 µg I-TEQ tonne^{-1} (for a 380 MW plant), 0.25 µg I-TEQ tonne^{-1} (380 MW), 0.2 µg I-TEQ tonne^{-1} (189 MW) and 0.06 µg I-TEQ tonne^{-1} (500 MW). The average emission factor for power generation reported in the US Inventory is 0.136 µg I-TEQ tonne^{-1} (US EPA, 1998). The New Zealand results are therefore in good agreement with the United Kingdom and United States data, and have been adopted for this inventory.

National emission estimate

PCDD and PCDF emissions from coal fired power generation are summarised in Table 9.2. The annual emission from this source is estimated to be in the range 0.059 – 0.11 g I-TEQ yr^{-1}.

Table 9.2 PCDD and PCDF emissions from coal fired power generation

Source	Coal use (tonne yr^{-1})	Emission factor (µg I-TEQ tonne^{-1})	Annual emission range (g I-TEQ yr^{-1})
Power generation	294,000	0.2 – 0.36	0.059 – 0.11

A previous estimate of PCDD and PCDF emissions from coal fired power generation ranked this activity as a minor source of these contaminants in New Zealand (see Section 1.3; Bingham, 1992). The findings of the current inventory are consistent with the estimate made in this earlier study.

Certainty

Activity statistic	H
Emission factor	M

The activity statistic is assigned a ‘high’ certainty ranking because it is based on survey data that are in excellent agreement with coal consumption data provided by the industry. The emission factor is assigned a ‘medium’ certainty ranking because it is based on limited emission test data at New Zealand’s only operational coal fired power station, and these data compare well with overseas emission factors for coal fired power generation.

9.2 Releases to land

As previously noted, the amount of coal used for power generation was 294,000 tonnes per year. Coal Research Association data (CRA, 1996) indicate an ash content for Waikato region coal (the principal coal source used for power generation) in the range of 3.1 – 4.1%. This would result in a total ash production of 9,100 – 12,030 tonnes per year.

The power generation facility uses pulverised coal boilers with electrostatic precipitation to minimise particulate emissions from the stacks. Based on industry data, the pulverised coal boilers generate fly ash and grate ash at a ratio of approximately 3:1 and the ESPs collect between 99.7 – 99.9% of the fly ash.

Data have been reported for total PCDD and PCDF concentrations (sum of tetrachloro- to octachloro- congeners) in ash from coal combustion at the New Zealand coal fired power station in the range 76 – 164 ng kg^{-1}, but no TEQ levels were provided (ECNZ, 1992). However, using proportionality factors published by Birmingham (1990), the TEQ level has been estimated to be in the range 2.7 – 5.4 ng I-TEQ kg^{-1}. This is in good agreement with data from the UK Land and Water Review that quotes PCDD and PCDF concentrations in grate ash from industrial coal combustion between 0.02 – 13.5 ng I-TEQ kg^{-1} and in fly ash (cyclone and bag filter fines) between 0.23 – 8.7 ng I-TEQ kg^{-1} (Environment Agency, 1997). Since the New Zealand TEQ data have been estimated, the United Kingdom data, which brackets the New Zealand data, are used to estimate releases to land.

National release estimate

PCDD and PCDF releases in ash from coal fired power generation are summarised in Table 9.3. The total annual release from this source is estimated to be in the range of 0.0016 – 0.12 g I-TEQ yr^{-1}.

Table 9.3 PCDD and PCDF releases to land from coal fired power generation

Ash type	Coal use (tonne yr^{-1})	Ash production (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual releases range (g I-TEQ yr^{-1})
Grate ash	294,000	2,280 – 3,010 [1,3]	0.02 – 13.5	0.000046 – 0.041
Fly ash	294,000	6,820 – 9,020 [2,3]	0.23 – 8.7	0.0016 – 0.078
Total		9,100 – 12,030		0.0016 – 0.12

1. 25% of total ash production is grate ash.
2. 75% of total ash production is fly ash of which 99.8% is collected by ESPs.
3. Assumes an ash content of 3.1 – 4.1%.

The collected fly ash from the ESPs is either used, dry, as a cement additive or is slurried in ash ponds at the site along with ground grate ash. Some grate ash is sold and goes off-site.

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a ‘high’ certainty ranking because it is based on survey data for coal consumption that is in excellent agreement with data provided by the industry, and because it uses industry data on the proportions of bottom ash and fly ash produced. The ash content of the coal is also well established. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand TEQ data are available. The emission factor is based solely on overseas data for PCDD and PCDF concentrations in fly ash and grate ash.

9.3 Releases to water

Fly ash and ground grate ash may be deposited in ash ponds. As such, a component of this release may be to water. There is insufficient information to assess this release, but given the high partition coefficient of PCDDs and PCDFs with solid matter, the majority of these contaminants will remain associated with the ash rather than the aqueous phase. Any releases to water are therefore likely to be negligible.

10 Industrial, commercial and agricultural coal combustion

10.1 Emissions to air

A wide range of coal fired combustion appliances are used in the industrial manufacturing and commercial sector. For the purposes of estimating releases, the combustion of coal in agriculture is considered along with industrial and commercial combustion.

10.1.1 Industrial manufacturing and commercial appliances

The amount of coal used for industries other than power generation, steel manufacturing and cement and lime manufacturing is approximately 798,000 tonnes per year (see Section 9, Table 9.1).

PCDD and PCDF emissions are generally dependent on the appliance size, with the smaller installations typically having the greater emission factors. For example, Sloss and Smith (1993) reported the following emission factors for industrial boilers:

- 0.19 (5 MW) – 2.24 µg I-TEQ tonne^{-1} (0.15 MW) for six industrial/commercial plants burning bituminous coal
- 0.04 (36 MW) – 4.8 µg I-TEQ tonne^{-1} (17.5 kW) for 13 plants (coal type not specified).

From these data, the emission factor range used in the UK Review to estimate emissions from industrial and commercial coal fired plants was 0.04 – 4.8 µg I-TEQ tonne^{-1} (HMIP, 1995).

As part of Phase II for this inventory, emission monitoring was carried out at two coal fired boilers in New Zealand. The first was a medium sized boiler (by New Zealand standards) rated at 7.2 MW steam, from which two emission samples were collected. The second was a small underfeed stoker hot water boiler rated at 210 kW (output), which is typical of many smaller installations that use coal for space heating, from which a single emission sample was collected. The 7.2 MW unit gave stack emission concentrations of 0.055 ng I-TEQ Sm^{-3} and 0.10 ng I-TEQ Sm^{-3}, which corresponds to an emission factor range of 1.16 – 1.95 µg I-TEQ tonne^{-1}. The 210 kW unit reported a stack emission concentration of 0.12 ng I-TEQ Sm^{-3}, which corresponds to an emission factor of 2.9 µg I-TEQ tonne^{-1}.

Although the New Zealand test data are consistent with the data reported in the UK Review, given the wide range of operating conditions that can be found in coal fired appliances, the UK Review data (with a greater range) have been adopted for this inventory.

National emission estimate

PCDD and PCDF emissions from coal fired industrial and commercial appliances are summarised in Table 10.1. The annual emission from this source is estimated to be in the range 0.032 – 3.8 g I-TEQ yr^{-1}.

Table 10.1 PCDD and PCDF emissions from industrial manufacturing, commercial and agricultural coal combustion

Source	Coal use [1] (tonne yr^{-1})	Emission factor (µg I-TEQ tonne^{-1})	Annual emission range (g I-TEQ yr^{-1})
Industrial manufacturing and commercial appliances	798,000	0.04 – 4.8	0.032 – 3.8
Agricultural appliances	42,000	0.04 – 4.8	0.0017 – 0.20
Total	840,000		0.034 – 4.0

1. See Table 9.1.

10.1.2 Agricultural appliances

Data published by the Ministry of Commerce indicate that coal consumption in the agricultural sector accounts for approximately 2% of the total New Zealand coal consumption (MOC, 1997). This is equivalent to approximately 42,000 tones of coal per annum.

Information supplied by the coal suppliers is that this coal is used predominantly in horticultural activities such as glasshouse heating as well as lucerne driers and similar “industrial” type appliances. The same UK Review emission factors that were adopted for industrial and commercial appliances (0.04 – 4.8 µg I-TEQ tonne^{-1}) have therefore been applied to small scale coal combustion in the agricultural sector.

National emission estimate

PCDD and PCDF emissions from coal fired agricultural appliances are summarised in Table 10.1. The annual emission from this source is estimated to be in the range 0.0017 – 0.20 g I-TEQ yr^{-1}. It should be noted, however, that since most of the appliances used in the agricultural sector in New Zealand will be in the mid to low thermal output range compared to those reported in the UK Review, it can be expected that the actual emissions would lie within the mid to top end of this range.

Certainty

Activity statistic	H
Emission factor	M (Industrial) L (Agricultural)

The activity statistic is assigned a ‘high’ certainty ranking because it is based on Ministry of Commerce survey data for coal use in New Zealand. The emission factor for industrial appliances is assigned a ‘medium’ certainty ranking because recent emission test data for two New Zealand coal fired plants agree well with the overseas emission factors used. The emission factor for agricultural appliances is assigned a ‘low’ certainty ranking because no New Zealand data are available and such appliances have been assumed to be similar to industrial appliances.

10.2 Releases to land

As previously noted, the total amount of coal used in the industrial manufacturing, commercial and agricultural sectors is approximately 840,000 tonnes per year (see Section 9, Table 9.1). The ash content of New Zealand coals range from 1.4 – 12.4% (CRA, 1996). The mean weighted average ash content for coal produced throughout New Zealand, with the component of Waikato region coal used for power generation and steel manufacturing deducted, is 3.1% (CRA, 1996). The annual production of grate ash was determined assuming 90% of coal ash is collected as grate ash.

There is insufficient information to assess the amount of fly ash that may be collected from coal fired appliances. No estimate is therefore made of PCDDs and PCDFs associated with fly ash, and it should be noted this source would represent a further release to land.

There are no New Zealand data on PCDDs and PCDFs in grate ash from industrial, commercial or agricultural coal combustion. A PCDD and PCDF content ranging from 0.02 – 13.5 ng I-TEQ kg^{-1} has been reported in the UK Land and Water Review for grate ash from industrial coal combustion (Environment Agency, 1997), and these values were therefore used to assess PCDD and PCDF releases from these sectors.

National release estimate

PCDD and PCDF releases in grate ash from coal combustion in industrial, commercial and agricultural appliances are summarised in Table 10.2. The total annual release from these sectors is estimated to be in the range of 0.00047 – 0.32 g I-TEQ yr^{-1}.

Table 10.2 PCDD and PCDF releases to land from industrial manufacturing, commercial and agricultural coal combustion

Source	Coal use (tonne yr^{-1})	Grate ash production [1] (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Industrial and commercial appliances	798,000	22,260	0.02 – 13.5	0.00045 – 0.30
Agricultural appliances	42,000	1,170	0.02 – 13.5	0.000023 – 0.016
Total	840,000	23,430		0.00047 – 0.32

1. Based on an average ash content of 3.1% and assuming 90% of the ash is collected as grate ash.

The fate of ash produced by these appliances has not been determined. It is likely that the majority of this ash is disposed of to land, including its use as a basecourse for roading. A component of the ash will go to landfill.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a ‘medium’ certainty ranking because it is based on Ministry of Commerce data for the amount of coal used in New Zealand. However, some assumptions are made on the amount of grate ash produced and collected upon combustion and no account is taken of fly ash and grit. The emission factor is assigned a ‘low’ certainty ranking because no New

Zealand data are available. The emission factor is based solely on overseas data for PCDD and PCDF concentrations in grate ash from industrial coal combustion.

10.3 Releases to water

There is insufficient information to assess the nature or magnitude of any direct releases to water that may occur from the burning of coal in the industrial, commercial or agricultural sectors.

Any leaching of PCDDs and PCDFs from the ash residues that are deposited to land is not considered a direct release to water. The leaching of ash that is deposited in landfills will be accounted for in the estimate of PCDD and PCDF releases to water from landfill leachate (see Section 26).

11 Domestic coal burning

11.1 Emissions to air

As noted in Section 9 and Table 9.1, the total amount of coal burnt in domestic appliances is approximately 63,000 tonnes per year.

The domestic burning of coal typically results in higher PCDD and PCDF yields than industrial combustion, predominantly because of the poorer combustion conditions that exist in smaller appliances. No PCDD and PCDF emission data are available for the burning of coal in domestic appliances in New Zealand. The UK Review identified emission factors for anthracite, processed fuel and bituminous coal (HMIP, 1995). In New Zealand, indigenous coal used in the domestic market is a mixture of sub-bituminous and bituminous coal. In the absence of New Zealand specific data, the emission factors from the UK Review have been adopted. For bituminous coal, the range is 5.7 – 9.3 µg I-TEQ tonne^{-1}.

National emission estimate

PCDD and PCDF emissions from domestic coal burning are summarised in Table 11.1. The annual emission from this source is estimated to be in the range 0.36 – 0.59 g I-TEQ yr^{-1}.

Table 11.1 PCDD and PCDF emissions from domestic coal burning

Source	**Coal use** [1] **(tonne yr^{-1})**	**Emission factor (µg I-TEQ tonne^{-1})**	**Annual emission range (g I-TEQ yr^{-1})**
Domestic appliances	63,000	5.7 – 9.3	0.36 – 0.59

1. See Table 9.1.

It should be noted that these factors do not allow for the burning of waste, such as plastics, paper and other household rubbish on domestic fires, which could cause a large short term increase in PCDD and PCDF emissions. Limited testing overseas has shown an increase in emissions of several orders of magnitude when domestic waste is added to a domestic heating appliance (Schatowitz *et al.*, 1993). However, the quantity of domestic waste burnt in domestic appliances in New Zealand is unknown and therefore no estimate of emissions from this source has been included here. Domestic waste is also burnt in backyard fires, and emissions from this source have been addressed in Section 14.

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a ‘high’ certainty ranking because it is based on Ministry of Commerce survey data for domestic coal usage in New Zealand. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand emissions test data are available. The emission factors used are taken solely from data reported in the UK Review.

11.2 Releases to land

The amount of coal burnt in the domestic sector is approximately 63,000 tonnes per year (see Section 9, Table 9.1). The ash content of New Zealand coals range from 1.4 – 12.4% (CRA, 1996). The mean weighted average ash content for coal produced throughout New Zealand, with the component of Waikato region coal used for power generation and steel manufacturing deducted, is 3.1% (CRA, 1996). Assuming 90% of coal ash is collected as grate ash, this gives a production of approximately 1,760 tonnes of grate ash per year.

There are no New Zealand data on PCDDs and PCDFs in grate ash from domestic coal burning. A PCDD and PCDF concentration in ash of 0.41 ng I-TEQ kg^{-1} from the domestic burning of bituminous coal has been reported in the UK Land and Water Review (Environment Agency, 1997), and this was used to estimate releases from this sector.

National release estimate

PCDD and PCDF releases in ash from domestic coal burning are summarised in Table 11.2. The annual release from this sector is estimated to be 0.00072 g I-TEQ yr^{-1}.

Table 11.2 PCDD and PCDF releases to land from domestic coal burning

Source	Coal use (tonne yr^{-1})	Grate ash production [1] (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual emission (g I-TEQ yr^{-1})
Domestic appliances	63,000	1,760	0.41	0.00072

1. Based on an average ash content of 3.1% and assuming 90% of the ash is collected as grate ash.

Ash from domestic coal burning is primarily disposed of to landfills, via domestic waste collections, or is scattered on gardens. No information is available on the relative quantities disposed of via each disposal route.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a ‘medium’ certainty ranking because it is based on Ministry of Commerce data for domestic coal usage in New Zealand, but with some assumptions on the amount of grate ash produced and collected upon combustion. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand data are available. The emission factor is based solely on overseas data for PCDD and PCDF concentrations in grate ash from domestic coal burning.

11.3 Releases to water

There are no direct releases to water from the domestic burning of coal.

Any leaching of PCDDs and PCDFs from the ash residues that are deposited in landfills will be accounted for in the estimate of releases to water from landfill leachate (see Section 26).

12 Industrial wood combustion

12.1 Emissions to air

Wood consumption

The combustion of wood in New Zealand comprises the large scale combustion of waste materials from the forestry and wood processing industries, medium scale combustion of waste from wood manufacturing industries and small scale domestic burning of wood. PCDD and PCDF emissions will be dependent on the combustion equipment and conditions, and whether the wood fuel is contaminated with chemicals such as preservatives, adhesives or surfacing materials.

Collectively, black liquor and woody biomass form almost all the primary energy source of 31.7 PJ yr^{-1} (equivalent to 2,100,000 tonne yr^{-1}) identified as biomass and animal products in the New Zealand energy data file (MOC, 1997). Estimates (EECA and CAE, 1996) indicate that about 50% of this primary energy source is black liquor from pulping operations (see Section 22) and 50% (1,050,000 tonnes) is wood biomass. Of the latter, approximately 20% is reported as domestic fuel wood, while the remaining 30% is primarily the combustion of bark and timber processing wastes, referred to herein as “wood processing waste”. This is illustrated in Table 12.1.

The wood processing wastes include a portion of “contaminated” wood. This refers to non-PCP treated wood which includes sawdusts, shavings, and off-cuts that contain antisapstains, preservatives, resins, hardeners, surface coatings, and other glues. For the purpose of this assessment it is assumed that the combustion of “contaminated” wood waste in the industrial sector is 10% of the total wood processing waste. This estimate is based on information provided by some selected wood processing plants.

Burning wood contaminated with PCP leads to significantly higher PCDD and PCDF emissions compared to burning virgin wood or wood processing wastes. However, it is unlikely that PCP treated wood would be burned in the industrial sector. The use of PCP in the timber industry ceased in 1988, and PCP was deregistered by 1991. Stockpiles of PCP treated wood are unlikely to be held by industry, and therefore PCDD and PCDF emissions from the combustion of PCP treated wood in the industrial sector are not considered as a part of this inventory.

The wood consumption figures used in this inventory are summarised in Table 12.1.

Table 12.1 National wood consumption estimates

Wood fuel	EECA/CAE estimates		Adjusted values
	(tonne yr^{-1})	(%)	(tonne yr^{-1})
Wood processing waste	630,000	30	567,000
“Contaminated” wood waste	NA	-	63,000 [1]
Domestic fuel wood (see Section 13 for discussion of adjusted value)	420,000	20	713,000
Total wood consumption	1,050,000	50	1,343,000

1. “Contaminated” wood waste is assumed to be 10% of wood processing waste.

Emission factors

The sawdust, bark and other wood processing wastes that is burnt to provide heat and steam for sawmill and primary wood processing operations, and for forestry co-generation plants, is primarily uncontaminated wood. For uncontaminated wood processing wastes, the UK Review reports an emission factor range of 1 – 2.2 µg I-TEQ $tonne^{-1}$ (HMIP, 1995). Similarly, the US Inventory reports emission factors in the range 0.50 – 1.32 µg I-TEQ $tonne^{-1}$ (US EPA, 1998), which is consistent with the UK Review.

As part of Phase II for this inventory, two emission tests were carried out on two wood fired boilers, each rated at about 6 MW. This is a typical size for wood fired boilers in New Zealand. One of the units was relatively old (about 30 years) with a stepping grate fed with an underfeed stoker. The second unit (about 10 years old) employs a combination of suspension and grate combustion with pneumatic feed. Both units use cyclone grit arrestors. The new unit reported a stack emission concentration of 0.028 ng I-TEQ Sm^{-3}, corresponding to an emission factor of 0.26 µg I-TEQ $tonne^{-1}$, and the older unit a stack emission concentration of 0.15 ng I-TEQ Sm^{-3}, corresponding to an emission factor of 1.7 µg I-TEQ $tonne^{-1}$. The difference is assumed to be due to the improved combustion characteristics of the newer unit. These data are consistent with the emission factors reported in the UK Review (HMIP, 1995) and the US Inventory (US EPA, 1998). Since only limited testing was done, to estimate emissions from uncontaminated wood combustion, an emission factor range based on the lower bound US Inventory value of 0.50 µg I-TEQ $tonne^{-1}$ and the upper bound UK Review value of 2.2 µg I-TEQ $tonne^{-1}$ has been applied.

For the industrial combustion of "contaminated" (i.e. non-virgin) wood, the UK Review presents a range of emission factors of 9 – 19 µg I-TEQ $tonne^{-1}$ (HMIP, 1995). Similarly, Bremmer *et al.* (1994) reports emission factors for non-PCP treated wood as being between 5 and 10 µg I-TEQ $tonne^{-1}$. The UK Review emission factor range has been adopted for this inventory.

National emission estimate

PCDD and PCDF emissions from industrial wood fired appliances are summarised in Table 12.2. The total annual emission from this source is estimated to be in the range 0.85 – 2.4 g I-TEQ yr^{-1}.

Table 12.2 PCDD and PCDF emissions from industrial wood combustion

Source	Wood use (tonne yr^{-1})	Emission factor (µg I-TEQ $tonne^{-1}$)	Annual emission range (g I-TEQ yr^{-1})
Wood processing waste	567,000	0.50 – 2.2	0.28 – 1.2
"Contaminated" wood waste	63,000 [1]	9 – 19	0.57 – 1.2
Total	630,000		0.85 – 2.4

1. 10% of the total wood combusted is assumed to be "contaminated".

Certainty

Activity statistic	M
Emission factor	M (wood processing waste)
	L ("contaminated" wood waste)

The activity statistic is assigned a ‘medium’ certainty ranking because it is based on survey data. However, there are some estimates and assumptions made in determining the relative amounts of wood processing waste and “contaminated” wood waste combusted. The emission factor for wood processing waste is assigned a ‘medium’ certainty ranking because recent, but limited, emission test data for two New Zealand wood fired boilers agree well with the overseas emission factors available. The emission factor for “contaminated” wood waste is assigned a ‘low’ certainty ranking because no New Zealand emissions test data are available. The emission factors used are taken from those reported in the UK Review.

12.2 Releases to land

As previously noted in Section 12.1, approximately 630,000 tonnes of wood is burnt each year for industrial purposes. An ash content of wood of 1 – 3% by weight (Perry, 1997; Brunner 1996; Shula *et al*., 1993) was adopted as wood moisture contents are likely to be variable. It was assumed that 90% of this ash is collected as grate ash (as for coal combustion; see Section 10), and that 10% of wood burnt in this sector is “contaminated”, as discussed in Section 12.1. For wood processing wastes, this equates to a grate ash production of 5,100 – 15,300 tonnes per year, and for “contaminated” wood wastes a grate ash production of 570 – 1,700 tonnes per year.

Fly ash will also be collected at the larger facilities that have cyclones and baghouses in place, and PCDD and PCDF levels in fly ash may be expected to be significantly higher than levels in grate ash (Oehme and Muller, 1995). However, there is insufficient information to assess the amount of fly ash collected from industrial wood fired appliances in New Zealand, and although no estimate can be made, it should be noted that this will represent a further release to land.

The UK Land and Water Review cites a PCDD and PCDF concentration in grate ash for untreated wood of 0.23 – 1.12 ng I-TEQ kg^{-1} and for treated wood of 584 – 1,090 ng I-TEQ kg^{-1} (Environment Agency, 1997). In the absence of any New Zealand specific data, these factors have been used in this inventory.

National release estimate

PCDD and PCDF releases in ash from industrial wood fired appliances are summarised in Table 12.3. The total annual release from this source is estimated to be in the range of 0.33 – 1.9 g I-TEQ yr^{-1}.

Table 12.3 PCDD and PCDF releases to land from industrial wood combustion

Source	Wood use (tonne yr^{-1})	Grate ash production [1] (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Wood processing waste	567,000	5,100 – 15,300	0.23 – 1.12	0.0012 – 0.017
“Contaminated” wood waste	63,000 [2]	570 – 1,700	584 – 1,090	0.33 – 1.9
Total	630,000	5,670 – 17,000		0.33 – 1.9

1. Based on an ash content of 1 – 3% and assuming 90% of the ash is collected as grate ash.
2. 10% of the total wood combusted is assumed to be “contaminated”.

The fate of ash produced by these plants has not been precisely determined, although it is likely that the major quantity will be disposed of to land. A quantity of the ash will go to landfills.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a ‘medium’ certainty ranking because it is based on survey data. However, there are some estimates and assumptions made in determining the actual amount of wood combusted in the industrial sector. Furthermore, no attempt was made to quantify the releases from fly ash which are typically more contaminated. The emission factor for both wood processing waste and “contaminated” wood waste is assigned a ‘low’ certainty ranking because no New Zealand data are available. The emission factor ranges used are based solely on overseas data for PCDD and PCDF concentrations in wood ash.

12.3 Releases to water

There is insufficient information to assess the nature or magnitude of any direct releases to water that may occur from industrial wood combustion.

Any leaching of PCDDs and PCDFs from the ash residues that are deposited to land is not considered a direct release to water. The leaching of ash that is deposited in landfills will be accounted for in the estimate of PCDD and PCDF releases to water from landfill leachate (see Section 26).

13 Domestic wood burning

13.1 Emissions to air

Wood consumption

Domestic wood consumption has been estimated as 420,000 tonnes per year (see Section 12, Table 12.1) (EECA and CAE 1996). However, fuel inventory data for Christchurch (population 310,000) indicate a total of about 64,580 tonnes of wood per year was burnt in the domestic sector in 1995, increasing at a rate of 1.7% per annum (CRC, 1996). The estimated quantity of wood burnt domestically in 1998 is therefore approximately 67,900 tonnes. The Auckland Regional Council have also assessed the quantity of domestic wood consumption (ARC, 1998). For the “Auckland Study Area”, it was estimated that approximately 182,000 tonnes of firewood was burnt in the domestic sector. The Auckland Study Area had an estimated population of 1,019,000 at 1998 (ARC, 1998).

Christchurch relies heavily on solid fuel for domestic space heating, whereas Auckland utilises a greater range of heating methods and has a higher average winter temperature. On the reasonable assumption that these two centres represent the extremes of the heating demands across New Zealand, and based on a population for New Zealand of 3,790,000 at mid 1998 (Statistics NZ, 1998), the average national wood consumption has been determined, on a pro-rata basis, to be approximately 713,000 tonnes per year. This is considerably higher than the EECA and CAE (1996) estimate, but is considered to be closer to the actual consumption as it is based on fuel inventories and surveys which include contributions from scavenged fuel.

Fuel inventory data for Christchurch report 31% of wood is burnt on open fires (NIWA, 1997), whereas in Auckland 40% of wood is believed to be burnt on open fires. It is therefore assumed that, nationally, about 35% of wood is burnt on open fires, and correspondingly 65% is burnt in enclosed appliances.

Emission factors

No PCDD and PCDF emission data are available for the burning of wood in domestic appliances in New Zealand. The UK Review (HMIP, 1995) quotes emission factors for domestic burning of wood of:

1 – 3 µg I-TEQ tonne^{-1} for enclosed stoves
1 – 29 µg I-TEQ tonne^{-1} for open fires burning clean wood
10 – 50 µg I-TEQ tonne^{-1} for treated wood, including a small amount of PCP treated wood.

The US Inventory (US EPA, 1998) has derived an emission factor of 2 µg I-TEQ tonne^{-1} for residential wood stoves (enclosed appliances), which falls within the range used in the UK Review. Therefore, to estimate PCDD and PCDF emissions from this sector, the emission factors given in the UK Review (HMIP, 1995) for both open and enclosed appliances have been adopted.

As noted in Section 12, the use of PCP for timber treatment ceased in New Zealand in 1988, and although the quantity of PCP contaminated wood burnt in New Zealand is unknown, it is likely to be very small. As it is not possible to obtain an accurate estimate of the amount of treated wood (both PCP treated and “contaminated” wood waste of the type discussed in Section 12.1) burnt domestically, no estimate of annual emissions from this source has been attempted.

National emission estimate

PCDD and PCDF emissions from domestic wood fired appliances are summarised in Table 13.1. The annual emission from the burning of clean wood is estimated to be in the range 0.71 – 8.7 g I-TEQ yr^{-1}.

Table 13.1 PCDD and PCDF emissions from domestic wood burning

Source	Wood use (tonne yr^{-1})	Emission factor (µg I-TEQ $tonne^{-1}$)	Annual emission range (g I-TEQ yr^{-1})
Enclosed appliances	463,000	1 – 3	0.46 – 1.4
Open fires	250,000	1 – 29	0.25 – 7.3
Total	713,000		0.71 – 8.7

Ambient air monitoring in residential areas of a number of New Zealand cities has demonstrated the significance of domestic wood burning as a source of PCDD and PCDF emissions (Buckland *et al.*, 1999a,b). High concentrations (up to 262 fg I-TEQ m^{-3}) were measured during the coldest winter months, while lower concentrations (down to 6.15 fg I-TEQ m^{-3}) were measured in the summer months. A significant negative correlation was observed with mean night time temperature, and a positive correlation with retene (the aromatic hydrocarbon, retene, has been identified as a molecular marker of wood combustion; Ramdahl, 1983). These findings are consistent with the results of the current inventory, which ranks domestic wood burning as one of the major sources of PCDDs and PCDFs in New Zealand.

It should be noted that the current estimate does not take into account the burning of:

- Treated wood and other "contaminated" wood wastes;
- Plastics, paper and other household rubbish.

The burning of these types of material on domestic fires can cause a large short term increase in PCDD and PCDF emissions. Limited testing overseas has shown an increase in emissions of several orders of magnitude when domestic waste is added to a domestic heating appliance (Schatowitz *et al.*, 1993). However, the quantity of treated and contaminated wood, and household waste burnt in domestic appliances in New Zealand is unknown and therefore no estimate of emissions from these sources has been included here. Domestic waste is also burnt in backyard fires, and emissions from this source have been addressed in Section 14.

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a 'high' certainty ranking because it is based on fuel inventories and surveys that include contributions from scavenged fuel. The emission factor is assigned a 'low' certainty ranking because no New Zealand emissions test data are available. The factors used are taken from overseas emission factors that were derived from a limited number of direct measurement studies.

13.2 Releases to land

As discussed in Section 13.1, approximately 713,000 tonnes of wood is burnt in domestic fires each year. An ash content of wood of 1 - 3% by weight (Perry, 1997; Brunner 1996; Shula *et al.*, 1993) was adopted as wood moisture contents are likely to be variable. Assuming that 90% of ash is collected as grate ash, this would produce between 6,400 – 19,300 tonnes of wood ash per year.

No New Zealand concentration data are available for PCDDs and PCDFs in residues from domestic wood burning. The UK Land and Water Review cites a concentration range for PCDDs and PCDFs in grate ash from wood burnt in household heating systems of 75 – 500 ng I-TEQ kg^{-1} (Environment Agency, 1997). It is unclear from the original reference whether this included any treated wood, although the high end emission factor of 500 ng I-TEQ kg^{-1} would seem to indicate that material other than virgin wood was possibly burnt. The US Inventory in their review of this sector comment that there is a general lack of concentration data for PCDDs and PCDFs in wood ash from domestic appliances (US EPA, 1998). In the absence of any New Zealand specific data, the concentration range given in the UK Land and Water Review has been adopted for this inventory.

National release estimate

PCDD and PCDF releases in ash from domestic wood fired appliances are summarised in Table 13.2. The annual release from this source is estimated to be in the range of 0.48 – 9.7 g I-TEQ yr^{-1}.

Table 13.2 PCDD and PCDF releases to land from domestic wood burning

Source	Wood use (tonne yr^{-1})	Grate ash production [1] (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Domestic appliances	713,000	6,400 – 19,300	75 – 500	0.48 – 9.7

1. Based on an ash content of 1 – 3% and assuming 90% of the ash is collected as grate ash.

Ash from domestic fires is primarily disposed of to landfills, via domestic waste collections, or is scattered on gardens. No information is available on the relative quantities disposed of via each disposal route.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a ‘medium’ certainty ranking because it is based on fuel inventories and surveys which include contributions from scavenged fuel. However, some assumptions have been made on the amount of grate ash produced and collection upon combustion. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand data are available. The emission factor is based solely on overseas data for PCDD and PCDF concentrations in wood ash from domestic burning.

13.3 Releases to water

There are no direct releases to water from the domestic burning of wood.

Any leaching of PCDDs and PCDFs from the ash residues that are deposited in landfills will be accounted for in the estimate of releases to water from landfill leachate (see Section 26).

14 Domestic waste burning

This section covers the emissions from the burning of waste in backyard fires where combustion conditions are poor and no controls are applied.

14.1 Emissions to air

The majority of domestic waste burnt usually comprises wood, paper, leaves and vegetation, together with a range of other materials that may include scrap rubber, household scraps and plastics. Although the extent to which domestic waste burning occurs throughout New Zealand is unclear, the Auckland Regional Council has investigated the occurrence of this activity (ARC, 1998). For the "Auckland Study Area", it was estimated that approximately 15,700 tonnes of domestic waste would have been combusted in 1998. This covers primarily the combustion of garden waste (such as tree prunings and leaves) and paper. The Auckland Study Area had an estimated population of 1,019,000 in 1998 (ARC, 1998), with the national population being 3,790,000 at mid 1998 (Statistics NZ, 1998). On the assumption that domestic waste burning patterns are similar nationwide, an estimate of 58,000 tonnes per year is obtained for the whole of New Zealand on a pro-rata basis. The uncertainty in this data should, however, be noted. In particular, it is unknown what proportion potentially high PCDD and PCDF generating material (e.g. PVC and other plastics, "contaminated" wood wastes etc.) makes to the total quantity of the waste that is burnt.

The current inventory has assumed that the composition of domestic waste burnt in New Zealand is approximately 70% organic waste (including green waste) and 30% "house" waste (including paper and plastics). This assumption is based on the composition of residential waste landfilled (see Section 26.1; MfE 1997c), which is then adjusted on a pro-rata basis to exclude the inorganic component (metals, glass and a non-combustible component of construction and demolition waste). This is equivalent to approximately 40,600 tonnes of organic waste and green waste, and 17,400 tonnes of "house" waste burnt in backyard fires.

No New Zealand data are available on the emission of PCDDs and PCDFs from domestic waste burning. The UK Review cited an emission factor range for the open burning of clean wood of 1 – 29 µg I-TEQ tonne^{-1} (HMIP, 1995), which could be used as a surrogate for the burning of green waste. In comparison, the US EPA has reported an emission factor of 300 µg I-TEQ tonne^{-1} from measurements on a simulated open burn of mixed domestic refuse in barrels (Lemieux, 1997). Hazardous wastes (i.e. chemicals, paints, oils etc.) were not included in the test waste. More recently, two studies have reported a series of emission factors for the uncontrolled burning of domestic waste (Gullett *et al.*, 1999) and other selected wastes (Ikeguchi and Tanaka, 1999). These emission factors generally fell within a range of the lower bound UK Review factor and the emission factor reported by Lemieux (1997). For example, Ikeguchi and Tanaka (1999) reported an emission factor of 4.6 µg I-TEQ tonne^{-1} for the open burning of trees and leaves and an emission factor of 220.9 µg I-TEQ tonne^{-1} for scrap tires. Significantly, both studies reported emission factors over 6,000 µg I-TEQ tonne^{-1} for waste with a high PVC content (Gullett *et al.*, 1999; Ikeguchi and Tanaka, 1999), although statistical analysis by Gullett *et al.* (1999) indicated that combustion conditions and not PVC content were the best indicator of PCDD and PCDF emissions.

In the absence of any data for backyard burning in New Zealand, an emission factor range based on the UK Review data of 1 – 29 µg I-TEQ tonne^{-1} has been applied to organic waste (including green waste) and an emission factor range of 29 – 300 µg I-TEQ tonne^{-1} based on the upper bound UK Review value and an upper bound value from Lemieux (1997), has been applied to “house” waste.

National emission estimate

PCDD and PCDF emissions from domestic waste burning are summarised in Table 14.1. The annual emission from this source is estimated to be in the range 0.54 – 6.4 g I-TEQ yr^{-1}.

Table 14.1 PCDD and PCDF emissions from domestic waste burning

Source	**Waste burnt (tonne yr^{-1})**	**Emission factor (µg I-TEQ tonne^{-1})**	**Annual emission range (g I-TEQ yr^{-1})**
Organic waste (inc. green waste)	40,600	1 – 29	0.041 – 1.2
“House” waste (inc. paper and plastics)	17,400	29 – 300	0.50 – 5.2
Total	58,000		0.54 – 6.4

Because of the lack of good data on this source, this estimate of emissions must be considered as a preliminary indication only. It is noteworthy that the top end estimate of 6.4 g I-TEQ yr^{-1} is similar to that from domestic wood burning (see Section 13) estimated at 8.7 g I-TEQ yr^{-1}, yet ambient air monitoring studies (Buckland *et al.*, 1999a,b) strongly indicate domestic wood burning as a significant source of PCDDs and PCDFs during the winter months in New Zealand, while much lower ambient air concentrations are found in urban residential areas in the summer months when backyard burning might be expected to peak. This would suggest that backyard burning, at least in urban residential areas, is not the major domestic source of PCDDs and PCDFs relative to domestic wood burning. Backyard burning of domestic waste may, however, be more significant in rural areas, particularly those where there is no kerbside waste collection.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a ‘low’ certainty ranking because no national data are available, and no allowance has been made for differing waste disposal patterns across the country. In addition, it is unknown exactly what proportion potentially high PCDD and PCDF generating material (e.g. plastics) makes to the total quantity of waste that is burnt. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand emissions test data are available. The estimate of emissions made is based solely on overseas emission factors that were derived from a limited number of studies.

14.2 Releases to land

Ash production from the domestic burning of waste can be expected to vary depending on the degree of combustion, but is likely to be greater than the rate of ash production from controlled waste incineration, which is typically up to 30% (IAWG, 1995).

Lemieux *et al.*, (1997) measured ash generation rates of 51% for mixed household waste burned in barrels. For mixed waste, a concentration of 642 ng I-TEQ kg^{-1} was reported, giving an emission factor in residues of 326 ng I-TEQ kg^{-1} waste burned. In the absence of New Zealand data on PCDD and PCDF concentrations in ash residues from domestic waste burning, the data from Lemieux *et al.*, (1997) is adopted for this inventory.

National release estimate

PCDD and PCDF releases in ash from the domestic burning of "house" waste are summarised in Table 14.2. For 17,400 tonnes of "house" waste, the annual release from this source is estimated to be 5.7 g I-TEQ yr^{-1}. The lack of emission factor data for PCDDs and PCDFs in ash from the domestic burning of organic waste precludes any estimate of releases from this source.

Table 14.2 PCDD and PCDF releases to land from domestic waste burning

Source	Waste burnt (tonne yr^{-1})	Emission factor (µg I-TEQ tonne^{-1})	Annual emission range (g I-TEQ yr^{-1})
"House" waste (inc. paper and plastics)	17,400	326	5.7

This estimate must be considered a preliminary indication only due to uncertainties in the quantity of waste burnt domestically in New Zealand, and the relative proportions of organic/green waste and "house" waste.

Ash from the backyard burning of domestic waste is likely to be disposed of to landfills or is scattered directly on the land.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a 'low' certainty ranking because no national data are available, and no allowance has been made for differing waste disposal patterns across the country. In addition, it is unknown exactly what proportion potentially high PCDD and PCDF generating material (e.g. plastics) makes to the total quantity of waste that is burnt. The emission factor is assigned a 'low' certainty ranking because no New Zealand ash concentration data are available. The estimate of release made is based solely on data taken from a single study in the United States.

14.3 Releases to water

There are no direct releases to water from domestic waste burning.

Any leaching of PCDDs and PCDFs from the ash residues that are deposited in landfills will be accounted for in the estimate of releases to water from landfill leachate (see Section 26).

15 Land transport

This section covers emissions to air from the combustion of unleaded petrol and diesel fuels for land transportation. PCDDs and PCDFs in used oil are addressed in Section 24.

15.1 Emissions to air

PCDDs and PCDFs have been measured in the tailpipe exhausts of motor vehicles, and in roadside dusts, in a number of studies in a number of countries. The combustion of leaded petrol has been associated with PCDD and PCDF emissions due to the presence of a chlorine source in the form of additives in the fuel (such as dichloroethane) that were used as a scavenger for the lead. In comparison, unleaded fuel, in which these scavengers are absent, results in much lower PCDD and PCDF emissions. Other aspects of fuel quality, including the presence of chlorine that may occur naturally in fuel in some cases, the presence of chlorides in air (e.g. sodium chloride in coastal air) aspirated into the engine via the carburetor, and general combustion performance may also influence PCDD and PCDF formation and emissions. A detailed review of this sector is provided in the US Inventory.

Leaded petrol has largely been phased out in New Zealand. Unleaded (91 octane) regular petrol was introduced in 1986, and in early 1996, premium (96 octane) petrol was changed to an unleaded formulation. A small amount of leaded fuel is still used for piston-engined aeroplanes and for specialist motor racing.

Catalytic converters for petrol vehicles are not required in New Zealand. However, they are present on many imported used cars. Approximately 50% of the New Zealand vehicle fleet is second-hand vehicles that are imported from overseas, and this market is dominated by Japanese imports (CRC, 1996). Most of these vehicles are fitted with catalytic converters, but because of the age of the vehicles the condition and effectiveness of the catalysts are unknown. The use of catalytic converters is thought to reduce tailpipe emissions of PCDDs and PCDFs (US EPA, 1998).

Vehicle kilometres travelled

Vehicle kilometres traveled (VKT) for petrol and diesel vehicles in New Zealand were available from the Vehicle Fleet Emissions Model (MoT, 1998) of the Vehicle Fleet Emissions Control Strategy (VFECS). The VFECS concerns the formulation of Government policy for the management of local air quality impacts of traffic emissions. The Vehicle Fleet Emissions Model, the base year for which is 1998, has been developed from the national traffic database, and household and regional traffic surveys. VKT data drawn from the model were as follows:

- 28,770 x 10^6 km for unleaded petrol in cars and light commercial vehicles (< 3.5 tonnes)
- 4,920 x 10^6 km for diesel in cars and light commercial vehicles (light diesel)
- 2,910 x 10^6 km for diesel in heavy commercial vehicles (heavy diesel).

Emission factors for petrol

Testing of vehicle emissions has been limited due to the difficulties encountered in gathering samples that are representative of the multitude of vehicles, road conditions and driving styles. Only one study under New Zealand conditions has been undertaken, and this involved the testing of four cars using leaded petrol and one car using unleaded petrol (Bingham *et al.*, 1989a,b).

HpCDD and OCDD were the only congeners detected in the exhaust from the vehicle using unleaded petrol, which, based solely on these detected congeners, gave an emission factor of 1 pg I-TEQ km^{-1}. The detection limit for the other congeners was a combined 28 pg I-TEQ km^{-1}. The emission factors for the cars driven on leaded petrol were 5 – 39 pg I-TEQ km^{-1} based on detected congeners only.

The emission factors compiled for petrol usage in vehicles in the UK Review were 0.36 – 21 pg I-TEQ km^{-1} for unleaded petrol with no catalytic conversion of the exhaust gas, and 0.36 – 13 pg I-TEQ km^{-1} for unleaded petrol with catalytic conversion (HMIP, 1995). These ranges were derived from consideration of published literature data. Examination of comprehensive German studies suggests values of 9.7 pg I-TEQ km^{-1} for non-catalyst equipped vehicles and 2.2 pg I-TEQ km^{-1} for catalyst equipped vehicles (Essers *et al.,* 1992). From a review of the published data, the US Inventory derived an emission factor of 1.7 pg I-TEQ km^{-1} for unleaded petrol (US EPA, 1998).

Given the uncertainty in the condition of the catalyst equipped vehicles in New Zealand, the emission factor range for unleaded petrol from the UK Review for vehicles with no catalytic conversion has been adopted for this inventory. The factors derived from the German study and the more recent US Inventory fall within the range, adding a degree of confidence to the calculated emissions. It should be noted, however, that there are inherent uncertainties in adopting emission factor data from overseas to derive a New Zealand emissions estimate from land transport. This is because the New Zealand motor vehicle fleet has a significantly different make up to that of other countries, as well as different driving cycles. These differences include engine size, length of trip, and the number of imported catalyst-equipped vehicles.

Emission factors for diesel

Few data are available upon which to base any evaluation of the PCDD and PCDF emissions from diesel fuel combustion. Also confounding an evaluation is the great discrepancy that exists in estimated PCDD and PCDF emissions between laboratory tests and some of the tunnel studies that have been carried out.

The German study of Essers *et al.* (1992) reports variable emission results, with a mean for steady state operation of 22 pg I-TEQ L^{-1} for light duty diesel vehicles (assumed to be equal to 3.7 pg I-TEQ km^{-1} for a fuel economy of 6 km L^{-1})[1]. Test cycles (FTP-75) gave a mean emission of 40 pg I-TEQ L^{-1} (equal to 6.7 pg I-TEQ km^{-1}). Other German data report an emission factor for diesel trucks (up to 3.5 tonnes weight) of 76 pg I-TEQ L^{-1}, equivalent to 12.7 pg I-TEQ km^{-1} (IFEU, 1998, as reported in UNEP, 1999).

Recent studies in the United States on heavy duty vehicles have been reported by Gullett and Ryan (1997) for on-road tests. An average of 29 pg I-TEQ km^{-1} was given for highway and city use. Gertler *et al.* (1997) presented results of a recent tunnel study in the United States and gave a value of 0.28 ng I-TEQ mile^{-1}, equivalent to 174 pg I-TEQ km^{-1}.

The other tunnel study that is often used to calculate emission factors for heavy duty vehicles was carried out in Norway (Oehme *et al.* 1991). This study reported an average of 5,100 pg Nordic-TEQ km^{-1}. However, this result depends on a large extrapolation and may not be representative.

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[1] Data drawn from the Vehicle Fleet Emissions Model (MoT, 1998) provide a fleet weighted average fuel economy of 6 km L^{-1} for light diesel vehicles (< 3.5 tonnes).

To estimate emissions from light diesel, an emission factor range of 3.7 – 12.7 pg I-TEQ km^{-1} has been adopted from the German data (Essers *et al*., 1992; IFEU, 1998), and for heavy diesel vehicles, a range of 29 – 174 pg I-TEQ km^{-1} has been used, based on the recent United States studies (Gullett and Ryan, 1997; Gertler *et al*., 1997). As a comparison, the US Inventory (US EPA, 1998) does not distinguish between heavy and light duty diesels, and has applied an emission factor of 172 pg I-TEQ km^{-1} based on the work of Gertler *et al*. (1997).

National emission estimate

PCDD and PCDF emissions from unleaded petrol and diesel use in land transport are summarised in Table 15.1. The total annual emission from this source is estimated to be between 0.11 – 1.2 g I-TEQ yr^{-1}.

Table 15.1 PCDD and PCDF emissions from land transport

Fuel	Annual VKT (10^6 km)	Emission factor (pg I-TEQ km^{-1})	Annual emission range (g I-TEQ yr^{-1})
Unleaded petrol	28,770	0.36 – 21	0.010 – 0.59
Light diesel	4,920	3.7 – 12.7	0.018 – 0.062
Heavy diesel	2,910	29 – 174	0.084 – 0.51
Total			0.11 – 1.2

Bingham (1992) has made a previous emission estimate of 5 g I-TEQ yr^{-1} from motor vehicles fuelled by leaded petrol (see Section 1.3). The current lower estimate of emissions is consistent with the removal of lead from petrol for New Zealand's motor vehicle fleet.

Certainty

Activity statistic	H
Emission factor	L

For all fuels (i.e. unleaded petrol, light diesel and heavy diesel), the activity statistic is assigned a 'high' certainty ranking because the VKTs are drawn from the Ministry of Transport's Vehicle Fleet Emissions Model, which is based on national, regional and household data. The emission factor is assigned a 'low' certainty ranking for all fuel types because it is based on factors derived primarily from overseas vehicle studies, some of which were limited in scope and are now several years old. In addition, the applicability of these emission factors to the New Zealand vehicle fleet, particularly with respect to the fuels, engine operation and emission control technology, is uncertain.

15.2 Releases to land

No direct releases to land are expected and no estimate of PCDDs and PCDFs released to land specifically from land transport has been made.

PCDDs and PCDFs in used oil may be applied to land from road oiling activities. This source has been addressed separately in Section 24.

15.3 Releases to water

There are no direct releases to water from the combustion of unleaded petrol and diesel fuels for land transport. PCDD and PCDF releases to water from used oil disposal via discharges to drains are addressed separately in Section 24.

16 Uncontrolled fires

Uncontrolled fires are potentially a major contributor of PCDD and PCDF emissions to the environment, particularly due to poor combustion and the range of materials that may be burnt. This section presents estimates of the PCDD and PCDF emissions from forest, structure and vehicle fires, and discusses other uncontrolled burning activities in New Zealand.

16.1 Emissions to air

16.1.1 Forest, scrub and grass fires

Information from the New Zealand Fire Service indicates that, on average, for the years 1988 to 1998, 340 ha of forest, 1,570 ha of scrub and 1,990 ha of grass were burnt each year (Grieve, 1999). Estimates have been made of the combustible material lost in these fires by the New Zealand Forestry Research Institute (FRI) (Pearce, 1999). These estimates are: 10 tonnes ha^{-1} for forests; 20 tonnes ha^{-1} for scrub; and 2.5 tonnes ha^{-1} for grass. These can be compared to the US Inventory figure of 9.43 tonnes acre^{-1} (equivalent to 23.3 tonnes ha^{-1}; US EPA, 1998). Given that the species of wood and scrub are different in the two countries, it is appropriate to use the losses estimated by the FRI. The total quantities of material that are estimated to be burnt annually in New Zealand are given in Table 16.1.

No New Zealand test data are available on the emission of PCDDs and PCDFs from forest, scrub and grass fires. There are also very limited international data from which to generate emissions factors for natural fires. The problems in collecting a representative sample for this source are very difficult to overcome. A number of studies have attempted to infer emissions by studying the soils from sites of biomass fires and others have attempted to derive emission factors from PCDD and PCDF concentrations measured in soot. A problem with the latter approach is that deposited soot can accumulate PCDDs and PCDFs over time and may therefore be unrepresentative of concentrations in emitted particulate matter. Useful reviews of the available data from which to derive emission factors is provided in the UK Review (HMIP, 1995) and the US Inventory (US EPA, 1998).

To estimate emissions in the United States, the US Inventory used an emission factor based on wood stove emissions for enclosed appliances of 2 µg I-TEQ tonne^{-1} of woody biomass burned. This factor has been used in this inventory to provide a lower bound estimate of emissions. The same approach based on open appliances can be used to provide an upper bound estimate of emissions. For natural fires, the UK Review used an emission factor for clean wood burnt in open domestic fireplaces taken from the study published by Bremmer *et al.* (1994) of 28.5 µg I-TEQ tonne^{-1}. The current inventory therefore uses an emission factor range of 2 – 29 µg I-TEQ tonne^{-1}. This range brackets emission factors that have been reported for the burning of straw in a domestic heating furnace of 17 µg I-TEQ tonne^{-1} (HMIP, 1995) and for the open burning of straw of 20.2 µg TEQ tonne^{-1} (Ikeguchi and Tanaka, 1999).

National emission estimate

PCDD and PCDF emissions from uncontrolled forest, scrub and grass fires are summarised in Table 16.1. The total annual emission from this source is estimated to be in the range 0.080 – 1.1 g I-TEQ yr^{-1}.

Table 16.1 PCDD and PCDF emissions from forest, scrub and grass fires

Source	Area burned ($ha\ yr^{-1}$)	Combustible material ($tonnes\ ha^{-1}$)	Quantity burnt ($tonne\ yr^{-1}$)	Emission factor (μg I-TEQ $tonne^{-1}$)	Annual emission range (g I-TEQ yr^{-1})
Forests	340	10	3,400	2 – 29	0.0068 – 0.099
Scrub	1,570	20	31,400	2 – 29	0.063 – 0.91
Grass	1,990	2.5	4,980	2 – 29	0.010 – 0.14
Total	3,900		39,780		0.080 – 1.1

It must be noted that this is an initial estimate only and does not account for the authorised burning that takes place in forest, scrub and stubble clearing where the Fire Service is not called on. An estimate for the total emission could reasonably be assumed to be twice the calculated figure. This would mean that the total PCDD and PCDF emission could potentially be in the range 0.16 – 2.2 g I-TEQ yr^{-1}.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a ‘low’ certainty ranking because there are assumptions made in estimating the quantity of combustible material lost in forest, scrub and grass fires, and because it does not include any authorised burning that takes place. The emission factor is assigned a ‘low’ certainty ranking because it is based on a data for wood burning in wood stoves (enclosed appliances) and in open fireplaces, and these may not be representative of natural forest, scrub and grass fires.

16.1.2 Structure fires

Structure fires vary enormously in size, intensity and the materials involved. The poor combustion conditions and the multitude of materials present in most fires will lead to the release of PCDDs and PCDFs. Because of this complexity, it is difficult to develop estimates for either emission factors or masses of material involved in the fires. To date, few inventories have even attempted to quantify emissions from these sources.

The New Zealand Fire Service reports that the total number of structure fires in New Zealand for the period July 1997 to June 1998 was 7,310 (NZFS, 1999). These included fires at residential properties, commercial and manufacturing establishments, educational institutes and miscellaneous buildings. Unfortunately there is no information on the quantity of material consumed in these fires.

Advice from the New Zealand Fire Service indicates that most of these fires would have been relatively small, increasing in size and severity with decreasing frequency (Chubb, 1999). An estimate of the quantity of material consumed in New Zealand structure fires has therefore been made by assuming that:

- 90% of the 7,310 fires are small, consuming 100 – 250 kg material $fire^{-1}$;
- 90% of the remaining 730 fires are moderate, consuming 1 – 2.5 tonne material $fire^{-1}$;
- 90% of the remaining 73 fires are large, consuming 10 – 25 tonne material $fire^{-1}$;
- The remaining 7 fires are very large, consuming 250 – 1,000 tonne $fire^{-1}$.

On this basis, the total quantity of material burnt in New Zealand structure fires is estimated to be between 2,680 – 6,690 tonnes per year.

No PCDD and PCDF emission data are available for structure fires in New Zealand. Estimates of PCDD and PCDF emissions from PVC consumed in household fires in the United States have been reviewed (Carroll, 1996). Here, four different methods were used to determine the PCDD and PCDF emissions from the PVC burned, including the analysis of soot and ash, and the PVC content of typical houses. Based on a total of 341,000 fires per year, 9.5% material loss, and a typical house footprint area of 1500 ft^2, Carroll (1996) estimated PCDD and PCDF emissions were between 0.074 – 22.8 g I-TEQ yr^{-1}. The corresponding emission factors ranged from 30 – 3,500 µg I-TEQ $tonne^{-1}$ of PVC.

The US Inventory also reviewed emissions from structure fires and concluded that the uncertainty in the emission estimates was too great to warrant an estimation of the annual PCDD and PCDF release to air from this source (US EPA, 1998).

In experimental studies, Merk *et al.* (1995) combusted 40 kg of PVC and 400 kg of wood in a closed hall and reported air concentrations of 5 ng m^{-3} in the hall and 50 ng m^{-2} in wipe samples from surfaces. Emission factors were in the range 560 – 2,800 µg I-TEQ $tonne^{-1}$ (presuming all the PCDDs and PCDFs come from the PVC only) or 50 – 250 µg I-TEQ $tonne^{-1}$ if the PCDDs and PCDFs come from the wood and PVC. The original data do not make clear whether all the PCDDs and PCDFs in the air were deposited in the hall or if some were transported out in smoke or whether the air concentration was to be added to the soot deposition.

Wichmann *et al.* (1995) reported on tests involving burning cars and railway carriages in a tunnel. Their data suggest emission factors (soot deposited in the tunnel) of 85 (old car), 78 (new car), 780 (old railway carriage) and 1,900 µg I-TEQ $tonne^{-1}$ (new railway carriage). These factors are based on the combustible fraction of the vehicles rather than their total mass.

For the purposes of making an initial estimate of PCDD and PCDF emissions from this source, an emission factor range of 100 – 400 µg I-TEQ $tonne^{-1}$ of material consumed has been applied.

National emission estimate

PCDD and PCDF emissions from uncontrolled structure fires are summarised in Table 16.2. The total annual emission from this source is estimated to be in the range 0.27 – 2.7 g I-TEQ $year^{-1}$. This should be regarded as an indicative estimate only.

Table 16.2 PCDD and PCDF emissions from structure fires

Source	Material consumed (tonne yr^{-1})	Emission factor (µg I-TEQ $tonne^{-1}$)	Annual emission (g I-TEQ yr^{-1})
Structure fires	2,680 – 6,690	100 – 400	0.27 – 2.7

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a 'low' certainty ranking because the quantity of material consumed in structure fires in New Zealand has been estimated in the absence of actual measured data. The emission factor is assigned a 'low' certainty ranking because there are only a limited amount of data available for this sector, and the data themselves are variable.

16.1.3 Vehicle fires

Information on the quantity of material that is burned in vehicle fires is unknown. In addition, there are only a limited amount of data relating to the emissions of PCDDs and PCDFs from this source. However, given the poor combustion conditions that are present, and the range of materials involved, vehicle fires will contribute to PCDD and PCDF emissions.

The New Zealand Fire Service attended 3,141 and 3,219 vehicle fires during the periods July 1996 to June 1997 and July 1997 to June 1998 respectively (NZFS, 1999). These included cars, busses, caravans, motorhomes, trucks, vans and passenger rail carriages. An average of 3,200 fires is assumed for this inventory.

No PCDD and PCDF emission data are available for vehicle fires in New Zealand. As previously noted, Wichmann *et al.* (1995) developed emission factors of 85 µg I-TEQ tonne^{-1} for an old car, 78 µg I-TEQ tonne^{-1} for a new car and 1,900 µg I-TEQ tonne^{-1} for a new railway carriage (based on the mass of combustible material). For cars, the emissions were given as 32 µg car^{-1} for an old car and 44 µg car^{-1} for a new car, and these factors have been used here.

National emission estimate

PCDD and PCDF emissions from vehicle fires are summarised in Table 16.3. The total annual emission from this source is estimated to be in the range 0.10 – 0.14 g I-TEQ yr^{-1}.

Table 16.3 PCDD and PCDF emissions from vehicle fires

Source	Vehicle fires (fires yr^{-1})	Emission factor (µg I-TEQ fire^{-1})	Annual emission range (g I-TEQ yr^{-1})
Vehicle fires	3,200	32 – 44	0.10 – 0.14

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a 'low' certainty ranking because the quantity and type of material consumed in vehicle fires is not fully characterised. The emission factor is assigned a 'low' certainty ranking because the data are based on limited measurements from a single study in the United States.

16.1.4 Flaring of gas and oil condensates

Other uncontrolled combustion events that involve the burning of organic matter in the presence of a chlorine source can be expected to lead to the formation and emission of PCDDs and PCDFs. One such activity that was known to occur during 1998, but for which insufficient data are available to make any estimate of emissions, was the flaring of gas and oil condensates.

The flaring of gas and condensates in a ‘flare pit’ from the exploration and production testing of oil and gas wells has occurred at a number of well sites in the Taranaki region that are operated by a number of companies. A flare-pit consists of a hole dug in the ground, typically measuring 200 – 300 m^2 to a depth of approximately 10 m. Gas and condensates from a well are fed into the bottom of the pit through a pipe. Ignition of the condensates is accompanied by a heavy black smoke emission. This clean-up phase generally lasts for only a matter of hours. Monitoring at two well sites measured PCDD and PCDF concentrations up to 2.34 ng I-TEQ m^{-3} in the plume (TRC, 1998a,b). Emission factors were between 4 µg I-TEQ $tonne^{-1}$ of fuel flared (gas well) and 250 µg I-TEQ $tonne^{-1}$ of fuel flared (condensate well).

Atmospheric dispersion modelling of PCDD and PCDF emissions from flaring at these wells, which are located in a rural environment, has been reported (Backshall, 1998). This modelling predicted monthly average ground level air concentrations of 20 – 60 fg I-TEQ m^{-3}, and these were similar to air levels previously reported for a rural Taranaki site (1.66 – 31.6 fg I-TEQ m^{-3}, mean of 16.0 fg I-TEQ m^{-3}; Buckland *et al.*, 1999a,b). Significantly, these air concentrations were markedly elevated compared to PCDD and PCDF concentrations measured at other rural and background ambient air sampling sites in New Zealand (0.77 – 9.88 fg I-TEQ m^{-3}, with a mean of 3.00 fg I-TEQ m^{-3}; Buckland *et al.*, 1999a,b).

The recent adoption of phase separation technology by one of the more extensive companies operating in this region has effectively eliminated the flaring of condensate (believed to be the main source of the PCDD and PCDF emissions) during the clean-up of their wells. Gas only flaring continues for intermittent periods during well testing and production operations during maintenance and emergency shut down. Other companies continue to operate wells in the Taranaki region without the use of phase separation technology.

16.2 Releases to land

In the case of forest, scrub and grass fires, ash will be left in-situ on the land. Ash from structure and vehicle fires will usually be removed as part of cleanup operations, it is assumed to disposal in landfill. Insufficient data are available to make an estimate of PCDDs and PCDFs released to land from these activities.

16.3 Releases to water

Releases to water will occur, particularly in the case of structure and vehicle fires, from fire fighting operations. However, insufficient data are available to make an estimate of PCDDs and PCDFs released to water from these activities.

17 Cement and lime manufacture

17.1 Emissions to air

17.1.1 Cement manufacture

Cement kilns account for a substantial proportion (up to 10%) of industrial coal use in New Zealand (see Section 9, Table 9.1).

There are two plants currently in operation in New Zealand, both of which use coal as the primary energy source. They are of similar size, each producing around 500,000 tonnes of cement per year. A smaller plant (maximum capacity about 50,000 tonnes per year, with an actual output of about 20,000 tonnes of cement per year) operated until late 1998. Emissions from this plant have been included in this inventory.

A range of emission factors have been reported for cement kilns, and these have shown that, in general, PCDD and PCDF emissions are low. Good combustion and long residence times reduce formation of PCDDs and PCDFs, and residual emissions are thought to be heavily dependent on the nature of the raw materials and the temperature of the gas cleaning system. Some overseas data have shown higher emissions for kilns burning hazardous wastes. In New Zealand, used oil is used as an auxiliary fuel in one plant, but the emissions are similar to that for coal burning. No other hazardous waste is burnt in cement kilns.

Of the two operating plants, one plant is a wet process and the other a dry process. They have similar firing characteristics and utilise electrostatic precipitators for gas cleaning. The counter current flow of cement clinker against the products of combustion of coal acts as an effective gas cleaning system and may remove PCDDs and PCDFs that may be produced.

New Zealand test data for the wet process plant reported stack emission concentrations in the range 0.0035 – 0.107 ng I-TEQ Sm^{-3} (mean for five samples of 0.0512 ng I-TEQ Sm^{-3}), corresponding to a mean emission factor of 0.25 µg I-TEQ $tonne^{-1}$ of clinker when burning coal, and emission concentrations in the range 0.0014 – 0.161 ng I-TEQ Sm^{-3} (mean for five samples of 0.0384 ng I-TEQ Sm^{-3}), corresponding to a mean emission factor of 0.20 µg I-TEQ $tonne^{-1}$ of clinker when burning a coal/used oil mix. Note that clinker comprises up to 95% of the final product. These data are consistent with the emission factor range quoted in the UK Review of 0.02 – 1.08 µg I-TEQ $tonne^{-1}$ of clinker (HMIP, 1995), and the US Inventory data of 0.32 µg I-TEQ $tonne^{-1}$ of clinker (US EPA, 1998).

Because the two New Zealand kilns operate different processes, as well as being fired on different coals, the New Zealand data have been used for the kiln where emission tests were carried out (range 0.20 – 0.25 µg I-TEQ $tonne^{-1}$) and the emission factor range of 0.02 – 1.08 µg I-TEQ $tonne^{-1}$ from the UK Review has been adopted for the kiln without measured emissions.

National emission estimate

PCDD and PCDF emissions from cement manufacture are summarised in Table 17.1. For a production of approximately 1,020,000 tonnes of cement per year, the total annual emission from this source is estimated to be in the range 0.10 – 0.65 g I-TEQ yr^{-1}.

Table 17.1 PCDD and PCDF emissions from cement manufacture

Source	Production (tonne yr^{-1})	Emission factor (μg I-TEQ $tonne^{-1}$ of clinker)	Annual emission range (g I-TEQ yr^{-1})
Cement kiln with measured emissions	500,000	0.20 – 0.25	0.095 – 0.12 [1]
Cement kilns without measured emissions	520,000 [2]	0.02 – 1.08	0.0099 – 0.53 [1]
Total cement manufacture	1,020,000 [3]		0.10 – 0.65

1. Assumes clinker comprises 95% of cement manufactured.
2. Includes 20,000 tonnes of product from the now closed small kiln.
3. Equivalent to 969,000 tonne yr^{-1} of clinker.

Certainty

Activity statistic	H
Emission factor	M

The activity statistic is assigned a 'high' certainty ranking because it is based on industry data for the amount of cement produced. The emission factor is assigned a 'medium' certainty ranking because emission monitoring has only been carried out at only one of the two major cement manufacturing plants in New Zealand.

17.1.2 Lime manufacture

Burnt lime for industrial and agricultural use is produced by the high temperature calcination of limestone. There are four lime plants (total of five kilns) in New Zealand, which collectively produce approximately 151,000 tonnes of burnt lime per year. These kilns are generally fired by coal or gas.

No New Zealand data are available on emissions of PCDDs and PCDFs from these processes. The UK Review quotes the same emission factor for lime manufacture as for cement manufacture (0.02 – 1.08 µg I-TEQ $tonne^{-1}$; HMIP, 1995), and this has been adopted here.

National emission estimate

PCDD and PCDF emissions from lime manufacture are summarised in Table 17.2. The total annual emission from this source is estimated to be in the range 0.0030 – 0.16 g I-TEQ yr^{-1}.

Table 17.2 PCDD and PCDF emissions from lime manufacture

Source	Production (tonne yr^{-1})	Emission factor (μg I-TEQ $tonne^{-1}$)	Annual emission range (g I-TEQ yr^{-1})
Lime manufacture	151,000	0.02 – 1.08	0.0030 – 0.16

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry data for the amount of lime produced. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand data are available; emission factors from the UK Review have been adopted.

17.2 Releases to land

17.1.2 Cement manufacture

As noted in Section 17.1, there are currently two operating cement plants in New Zealand that, together with a now closed plant, produced approximately 1,020,000 tonnes of cement in 1998 (equivalent to 969,000 tonnes per year of clinker). Reiner *et al*. (1995) have reported a PCDD and PCDF concentration for clinker of < 1 ng I-TEQ kg^{-1} for a kiln using a mixture of fuels. This concentration is used to provide an upper estimate of PCDD and PCDF releases in clinker for this inventory.

A large amount of dust is generated in cement kilns, some of which is captured ‘inside’ the process, with the bulk of the remainder being captured by ESPs. In the case of the dry plant, all the dust caught in the ESP is returned to the kiln system. In the case of the wet plant, most of the dust is returned, with a residual amount (approximately 13,000 tonnes per year) being taken out of the system. ESP dust comprises predominantly cement dust with a component of coal ash. A further quantity of dust is emitted by plants through dust that is not caught in the ESPs. Based on industry information, it is estimated that approximately 200 tonnes per year of dust is released in this manner for 1,020,000 tonnes of cement produced. The current inventory therefore estimates releases to land from 13,000 tonnes of rejected ESP dust and 200 tonnes of non-captured dust produced as a result of cement manufacture.

No New Zealand specific data for PCDD and PCDF concentrations in cement kiln dusts are available, and therefore data from the UK Land and Water Review have been used in this inventory. This quotes PCDD and PCDF concentrations in cement kiln dusts of 0.001 - 30 ng I-TEQ kg^{-1}, with most results below 10 ng I-TEQ kg^{-1} (Environment Agency, 1997).

National release estimate

PCDD and PCDF releases to land from cement manufacture are presented in Table 17.3. The total annual release from this source is estimated to be in the range 1.3×10^{-5} – 1.4 g I-TEQ yr^{-1}.

Table 17.3 PCDD and PCDF releases to land from cement manufacture

Material	**Production (tonne yr^{-1})**	**PCDD/PCDF concentration (ng I-TEQ kg^{-1})**	**Annual release range (g I-TEQ yr^{-1})**
Clinker	969,000	< 1	0.97
ESP dust	13,200	0.001 – 30	0.000013 – 0.40
Total			0.000013 – 1.4

In general, cement ESP dust is either spread on agricultural land as fertiliser or is used as a binding material for road basecourse.

Certainty

Activity statistic H

Emission factor L

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry sourced data. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand data are available. The emission factor is based solely on overseas data for PCDD and PCDF concentrations in clinker and cement kiln dusts.

17.2.2 Lime manufacture

Five lime kilns have been identified that collectively produce approximately 151,000 tonnes of burnt lime per year. Dust captured from the lime manufacturing process is around 5,000 tonnes per year. No New Zealand concentration data are available for lime dust. Therefore, to estimate releases to land from lime manufacture, it has been assumed that PCDD and PCDF concentrations in the dust are similar to their concentrations in ESP dust from cement manufacture. No estimate is made of releases of PCDDs and PCDFs in the lime produced.

National release estimate

PCDD and PCDF releases to land from lime manufacture are presented in Table 17.4. The total annual release from this source is estimated to be in the range 5.0 x 10^{-6} – 0.15 g I-TEQ yr^{-1}.

Table 17.4 PCDD and PCDF releases to land from lime manufacture

Material	Production (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Dust	5,000	0.001 – 30	0.0000050 – 0.15

Lime dust is applied to land through its use as a stabilizer.

Certainty

Activity statistic M

Emission factor L

The activity statistic is assigned a ‘medium’ certainty ranking, because although it is based on industry sourced data, some estimates have been made to derive the total quantity of dust collected across this industry sector. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand data are available. The emission factor is based solely on overseas data for PCDD and PCDF concentrations in cement kiln dusts.

17.3 Releases to water

There are no direct releases to water.

18 Iron and steel production

The iron and steel industry in New Zealand comprises two companies, both of which are located in the Auckland Region. One company manufactures steel from iron sand and coal, with some use of recycled steel (referred to as primary steel production). The other company solely recycles steel scrap (referred to as secondary steel production). Significantly, New Zealand has no sinter plants, which have been associated with relatively high emissions of PCDDs and PCDFs (HMIP, 1995; US EPA, 1998).

18.1 Emissions to air

18.1.1 Primary steel production

This plant is one of only a few of its kind in the world, and produces steel using the direct reduction process (Lurgi-Stelco process) from iron sand and coal. The coal is used as both a fuel in the multi-hearth furnaces and the source of carbon required for steel making. PCDD and PCDF emission tests have been conducted on the air discharges from the plant, the results of which are presented in Table 18.1.

Table 18.1 PCDD and PCDF concentrations in emissions to air from primary steel production

Source (number of)	Concentration in emission (ng I-TEQ Nm^{-3})	Annual emission (g I-TEQ yr^{-1})
Multi hearth furnaces (4)	0.0119	0.0399
Direct reduction kilns (4)	0.0186	0.0389
Steel making converter (1)	0.0062	0.0012
Electric arc furnace baghouse [1] (1)	0.0099	0.0139
Steel making fume baghouse (1)	0.0013	0.0072
Total		0.10

1. The arc furnace ceased operation in September 1998.

For a total steel output of 600,000 – 700,000 tonnes per year (average of 650,000 tonnes), an average emission factor across the plant of 0.16 µg I-TEQ tonne^{-1} of steel produced is derived.

National emission estimate

PCDD and PCDF emissions from primary steel production are summarised in Table 18.2. The total annual emission from this source is estimated to be 0.10 g I-TEQ yr^{-1}.

Table 18.2 PCDD and PCDF emissions from primary steel production

Source	Production (tonne yr^{-1})	Emission factor (µg I-TEQ tonne^{-1})	Annual emission range (g I-TEQ yr^{-1})
Primary steel production	650,000	0.16	0.10

It is difficult to compare these data with other primary steel making data because of the fundamental difference in the steel making process used at this plant compared with the standard processes most commonly found at iron and steel plants overseas. Nevertheless, these emissions are low compared to emissions from steel production reported elsewhere (HMIP, 1995; US EPA, 1998; UNEP, 1999).

Certainty

Activity statistic	H
Emission factor	H

The activity statistic is assigned a ‘high’ certainty ranking because it is based on precise industry data for the amount of steel manufactured from iron sand. The emission factor is also assigned a ‘high’ certainty ranking because it is based on extensive emission test data carried out at New Zealand’s only primary steel producer.

18.1.2 Secondary steel production

New Zealand’s sole secondary steel manufacturing plant, which uses a single electric arc furnace, has a rated capacity of 170,000 tonnes per year. Scrap steel comes from a variety of sources, including scrap motor vehicles. The melting of scrap ferrous metal contaminated with metal working fluids and materials containing chlorine provides conditions that are conducive to the formation of PCDDs and PCDFs. However, the process does not involve any scrap preheating which has been linked to high emissions of PCDDs and PCDFs at plants overseas. High concentrations of PCBs have been measured at the site (e.g. in sump pits and stormwater sediments), and it is probable that PCB contaminated materials have been processed through the plant.

Historically, the fume from the electric arc furnace was collected in a “dog box” and cleaned using fabric filtration. In 1999, a new fume plant was installed on the arc furnace and the “dog box” was replaced with a canopy hood in the roof of the building and a large capacity bag filter house. The new fume plant also controls fugitive emissions from the electric arc furnace building.

With the commissioning of the new fume plant, extensive emission monitoring has been undertaken. Thus, for six samples collected over a six month period, PCDD and PCDF concentrations in the emission were measured in the range 0.0064 – 0.0239 ng I-TEQ Nm^{-3} (mean of 0.0127 ng I-TEQ Nm^{-3}). These concentrations correspond to an emission factor range of 0.098 – 0.37 µg I-TEQ tonne^{-1} of steel produced. A single emission measurement was previously carried out on this plant in 1993. The test was performed on fugitive fume and some approximations were made to estimate the actual emissions from both fugitive and stack sources. The calculated emission factor using this measurement was 1.18 µg I-TEQ tonne^{-1}, which is only marginally higher than the top end emission factor from the recent monitoring programmes.

Overseas emission factors are available for electric arc furnaces, which provide useful comparative data. Thus, a mean emission factor of 1.15 µg I-TEQ tonne^{-1} of scrap processed has been reported based on German data (Umweltbundesamt, 1996), and this was used to estimate emissions from electric arc furnaces in the United States (US EPA, 1998). Higher emission factors have been reported by Tysklind *et al.* (1989), who studied the formation and emission of PCDDs and PCDFs at a pilot 10 tonne arc furnace in Sweden. This study found that the highest emissions occurred when the feedstock comprised scrap metal and PVC plastics. An emission factor of 13 µg Nordic-TEQ tonne^{-1} of feedstock was reported for batch-wise charge of the feedstock through the furnace and 7.7 µg Nordic-TEQ $tonne^{-1}$ for continuous charge of the feedstock. For the United Kingdom inventory, a range of 0.7 – 10 µg I-TEQ $tonne^{-1}$ was used for steel works processing scrap materials that was considered to be representative of “no chlorine” and “high chlorine” operational conditions (HMIP, 1995).

National emission estimate

PCDD and PCDF emissions from secondary steel production are summarised in Table 18.3. For an output of 170,000 tonnes per year, and using the most recent plant specific emission factor data, the total annual emission for this source is estimated to be in the range 0.017 – 0.063 g I-TEQ yr^{-1}.

Table 18.3   PCDD and PCDF emissions from secondary steel production

Source	Production (tonne yr^{-1})	Emission factor (µg I-TEQ $tonne^{-1}$)	Annual emission range (g I-TEQ yr^{-1})
Secondary steel production	170,000	0.098 – 0.37	0.017 – 0.063

Certainty

Activity statistic	H
Emission factor	H

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry data for the amount of scrap steel recycled. The emission factor is assigned a ‘high’ certainty ranking because it is based on extensive industry specific data.

18.2 Releases to land

18.2.1 Primary steel production

The primary solid waste streams are slag, sludges, waste lime and baghouse dusts.

Due to the nature of the steel making process, only very low levels of PCDDs and PCDFs are expected to be present in either the iron making slag or the steel making slag. As a result, no analyses have been carried out on these waste streams, and, therefore, no estimate of releases to land from iron making or steel making slag is made.

Iron making slag is commonly used as an aggregate replacement for drainage materials and roading. This slag is also marketed as Eco-Flow and used as a wetland filter where it can cope with the high flow rates of large volumes of water. Steel making slag produced by the steel making converter contains high concentrations of calcium and magnesium oxides, and is used as a lime based soil conditioner (marketed under the name of KOB-MAX). The steel making slag is also used for farm tracks and road stabilization, as the application of water encourages calcification and the formation of a hardened road surface.

Approximately 47,440 tonnes per year of sludges and dusts are generated during the primary steel making process, and PCDD and PCDF analyses have been conducted on each of these waste streams. The quantities of waste produced and PCDD and PCDF concentrations measured are summarised in Table 18.4.

National release estimate

PCDD and PCDF releases in sludges and dusts from primary steel production are summarised in Table 18.4. The total annual release from these wastes is estimated to be 0.67 g I-TEQ yr^{-1}.

Table 18.4 PCDD and PCDF releases to land from primary steel production

Waste stream	Quantity of waste (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release (g I-TEQ yr^{-1})
Steel making baghouse dust	3,000	36.5	0.11
Sand/char (RPCC)	30,000	3.3	0.099
Arc furnace baghouse dust [1]	1,300	357	0.46
Primary operations gas scrubber sludge	13,140	0.045	0.00059
Total	47,440		0.67

RPCC Reduced Primary Concentrate and Char.

1. The arc furnace ceased operation in September 1998.

Waste sludges and dusts are disposed of at the site landfill.

Certainty

Activity statistic	H
Emission factor	M

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry data for the various waste streams at New Zealand’s only primary steel manufacturing plant. The emission factor is assigned a ‘medium’ certainty ranking because it is based on limited site specific PCDD and PCDF concentration data obtained on each of these waste streams.

18.2.2 Secondary steel production

There are three main solid waste streams from the secondary steel manufacturing plant. These are waste lime (10,000 tonne yr^{-1}), slag (20,000 tonne yr^{-1}) and baghouse dust (2,000 tonne yr^{-1}). There are no PCDD and PCDF concentration data available for the waste lime and slag, and therefore no estimate of PCDD and PCDF releases to land from these materials can be made.

A small quantity of the waste lime is mixed with slag, while the remainder is sent to a landfill. Much of the slag is sold and is subsequently used in, for example, roading.

Of all of the solid waste streams, the most likely waste in which to find elevated levels of PCDDs and PCDFs is the baghouse dust. Recent testing of the baghouse dust from the new fume plant gave a PCDD and PCDF concentration of 700 ng I-TEQ kg^{-1}. This compares well with data reported in the UK Land and Water Review (Environment Agency, 1997), which quotes a concentration for electric arc furnace baghouse dust of 900 ng I-TEQ kg^{-1}. To estimate releases to land from secondary steel production, the New Zealand concentration data has been used.

National release estimate

PCDD and PCDF releases in baghouse dust from secondary steel production are summarised in Table 18.5. The annual release from this source is estimated to be 1.4 g I-TEQ yr^{-1}.

Table 18.5 PCDD and PCDF releases to land from secondary steel production

Waste stream	Quantity of waste (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release (g I-TEQ yr^{-1})
Baghouse dust	2,000	700	1.4

Baghouse dusts are treated (stabilised) and disposed of to landfill.

Certainty

Activity statistic	H
Emission factor	M

The activity statistic is assigned a 'high' certainty ranking because it is based on industry data for baghouse dust at New Zealand's only secondary steel manufacturing plant. The emission factor is assigned a 'medium' certainty ranking because it is based on limited site specific PCDD and PCDF concentration data obtained on the baghouse dust. Further, no estimate has been made of releases from waste lime and slag.

18.3 Releases to water

18.3.1 Primary steel production

Both treated wastewater and stormwater from the primary steel manufacturing plant are discharged to water. The total discharge from the site is approximately 8,500 m^3 per day.

PCDDs and PCDFs have been analysed for in the combined wastewater and stormwater discharge. No congeners were measured, with a TEQ level of 4.7 pg I-TEQ L^{-1} being calculated solely by assuming that non-detected congeners were present at half the LOD.

National release estimate

PCDD and PCDF releases to water at the primary steel manufacturing site are summarised in Table 18.6. The annual release is estimated to be 0.015 g I-TEQ yr^{-1}.

Table 18.6 PCDD and PCDF releases to water from primary steel production

Source	Volume of wastewater (10^6 m^3 yr^{-1})	PCDD/PCDF concentration (pg I-TEQ L^{-1})	Annual release (g I-TEQ yr^{-1})
Primary steel production	3.1	4.7	0.015

Certainty

Activity statistic	H
Emission factor	M

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry data from New Zealand’s only primary steel manufacturing plant. The emission factor is assigned a ‘medium’ certainty ranking because it is based on limited site specific concentration data on the water discharge at this site.

18.3.2 Secondary steel production

There is no information available on the release of PCDDs and PCDFs to water from secondary steel production in New Zealand.

19 Non-ferrous metal production

This section addresses emissions from non-ferrous metal production excluding aluminium production. PCDD and PCDF emissions from primary and secondary aluminium production are addressed in Section 20. The processing of non-ferrous metals is a varied and dispersed industry, especially compared to steel making, and this makes estimating emissions and releases especially difficult.

19.1 Emissions to air

Secondary smelters primarily engage in the processing and recovery of metals and alloys from new and used scrap materials. The processing of non-ferrous metals, and in particular the secondary processing of scrap that may contain organic impurities such as plastics and paint, can lead to the formation and release of PCDDs and PCDFs. In addition, the use of certain chlorine containing chemicals for refining, such as hexachloroethane and chlorine gas, has been associated with increased PCDD and PCDF emissions. The level of emissions from non-ferrous metal production will vary considerably from plant to plant and from time to time depending on factors such as the nature of the feed material, the types and quantities of contaminants on the feed and the gas cleaning systems applied.

There are no large-scale non-ferrous metal producers in New Zealand. There are, however, numerous small foundry operations that deal in both ferrous and non-ferrous metal products. These foundries typically produce anywhere from 0.5 to 30 tonnes per day of a variety of metals including brass, copper, bronze and lead. Due to the sheer number of small operators in this industry as a whole, and the lack of accurate production data for the individual types of activities, it is not possible to further break down this industry.

Without actual data on the quantity of non-ferrous metal produced in New Zealand, it is necessary to make an estimate of production levels based on the number of individuals employed in this sector. Information provided by the New Zealand Metal Casting Industry Association showed that a total of 934 persons were engaged in the industry and belonged to the Association (NZ MCIA, 1995). Total production was estimated to be between 15,000 – 27,000 tonnes per year for the Association members. In 1997 there were an estimated 1,260 persons in total engaged in the industry (Statistics NZ, 1998) which, when pro-rated, gives an estimated total production of 20,000 – 36,000 tonnes per year.

As part of Phase II for this inventory, two emission samples were collected from a New Zealand lead smelter that recycles lead/acid batteries. This facility uses a mechanical battery breaker to remove the PVC separators from the charge prior to loading into a gas fired rotary kiln furnace at > 800 °C. Bag filtration is used for gas clean-up. The first emission sample was collected during the first half of a five hour smelt and the second sample during the second half of a separate five hour smelt. These tests reported stack emission concentrations of 0.030 ng I-TEQ Sm^{-3} and 0.73 ng I-TEQ Sm^{-3} respectively, corresponding to an emission factor of 0.45 µg I-TEQ $tonne^{-1}$ of lead produced. This emission factor is similar to data reported in the US Inventory for a rotary furnace lead smelter of 0.24 – 0.66 µg I-TEQ $tonne^{-1}$ lead. In addition, the top end stack emission concentration of 0.73 ng I-TEQ Sm^{-3} agreed well with an earlier measurement of 1.2 ng I-TEQ m^{-3} for the same facility (Bird *et al*., 1990). No other test data are available on PCDD and PCDF emissions from non-ferrous metal production in New Zealand.

Bremmer *et al.* (1994) have reported emission factors for plants in the Netherlands fitted with a variety of gas cleaning devices of 5 µg I-TEQ tonne^{-1} (brass), 5 µg I-TEQ tonne^{-1} (lead), and 35 µg I-TEQ tonne^{-1} (copper/bronze). Based on these and other data for copper, nickel, magnesium, brass, bronze and lead, the UK Review derived a common emission factor range of 5 – 35 µg I-TEQ tonne^{-1} for all non-ferrous metal thermal operations in the United Kingdom (HMIP, 1995). From studies undertaken in the United States, the US Inventory reports emission factors for secondary lead smelters of 0.24 – 0.66 µg I-TEQ tonne^{-1} lead (rotary kiln furnace) and 0.63 – 8.31 µg I-TEQ tonne^{-1} lead (blast furnace). For the smelting of copper scrap, a much higher emission factor of 779 µg I-TEQ tonne^{-1} scrap metal was determined (US EPA, 1998). Data from Germany report factors for copper production (blast furnaces, metal converters and foundries) in the range 4.81 – 27.1 µg I-TEQ tonne^{-1} (IFEU, 1998, as reported in UNEP, 1999). This study also reported emission factors from secondary zinc production of 0.29 µg I-TEQ tonne^{-1} (remelting), 175 µg I-TEQ tonne^{-1} (rolling mill) and 521 µg I-TEQ tonne^{-1} (hot briquetting).

The wide range of emission factors available for non-ferrous metal production is problematic in deriving an estimate of PCDD and PCDF emissions. Nevertheless, in the absence of comprehensive New Zealand data, the emission factor range of 5 – 35 µg I-TEQ tonne^{-1} derived in the UK Review is adopted for this inventory.

National emission estimate

PCDD and PCDF emissions from non-ferrous metal production are summarised in Table 19.1. The total annual emission from this sector is estimated to be in the range 0.10 – 1.3 g I-TEQ yr^{-1}.

Table 19.1 PCDD and PCDF emissions from non-ferrous metal production

Source	Production (tonne yr^{-1})	Emission factor (µg I-TEQ tonne^{-1})	Annual emission range (g I-TEQ yr^{-1})
Non-ferrous metal production	20,000 – 36,000	5 – 35	0.10 – 1.3

This estimate of emissions does not include the non-consented and poorly controlled burning of copper wire for copper reclamation. Anecdotal information indicates that this practice occurs in New Zealand, but the magnitude of the activity is not known and is almost impossible to assess. Nevertheless, copper is known to catalyse the formation of PCDDs and PCDFs in thermal processes, and high PCDD and PCDF emissions would be expected. The potential for elevated emissions to occur is illustrated by the work of Bremmer *et al.* (1994), who have estimated an emission factor of 500 µg I-TEQ tonne^{-1} for cable burning. Similarly, the US Inventory reports a comparatively high emission factor for copper smelting of 779 µg I-TEQ tonne^{-1} scrap. However, in the absence of data on the quantities of copper wire processed in cable burning operations in New Zealand, no estimate of the potential emissions can be made, but it should be noted that this activity will represent a further release to air.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a ‘low’ certainty ranking because the quantities of individual metal products are not known and the total quantity of non-ferrous metal produced has been estimated on the basis of the number of people working in the industry. The emission factor is assigned a ‘low’ certainty ranking because it is based on overseas test data that may not fully reflect the range of non-ferrous metal processes in New Zealand.

19.2 Releases to land

Solid waste streams from foundry operations include filter fines, dusts and sludges from gas cleaning equipment, and slags. Of the 21 foundries listed in the 1995 New Zealand Foundry Industry Directory (NZ MCIA, 1995), seven of the larger foundries are known to have some form of gas cleaning. It is estimated that this would encompass 60 – 75% of the total annual production of between 20,000 – 36,000 tonnes per year. An approximation of the quantity of fines, dusts and sludge produced from gas cleaning can be made by assuming that waste production will be 8% of metal production (Environment Agency, 1997; see also Section 20.2.2, secondary aluminium production). This would indicate filter fines, dusts and sludge production in the order of 1,000 – 2,000 tonnes per year.

It is assumed that the remainder of the foundries, which are generally relatively small in terms of production, will have no form of gas cleaning and, as such, no solid releases of filter fines, dust or sludge.

No reliable information is available on the amount of slag produced by these operations. There is therefore insufficient information to make any estimate of PCDD and PCDF releases in slags from non-ferrous metal production.

Concentrations of PCDDs and PCDFs in filter fines from a New Zealand lead smelter processing lead/acid batteries have been reported (Bird *et al.*, 1990). Prior to the installation of a mechanical battery breaker to remove PVC separators and other plastic material from the charge, levels were measured at 70 ng I-TEQ kg^{-1}. Following the installation, levels in the filter fines fell to 4.7 ng I-TEQ kg^{-1}. Data for non-ferrous metal operations are also referenced in the UK Land and Water Review (Environment Agency, 1997). This report presents concentrations of 7,700 - 17,800 ng I-TEQ kg^{-1} for filter ash from a secondary lead plant in the Netherlands (Bremmer *et al.*, 1994) and around 12,000 ng Nordic-TEQ kg^{-1} from a smokestack filter powder at a secondary copper plant in Sweden (Strandell *et al.*, 1994). These data are markedly higher than the New Zealand concentrations and their relevance to the current inventory is uncertain. However, to reflect the possible range of New Zealand processes, an estimate of emissions in filter fines and dust from non-ferrous metal production can be made using a concentration range of 190 – 1,100 ng I-TEQ kg^{-1}, which represent the geometric means of the lower bound and upper bound concentrations for the New Zealand and Dutch data for secondary lead plants.

National release estimate

PCDD and PCDF releases from non-ferrous metal production are summarised in Table 19.2. The total annual release from this source is estimated to be in the range 0.19 – 2.2 g I-TEQ yr^{-1}.

Table 19.2 PCDD and PCDF releases to land from non-ferrous metal production

Waste stream	Quantity of waste (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Filter fines and dust	1,000 – 2,000	190 – 1,100	0.19 – 2.2

The uncertainty in this emission estimate is considerable, and may represent a significant underestimate of actual releases to land from non-ferrous metal production. This is shown by using the concentration range as reported by Bremmer *et al.* (1994) of 7,700 – 17,800 ng I-TEQ kg^{-1}, which would result in a markedly higher emission estimate in the range 7.7 – 35.6 g I-TEQ kg^{-1} for this source.

Filter fines, dusts and sludges from gas cleaning are likely to be disposed of primarily to landfill. It is known that some slags are reused, with the remainder likely to go to landfill.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a 'low' certainty ranking because the amount of metal product produced has been estimated based on the number of people working in the industry (see Section 19.1), and, from this, the quantity of solid waste has been calculated by assuming that waste production will be 8% of metal production. The emission factor is assigned a 'low' certainty ranking because only limited New Zealand data are available. This data are several years old and do not agree well with data from the Netherlands or Sweden. It is unknown which concentration data more accurately reflect current New Zealand operations for non-ferrous metal production.

19.3 Releases to water

There is insufficient information to assess the nature or magnitude of any direct releases to water that may occur from non-ferrous metal production.

Any leaching of PCDDs and PCDFs from the waste streams that are deposited in landfills will be accounted for in the estimate of releases to water from landfill leachate (see Section 26).

20 Aluminium production

20.1 Emissions to air

There are two aluminium smelters in New Zealand. One is a primary aluminium smelter located on Tiwai Peninsula, Southland, and the other a secondary aluminium smelter located in the Auckland region. PCDD and PCDF emissions and releases from these operations are considered separately.

20.1.1 Primary aluminium production

The primary aluminium smelter produces approximately 320,000 tonnes of aluminium per year by the prebake Hall-Heroult process. High purity ingots are the major product from this smelter. Typically, around 20% of the aluminium production is cast as extrusion billets. Materials containing chlorine can be used during the billet casting process.

No New Zealand test data are available for emissions to air from this plant, and no emission factors for primary aluminium production could be sourced from the international literature. There is therefore insufficient information available to estimate PCDD and PCDF emissions from primary aluminium production in New Zealand.

20.1.2 Secondary aluminium production

Secondary aluminium smelters reclaim aluminium from a variety of scrap wastes. Scrap metal and metal wastes may contain organic impurities such as plastics, paints and solvents, and their presence during the reclamation processes can result in the formation and emission of PCDDs and PCDFs. In addition, the use of chlorine and hexachloroethane as degassing agents in aluminium production has been associated with elevated PCDD and PCDF emissions.

There are three major secondary aluminium smelters in New Zealand, all located in the Auckland region, along with a fourth smelter in New Plymouth that processes a comparable quantity of scrap aluminium to these smelters as well as other non-ferrous metals. The total aluminium production from these four smelters is approximately 35,000 tonnes per year. Some smelting of aluminium scrap could also occur at the numerous small foundries around the country, and although precise information is not available on the amount of scrap material that would likely be handled, it is not thought to be significant. However, in the absence of data on the likely quantities of scrap processed, no estimate of emissions can be made from secondary aluminium production at these small foundries.

There are no data on PCDD and PCDF emissions from the secondary aluminium smelter in New Zealand. Bremmer *et al*. (1994) have reported emission factors for secondary aluminium plants in the Netherlands that are fitted with a variety of gas cleaning devices ranging from 1.7 – 35 µg I-TEQ tonne^{-1} (of scrap feed). The US Inventory reports data from four secondary smelters in the United States that gave emission factors in the range 0.26 – 30 µg I-TEQ tonne^{-1} of charge material, and from two further studies that reported emission factors of 21.7 and 52.2 µg I-TEQ tonne^{-1} of charge. Similarly, the US Inventory reports German data (Umweltbundesamt, 1996) from 11 tested facilities that had emission factors in the range 0.01 – 167 µg I-TEQ tonne^{-1} of scrap feed, with a mean emission factor of 42 µg I-TEQ tonne^{-1}.

For the current study, an emission factor range of 0.26 – 52.2 μg I-TEQ tonne^{-1} is adopted, based on the data reported in the US Inventory. It should be noted that although the emission factors are based on input (i.e. per tonne of charge or scrap feed), for the purposes of making an initial estimate of emissions, the scrap input is assumed to be roughly equivalent to aluminium output.

National emission estimate

PCDD and PCDF emissions from secondary aluminium production are summarised in Table 20.1. The total annual emission from this source is estimated to be in the range 0.0091 – 1.8 g I-TEQ yr^{-1}.

Table 20.1 PCDD and PCDF emissions from secondary aluminium production

Source	Production (tonne yr^{-1})	Emission factor (μg I-TEQ tonne^{-1})	Annual emission range (g I-TEQ yr^{-1})
Secondary aluminium production	35,000	0.26 – 52.2	0.0091 – 1.8

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a 'medium' certainty ranking because although it is based on industry production data for recycled aluminium, some estimates have been made for this sector. In addition, the activity statistic does not include secondary aluminium that may be produced at the numerous small foundries in New Zealand. The emission factor is assigned a 'low' certainty ranking because no New Zealand emissions test data are available. The factors used are based solely on data taken from overseas studies, although there does appears to be reasonable agreement between the emission factors derived from separate studies in the Netherlands, Germany and the United States.

20.2 Releases to land

20.2.1 Primary aluminium production

The production of primary aluminium from ores is not thought to produce significant quantities of PCDDs and PCDFs (Environment Agency, 1997). The UK Land and Water Review states that there may be the possibility of graphite-based electrodes having some PCDD and PCDF contamination, and quote Swedish data that suggest the spent sludge from the cells may contain 7.8 ng Nordic-TEQ kg^{-1} (Environment Agency, 1997).

In 1998, the primary aluminium smelter in New Zealand produced approximately 3,000 tonnes per year of spent cathode lining and 2,000 tonnes per year of metal reclaim fines.

No New Zealand data are available for PCDD and PCDF concentrations in spent cathode wastes. The reduction cell cathode is a high purity carbon material and the reduction process does not involve chlorine/chloride materials. In addition, the spent cathode is not removed as sludge. The Swedish data are therefore not considered to be applicable to the New Zealand aluminium smelter, and no estimate of PCDD or PCDF releases from spent cathode lining is made.

One of the most likely waste streams in which to find PCDDs and PCDFs is in the metal reclaim fines, as chlorine/chloride based products are used to degas the fraction of the aluminium that is poured into extrusion billets. Data from 1992 for landfill dross from the primary aluminium smelter indicate a PCDD and PCDF concentration of 0.85 ng I-TEQ kg^{-1}. Whilst this is only a single data point from historic plant operations it can be used to provide a provisional assessment of releases from this waste stream. It should be noted, however, that since 1992, the billet casting process has changed, with significantly less chlorine now being used. The metal reclaim process has also been improved, and less metal reclaim fines are now deposited in the site landfill.

National release estimate

PCDD and PCDF releases via metal reclaim fines from primary aluminium production are summarised in Table 20.2. The total annual release from this source is estimated to be 0.0017 g I-TEQ yr^{-1}.

Table 20.2 PCDD and PCDF releases to land from primary aluminium production

Waste stream	Quantity of waste (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Metal reclaim fines	2,000	0.85	0.0017

The spent cathode wastes from primary aluminium production are placed in covered stores onsite. Metal reclaim fines are deposited in the site landfill.

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry data for the quantity of metal reclaim fines produced from primary aluminium production. The emission factor is assigned a ‘low’ certainty ranking because it is based on limited and historic data, and may not be representative of current plant operations.

20.2.2 Secondary aluminium production

Solid waste streams from secondary aluminium smelting and refining are likely to include filter fines and dusts from gas cleaning equipment, and slags and waste sand from cast product. This inventory addresses only filter fines and dusts collected in gas cleaning systems, as these are likely to have the highest levels of PCDDs and PCDFs.

Of the four smelters considered in this inventory, only two are known to have a baghouse or other form of gas cleaning system in place for the collection of filter fines and dust. These two smelters account for approximately 50 – 60% of the total secondary aluminium production in New Zealand. The UK Land and Water Review indicates that solids collected in exhaust gas treatment systems of typical furnaces are approximately 8% of metal production (Environment Agency, 1997). On this basis, for aluminium production of 35,000 tonnes per year, approximately 1,400 – 1,700 tonnes per year of filter fines and dust would be collected.

There are no New Zealand data on the concentration of PCDDs and PCDFs in filter fines and dust from secondary aluminium production. The UK Land and Water Review summarises available concentration data in filter dusts and ash of gas cleaning equipment from investigations on foundries in Europe. On the basis of these data, the Review adopted a range of 480 – 4,000 ng I-TEQ kg^{-1} to be reflective of the concentrations found at typical secondary aluminium smelters. This concentration range has been applied for the current inventory.

National release estimate

PCDD and PCDF releases in filter fines and dust from secondary aluminium production are summarised in Table 20.3. The total annual release from this source is estimated to be in the range 0.67 – 6.8 g I-TEQ yr^{-1}.

Table 20.3 PCDD and PCDF releases to land from secondary aluminium production

Waste stream	Quantity of waste (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Filter fines and dust	1,400 – 1,700	480 – 4,000	0.67 – 6.8

Dusts from gas cleaning are likely to be disposed of primarily to landfill.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a ‘low’ certainty ranking because the quantity of dust was estimated from the amount of aluminium produced, using a dust generation rate taken from UK Land and Water Review. No New Zealand specific data was available on the actual quantity of dust collected. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand emissions test data are available. The factors used are based solely on overseas emission factors as reviewed in the UK Land and Water Review.

20.3 Releases to water

There is insufficient information to make any assessment of the likely PCDD and PCDF releases to water from aluminium production in New Zealand.

Any leaching of PCDDs and PCDFs from the waste streams that are deposited in landfills will be accounted for in the estimate of releases to water from landfill leachate (see Section 26).

21 Glass production

21.1 Emissions to air

The main glass container producing plant, located in Auckland, New Zealand, has a capacity of 115,000 tonnes per year. Fibreglass insulation plants have a total output of about 5,000 tonnes per year, giving a total annual glass production of approximately 120,000 tonnes.

There are no New Zealand PCDD and PCDF emission data for glass production. The UK Review records that no measurements of PCDDs and PCDFs from glass production operations were available, and as a consequence derived emission factors of 0.002 – 0.005 µg I-TEQ tonne^{-1} based on energy consumption and the fuel used in the production process (HMIP, 1995). The US Inventory (US EPA, 1998) quotes emission factors of 0.002 – 0.007 µg I-TEQ tonne^{-1} for two glass manufacturing facilities in Germany (Umweltbundesamt, 1996), which are in line with those derived in the UK Review. However, a higher emission factor of 0.032 µg I-TEQ tonne^{-1} has also been reported for glass production in Germany (IFEU, 1998, as reported in UNEP, 1999). An emission factor range of 0.002 – 0.032 µg I-TEQ tonne^{-1} has therefore been adopted for this inventory.

National emission estimate

PCDD and PCDF emissions from glass production are summarised in Table 21.1. The annual emission from this source is estimated to be in the range 0.00024 – 0.0038 g I-TEQ yr^{-1}.

Table 21.1 PCDD and PCDF emissions from glass production

Source	**Production (tonne yr^{-1})**	**Emission factor (µg I-TEQ tonne^{-1})**	**Annual emission range (g I-TEQ yr^{-1})**
Glass production	120,000	0.002 – 0.032	0.00024 – 0.0038

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a ‘high’ certainty ranking because it is based on the production capacity of the main glass producing plant in New Zealand. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand emissions test data are available. The factors used are based on emission measurements made in Germany that bracket the theoretically derived emission factors from the United Kingdom.

22 Pulp and paper production

In New Zealand, pulp for paper production is produced by either chemical (e.g. kraft, sulphite) or mechanical pulping. There are two bleached kraft mills, one located in the Bay of Plenty (BoP) region and the other in the Waikato. Historically, both mills used elemental chlorine in the production of bleached pulp, which led to the formation and release of PCDDs and PCDFs in the pulp, effluent and solid waste streams. The two mills now use a modified kraft pulping process using oxygen delignification and chlorine dioxide to bleach the pulp, significantly reducing the formation of PCDDs and PCDFs. The sequence at both mills for the production of pulp and paper is as follows:

- Wood preparation to remove the bark and chipping;
- Cooking to remove most of the lignin and produce the pulp;
- Pulp washing to wash out the chemicals used in the cooking process and the extracted lignin;
- Pulp screening to remove knots and bundles of fibres;
- Bleaching of the pulp with oxygen and chlorine dioxide;
- Paper making in which the pulp is formed into a continuous sheet, dried and rolled.

The chlorine and sodium chlorate used for the generation of the chlorine dioxide are produced electrolytically from brine. The process is carried out in the absence of any carbon source and is therefore not expected to release any quantities of PCDDs and PCDFs. Other ancillary processes are used to recover the major chemicals that are re-utilised in the process.

A significant number of studies have been undertaken internationally to determine the concentrations of PCDDs and PCDFs in pulp, effluent and sludge from bleached kraft mills, such as those undertaken by the National Council for Air and Stream Improvement (NCASI, 1990; NCASI, 1994). Similarly, extensive investigations have been carried out at the two New Zealand bleached kraft mills. The estimates of emissions and releases made in this inventory are therefore based on this New Zealand data.

Since the earliest identification of PCDD and PCDF contamination from pulp bleaching (Amendola *et al*., 1989; Swanson *et al*., 1988), the pulp and paper industry has worked actively to reduce their formation and release to the environment. Whilst the use of elemental chlorine for bleaching was quickly identified as being important in the formation of PCDDs and PCDFs, notably the TCDD and TCDF congeners, other practices, including the use of certain oil based defoamers, were also contributory factors. Improvements in the industry were rapidly undertaken on a global basis, and within 6 years, emissions were down by approximately 90% from 1989 levels. Mill upgrades at both New Zealand kraft mills during the 1990s has meant that PCDD and PCDF levels in export vectors, which were always historically low compared to levels reported for bleached pulp mills overseas (NCASI, 1990; NCASI, 1994), have also fallen by around 90%, to current levels.

Non-kraft mills (such as thermomechanical and sulphite mills) do not use chlorine in the production of pulp, and therefore PCDDs and PCDFs are not directly associated with their discharges. However, where recycled paper is being produced and PCDDs and PCDFs are brought into the mill with the feed, then some releases to land and water may occur.

22.1 Emissions to air

22.1.1 Bleached kraft mills

In the kraft process, clean wood chips are cooked in a mixture of sodium hydroxide and sodium sulphide to produce wood pulp. The spent cooking liquor, known as black liquor, contains dissolved lignin and this is reclaimed and burnt in a chemical recovery boiler to produce steam and energy, and the inorganic chemicals are recycled. Overseas data have shown that PCDDs and PCDFs may be emitted to air during the combustion of the black liquor.

There are two recovery boilers at both the BoP and Waikato mills. The processes followed at the mills result in a high degree of recovery of the liquor, such that approximately 1.8 tonnes of black liquor solids are obtained per tonne of bleached kraft pulp. For a total of 700,000 tonnes of air dry pulp (10% moisture content) produced in New Zealand, approximately 1,260,000 tonnes of black liquor solids result, which comprises 35 % inorganics.

A monitoring programme undertaken on the two recovery boilers at the Waikato mill measured PCDD and PCDF concentrations in the emissions of 0.0099 ng I-TEQ m^{-3} and 0.060 ng I-TEQ m^{-3} (Arthur, 1994). Only 2,3,7,8-heptachloro- and octachloro- congeners were quantified, with all other 2,3,7,8- congeners below the limit of detection. Emission factors were calculated as 0.026 µg I-TEQ $tonne^{-1}$ of black liquor solids (dry material, 35% inorganics) and 0.036 µg I-TEQ $tonne^{-1}$ of black liquor solids respectively. These emission factors compare well with data in the US Inventory, which reported a mean emission factor across six facilities of 0.068 µg I-TEQ $tonne^{-1}$ (US EPA, 1998). The Waikato test data are used to estimate emissions to air from all four recovery boilers in the current study.

National emission estimate

PCDD and PCDF emissions from the combustion of black liquor solids are summarised in Table 22.1. The total annual emission from this source is estimated to be in the range 0.033 – 0.045 g I-TEQ yr^{-1}.

Table 22.1 PCDD and PCDF emissions from black liquor recovery boilers

Source	BLS combusted (tonne yr^{-1})	Emission factor (µg I-TEQ $tonne^{-1}$)	Annual emission range (g I-TEQ yr^{-1})
Black liquor solids (BLS)	1,260,000	0.026 – 0.036	0.033 – 0.045

Certainty

Activity statistic	H
Emission factor	M

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry data for the amount of blank liquor combusted at both New Zealand kraft mills. The emission factor is assigned a ‘medium’ certainty ranking because it is based on emission monitoring data from one of these mills, and these data compare well with data reported in the US Inventory.

22.2 Releases to land

22.2.1 Bleached kraft mills

Sludge is the only solid waste stream produced at New Zealand bleached kraft mills that will contain PCDD and PCDF residues. The wastewater treatment systems that are present at both mills result in the production of both primary and secondary sludge streams.

The quantity of primary sludge produced was estimated, based on regular industry monitoring data, at approximately 36,700 tonnes per year. The production of secondary sludge was calculated from BOD removal rates provided by industry. It was assumed that 0.5 tonnes of solid was produced per tonne of BOD removed (Metcalf and Eddy, 1991). On this basis, approximately 11,400 tonnes per year of secondary sludge is produced.

PCDD and PCDF concentrations used to estimate releases to land are based on analyses of primary sludge collected from the BoP mill in 1992 and secondary sludge dredged from the treatment ponds at the BoP mill in 1997. The primary sludge had a concentration of 4.5 ng I-TEQ kg^{-1} DW and the secondary sludge a concentration of 34 ng I-TEQ kg^{-1} DW. The concentrations measured in these sludges reflect historic mill operations when elemental chlorine was used in the bleach plants. With a bleaching sequence that is now elemental chlorine free, the concentrations of PCDDs and PCDFs in the primary and secondary sludge from current mill operations can be expected to be lower than the 1992 and 1997 data. This is supported by 1998 test data for the bleach plant effluents, which showed no detectable levels of PCDDs or PCDFs.

National release estimate

PCDD and PCDF releases to land from pulp and paper mill sludge are summarised in Table 22.2. The total annual release from this source is estimated to be 0.56 g I-TEQ yr^{-1}.

Table 22.2 PCDD and PCDF releases to land from pulp and paper production

Source	Sludge production (tonne yr^{-1} DW)	PCDD/PCDF concentration (ng I-TEQ kg^{-1} DW)	Total release (g I-TEQ yr^{-1})
Primary sludge	36,700	4.5	0.17
Secondary sludge	11,400 [1]	34	0.39
Total			0.56

1. Calculated from tonnes per day BOD removal (0.5 tonnes per day solid/ tonne of BOD removal)

This estimate will be conservative for current day emissions as modifications to the bleach plants at both kraft mills during the 1990s have led to non-detectable concentrations of PCDDs and PCDFs produced from the bleaching process.

Certainty

Activity statistic	H
Emission factor	M

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry data for the volume of primary sludge produced, and derived from BOD removal rates for the volume of secondary sludge produced. BOD levels are routinely monitored, and this parameter is known to be a good indicator of secondary sludge production. The emission factor is assigned a ‘medium’ certainty ranking because it is based on industry data for PCDD and PCDF concentrations in pulp and paper mill sludge from the BoP mill only. In addition, current concentrations are expected to be lower due to modifications in the bleaching process used at both mills.

22.2.2 Non-kraft mills

There are a number of non-kraft mills in New Zealand. These mills do not use a chlorine bleach process, and therefore PCDDs and PCDFs are not directly associated with their discharges. However, non-kraft mills could potentially represent a PCDD and PCDF source as a result of processing recycled paper. The potential for this release can be estimated by assuming:

- The total annual use of recycled paper in New Zealand is approximately 110,000 tonnes per year;
- The majority of the 110,000 tonnes per year is on repeat cycles. It is new input to these repeat cycles that provides any PCDD and PCDF release burden. Five repeat cycles are assumed. This is the normally accepted retention time in the paper fibre system;
- The bleached kraft content of paper is assumed to be 25%;
- The TEQ level of recycled pulp is the same as for New Zealand bleached kraft pulp (0.9 ng I-TEQ kg^{-1} based on 1991 data).

On this basis, the annual release to land can be determined from:

*[Quantity of recycled paper produced * kraft pulp content * TEQ level]/Number of repeat cycles*

National release estimate

The annual release of PCDDs and PCDFs to land from the use of recycled paper is estimated to be 0.0050 g I-TEQ yr^{-1}.

This may represent a conservative estimate of the release, as it has been assumed that all recycled paper is made from pulp having a TEQ level associated with 1991 bleaching technology. As the technology at New Zealand’s, and most other global bleach plants has changed to elemental chlorine free processes, concentrations of PCDDs and PCDFs in currently produced bleached kraft pulp have decreased, and therefore the levels of PCDDs and PCDFs in recycled paper are also likely to have decreased. On the other hand, this estimate does not take into consideration any PCDDs and PCDFs that may be introduced into the paper with dyes, pigments and printing inks that may be used in the production and use of paper products, and that may subsequently end up in the wastes from recycled paper processing.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a ‘medium’ certainty ranking because it is based on industry data for recycled paper production. The emission factor is assigned a ‘low’ certainty ranking because the data are primarily applicable to bleached kraft pulp produced using 1991 technology. Since then there have been changes to the bleaching process that have led to a reduction in the level of PCDDs and PCDFs in kraft pulp. In addition, the emission factor does not take into consideration PCDDs and PCDFs introduced into the paper from chemicals used in the production and use of paper products.

22.3 Releases to water

22.3.1 Bleached kraft mills

In terms of the quantity of material discharged, the major export vector from bleached kraft mills is the wastewater effluent discharged to receiving waters. A total effluent volume of 96 x 10^6 m^3 per year is discharged from this sector; approximately 52 x 10^6 m^3 per year from the BoP mill and approximately 44 x 10^6 m^3 per year from the Waikato mill.

PCDD and PCDF concentrations have been measured in the wastewater effluent at both mills. Monitoring undertaken in 1998 at the BoP mill gave a level of 2.1 pg I-TEQ L^{-1} in the effluent discharge. No PCDDs or PCDFs were detected, with the TEQ level arising solely from incorporation of half detection limits for non-detected congeners in the TEQ calculation. In 1997, the effluent concentration at the BoP mill was measured at 12 pg I-TEQ L^{-1} when half detection limits were included and at 8.5 pg I-TEQ L^{-1} when detection limits were excluded. At this time, elemental chlorine was still being used in the second of two bleach plants at the mill. The decrease in PCDD and PCDF effluent concentrations from 1997 to 1998 is a result of further mill modifications resulting in the second bleach plant also becoming elemental chlorine free. At the Waikato mill, monitoring in 1994 gave an effluent concentration of 5.5 pg I-TEQ L^{-1}. Further upgrades to the Waikato mill have also occurred since 1994, and it is likely that the 1998 BoP effluent data more realistically reflect current PCDD and PCDF concentrations in the Waikato mill effluent discharge.

These concentrations are used to derive the annual estimates of PCDDs and PCDFs released to water from pulp and paper production. Thus, a lower range of emissions from bleached kraft mills is estimated by applying the 1998 BoP concentration data to the total effluent discharge for this industry. An upper estimate of emissions is obtained by applying the most recent effluent concentration data for each mill to their own discharge.

National release estimate

PCDDs and PCDFs released to water from pulp and paper production are summarised in Table 22.3. The annual release from this source is estimated to be in the range 0.20 – 0.35 g I-TEQ yr^{-1}.

Table 22.3 PCDD and PCDF releases to water from pulp and paper production

Source	Wastewater effluent discharge (10^6 m^3 yr^{-1})	PCDD/PCDF concentration (pg I-TEQ L^{-1})	Annual release range (g I-TEQ yr^{-1})
Waikato mill	44	2.1 – 5.5	0.092 – 0.24
BoP mill	52	2.1	0.11
Total	96		0.20 – 0.35

A previous estimate of PCDD and PCDF releases to water from the Waikato mill has been reported by Campin *et al*. (1991). This study, which was done prior to the mill installing an oxygen delignification stage and modifying the bleaching sequence to one based on chlorine dioxide, estimated a release of 1.5 g I-TEQ yr^{-1} at the outfall to the receiving water. The authors estimated that only approximately 25% of the total PCDD and PCDF discharge was arising from formation in the bleach plants, with up to 60% of the TEQ measured at the outfall arising from material leaching from a timber milling area located on the mill site. The effluent from the timber milling area, where PCP had historically been used for wood preservation, drained into the mill's wastewater treatment system. Remedial work has since been carried out at the timber milling site to mitigate this release. A further discussion of PCDDs and PCDFs leaching from PCP timber treatment sites is given in Section 30.

Certainty

Activity statistic	H
Emission factor	M

The activity statistic is assigned a 'high' certainty ranking because it is based on industry data for the total volume of effluent discharged to receiving waters. The emission factor is assigned a 'medium' certainty ranking because it is based on concentration data for PCDDs and PCDFs in wastewater effluent discharged from New Zealand's bleached kraft mills.

22.3.2 Non-kraft mills

As previously noted in Section 22.2.2, PCDDs and PCDFs are not directly associated with discharges from non-kraft pulp mills. However, for mills that process recycled paper, PCDDs and PCDFs may be released if they are brought into the process in the paper feed. Given the estimates of release to land made earlier for non-kraft mills, it is likely that any releases to water would be exceedingly small. However, there is currently insufficient information available to make any detailed assessment of this sector.

22.4 Reservoirs

22.4.1 Bleached kraft mills

Primary and secondary sludge produced during the production of bleached kraft pulp is also a reservoir for PCDDs and PCDFs. As such, historic sludge production must be considered to quantify the size of the reservoir from pulp and paper production. For both kraft mills, sludge has been collected only since 1973. Prior to wastewater treatment systems being installed, the solids were discharged to the water column in the wastewater effluent.

The PCDD and PCDF reservoir at both bleached kraft mills has been estimated from:

- An annual release for primary sludge of 0.17 g I-TEQ yr^{-1} (see Section 22.2.1) for a period of 25 years (1973 – 1998);
- The PCDD and PCDF concentration in pre-1992 secondary sludge (measured at 77.3 ng I-TEQ kg^{-1} DW) for an average of 19 years (1973 to 1991 for one mill and 1973 to 1993 for the second mill, at which time mill upgrades of the bleach plant occurred);

- A sludge production rate of 11,400 tonnes DW per year for an average of 19 years. For a concentration of 77.3 ng I-TEQ kg^{-1}, a release of 0.88 g I-TEQ yr^{-1} is estimated;
- An annual release for secondary sludge of 0.39 ng I-TEQ yr^{-1} (see Section 22.2.1) for an average of 6 years (1991 to 1998 for one mill and 1993 to 1998 for the second mill).

National reservoir estimate

The quantity of PCDDs and PCDFs associated with reservoirs from pulp and paper production at bleached kraft mills is summarised in Table 22.4. The total size of the reservoirs is estimated to be approximately 24 g I-TEQ.

Table 22.4 PCDD and PCDF reservoir at bleached kraft pulp mills

Source	Annual release (g I-TEQ yr^{-1})	Period of sludge production (years)	Reservoir (g I-TEQ)
Primary sludge	0.17 [1]	25 (1973 – 1998)	4.3
Secondary sludge	0.88	19 (1973 – 1991/93)	17
	0.39 [1]	6 (1991/93 – 1998)	2.3
Total			24

1. See Section 22.2.1, Table 22.2.

At the BoP mill, sludge produced since 1985 has been dredged from the treatment ponds and stored on site. The fate of sludge dredged from the ponds prior to this is uncertain although the majority is thought to remain on site. At the Waikato mill, sludge dredged from the ponds has been landfilled on site.

Infiltration of the reservoir at both mills, either by rainwater or groundwater, has the potential to leach material, and thereby PCDDs and PCDFs, from the reservoir and into the wider environment. The potential for leaching to occur from reservoir sources is illustrated by the study of Campin *et al.* (1991) discussed in Section 22.3.1. For sludge reservoirs from bleached kraft mills, the magnitude of leachate releases is likely to be very small given the estimated size of the reservoir at 24 g I-TEQ, and the strong binding affinity of PCDDs and PCDFs to solid material.

Certainty

Activity statistic	M
Emission factor	M

The activity statistic is assigned a ‘medium’ certainty ranking because it is based on industry data for the volume of primary sludge produced annually, and derived from BOD removal rates for the volume of secondary sludge produced annually. BOD levels are routinely monitored, and this parameter is known to be a good indicator of secondary sludge production. However, this annual sludge production has been applied over 25 years from 1973 to 1998, by assuming that primary and secondary sludge production during this period has been fairly constant. The emission factor is assigned a ‘medium’ certainty ranking because it is based on industry data for PCDD and PCDF concentrations in pulp and paper mill sludge from the BoP mill only.

22.4.2 Non-kraft mills

The reservoir at non-kraft mill sites is likely to be negligible given the low annual release of PCDDs and PCDFs in sludge produced as a result of processing recycled paper (see Section 22.2.2). In addition, recycled paper production has been undertaken in New Zealand for only a relatively short period of time. As noted previously, however, this assessment does not consider any PCDDs or PCDFs that may be introduced into the paper from dyes, pigments and printing inks that may be used in the production and use of paper products. Insufficient information is therefore available to allow an accurate estimation of the reservoir at non-kraft mills to be made.

23 Cigarette smoking

23.1 Emissions to air

The combustion processes that occur during cigarette smoking are complex and the sources of PCDDs and PCDFs in cigarette smoke are not fully known. However, PCDDs and PCDFs have been measured in tobacco smoke by a number of investigators, and these are reviewed in the US Inventory (US EPA, 1998).

Using information sourced from the tobacco manufacturers' returns to the New Zealand Ministry of Health, the total number of cigarettes smoked in New Zealand is (Laugesen, 1999):

- 3,300 million manufactured cigarettes (0.767 grams each at 13.5% moisture content);
- 725 tonnes of loose tobacco (20% moisture);
- 16 tonnes of pipe tobacco (19% moisture);
- 17 tonnes of cigars (12% moisture).

Correcting these quantities to the manufactured "standard" cigarette, of 0.767 grams and 13.5% moisture content, gives a cigarette equivalent consumption of 4,200 million per year.

In a study of 20 different brands of cigarettes from seven different countries, Matsueda *et al.* (1994) reported PCDD and PCDF emission factors between 1.4 – 12.6 pg I-TEQ pack^{-1}. Assuming an average pack size of 20 cigarettes per pack, this is equivalent to 0.07 – 0.63 pg I-TEQ cigarette^{-1}. In a Swedish study, a single brand had an emission factor of 0.9 pg I-TEQ cigarette^{-1} for mainstream smoke and 2 pg I-TEQ cigarette^{-1} for sidestream smoke (Löfroth and Zebühr, 1992). In the absence of any data pertaining to the brands available in New Zealand, a range of 0.07 – 2 pg I-TEQ cigarette^{-1} is used to reflect both mainstream and sidestream smoke.

National emission estimate

PCDD and PCDF emissions from cigarette smoking are summarised in Table 23.1. The annual emission from this source is estimated to be in the range 0.00029 – 0.0084 g I-TEQ yr^{-1}.

Table 23.1 PCDD and PCDF emissions from cigarette smoking

Source	Cigarettes smoked (10^6 yr^{-1})	Emission factor (pg I-TEQ cigarette^{-1})	Annual emission range (g I-TEQ yr^{-1})
Cigarette smoking	4,200	0.07 – 2	0.00029 – 0.0084

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a 'high' certainty ranking because it is based on industry data for the amount of tobacco products sold in New Zealand, which is then adjusted to unit cigarette form. The emission factor is assigned a 'low' certainty ranking because there are no PCDD and PCDF data for New Zealand tobacco, and although the international data are reasonably consistent, they are from a limited number of studies.

23.2 Releases to land

Ash from cigarette smoking is a diffuse solid waste stream. Insufficient data are available to make an estimate of PCDDs and PCDFs released to land from cigarette smoking.

23.3 Releases to water

There are no direct releases to water from cigarette smoking.

24 Used oil use and disposal

A recent study of used lubricating oil use, disposal and management in New Zealand has reported that approximately 29 million litres of used oil is generated each year, of which 12 - 14 million litres per year is collected as part of known used oil collection schemes (Worley, 1999). The following uses of this "collected" oil were identified:

- 5 million litres is burnt as an auxiliary fuel in a cement kiln (see Section 17). Information from industry indicates that this is likely to be an underestimate, with the true volume probably between 8 – 9 million litres (Berg, 1999);
- 3.5 million litres is processed and used as fuel (12%), industrial lubricant (20%) and in fence stains (8%).

The destination of the remaining 3.5 – 5.5 million litres of "collected" oil is unknown. Similarly, the destination of the oil that is not collected as part of known collection schemes (approximately 15 –17 million litres) is unknown, but it is likely to be used as a fuel and in road oiling. In addition, some used oil, and the residues from the processing of used oil, are disposed of within landfills.

24.1 Emissions to air

The emissions from used oil that is burnt as an auxiliary fuel in cement manufacture are included in the emission estimates made in Section 17.

Available information indicates that approximately 420,000 litres of used oil per year is burned as fuel in low temperature agricultural, commercial and industrial appliances (Worley, 1999). The appliances range from small 50 kW space heaters and commercial greenhouse boilers to larger industrial boilers. Assuming a density of 0.8 g ml^{-1}, this equates to approximately 340 tonnes of used oil burned per year. This is used to provide a lower estimate of PCDD and PCDF emissions from this source. Of the oil that is collected but whose fate is unknown (3.5 – 5.5 million litres yr^{-1}) and the oil that is not collected as part of known collection schemes (15 – 17 million litres yr^{-1}), it is assumed that a further 5 million litres (4,000 tonne yr^{-1}) is burnt in low temperature appliances (MfE, 1997a). This is used to provide an upper estimate of emissions from this source.

There are no New Zealand data on PCDD and PCDF emissions from the low temperature combustion of used oil, and only limited data are available internationally. Bremmer *et al.* (1994) have reported the following emission factors relating to the combustion of oil:

- 2 µg I-TEQ $tonne^{-1}$ for untreated waste oil
- 4.8 µg I-TEQ $tonne^{-1}$ for solvent contaminated waste oil
- 6 µg I -TEQ $tonne^{-1}$ for "treated" waste oil.

No other data on used oil were available from the US Inventory (US EPA, 1998) that reviewed the published literature for this source. Therefore, based on the data from Bremmer *et al.* (1994), a range of 2 – 6 µg I-TEQ $tonne^{-1}$ has been adopted for this inventory.

National emission estimate

PCDD and PCDF emissions from low temperature burning of used oil are summarised in Table 24.1. The total annual emission from this source is estimated to be in the range 0.00068 – 0.024 g I-TEQ yr^{-1}.

Table 24.1 PCDD and PCDF emissions from low temperature used oil burning

Source	Used oil burnt (tonne yr^{-1})	Emission factor (µg I-TEQ tonne^{-1})	Annual emission range (g I-TEQ yr^{-1})
Used oil burning	340 – 4,000	2 – 6	0.00068 – 0.024

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a ‘low’ certainty ranking because it is based on preliminary data only. Accurate information on the total quantity of used oil burnt in low temperature appliances is lacking. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand emissions test data are available for low temperature used oil burning, and only limited international data exist.

24.2 Releases to land

The main use of used oil that is applied to land in New Zealand is as a dust suppressant on unsealed roads. The occurrence of road oiling has been examined on a regional basis, and, for most regions, has been found to occur only to a limited extent, if at all (MfE, 1997b). Whilst it is believed that the incidence of road oiling is currently on the decline, it has been estimated that approximately 4 million litres per year (equivalent to 3,200 tonne yr^{-1} assuming a density of 0.8 g ml^{-1}) of used oil is used for this purpose (MfE, 1997b).

The disposal of used oil mostly includes dumping within landfills, along with indiscriminate discharges to land. The residues from the processing of used oil are also likely to be deposited within landfills (Worley, 1999). Approximately 7 million litres per year (5,600 tonne yr^{-1}) of used oil have been estimated to be disposed of within landfills (MfE, 1997b).

A single New Zealand study has reported concentrations of total PCDDs and PCDFs (sum of tetrachloro- to octachloro- congeners) in motor oil from cars from below detection limits to 24,160 ng kg^{-1} (Bingham *et al.*, 1989b). Unfortunately, no TEQ data were provided. The UK Land and Water Review (Environment Agency, 1997) cites a NATO study that reported PCDD and PCDF concentrations in used oil between detection limits and 57,600 ng kg^{-1}. The UK Land and Water Review then estimated minimum TEQ levels from the NATO study by applying TEFs for the octa-substituted congeners. This resulted in levels of 14 – 60 ng TEQ kg^{-1}. This data is used in the current inventory to estimate releases to land from both road oiling and the disposal of used oil within landfills.

National release estimate

PCDD and PCDF releases to land from used oil use and disposal are summarised in Table 24.2. The total annual release from this source is estimated to be in the range 0.012 – 0.53 g I-TEQ yr^{-1}.

Table 24.2 PCDD and PCDF releases to land from used oil use and disposal

Source	Quantity of used oil (tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release range (g I-TEQ yr^{-1})
Road oiling	3,200	14 – 60	0.045 – 0.19
Deposition within landfills	5,600	14 – 60	0.078 – 0.34
Total	8,800		0.012 – 0.53

This estimate is based on PCDD and PCDF concentration data from the late 1980s. It is therefore likely to overestimate the actual discharges, as modern oils are expected to be cleaner. Furthermore, the phasing out of leaded petrol in New Zealand since the study by Bingham *et al.* (1989b) was undertaken (see Section 15) is also likely to have resulted in a decrease in PCDD and PCDF concentrations in used oil.

It should also be noted that this estimate does not include any contribution from the residual ash that is generated when used oil is burnt in low temperature appliances. The disposal of this ash will represent a further release to land.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a 'low' certainty ranking because it is based on preliminary data only. Accurate information on the total quantity of used oil applied to land for road oiling or disposed of in landfills is not available. The emission factor is assigned a 'low' certainty ranking because although New Zealand concentration data are available for PCDDs and PCDFs in used oil, they are not presented as TEQs. The emission factor used is based on limited overseas data, with an I-TEQ level for this data being estimated in the UK Land and Water Review.

24.3 Releases to water

It is possible that some used oil is disposed of via discharges to drains. Insufficient information is available on the likely significance of PCDD and PCDF releases via this pathway. Nonetheless, there does not appear to be widespread concern from local authorities and regulatory agencies in New Zealand regarding the dumping of used oil into sewers and stormwater systems. It can therefore be assumed that such practices represent a minor disposal route for used oil compared with burning, landfilling and road oiling.

25 Use of halogenated pesticides

This section presents an estimate of the release of PCDDs and PCDFs to land from the use of halogenated pesticides, including the current use of chlorinated phenoxy herbicides in agriculture. The historic use of 2,4,5-T is addressed separately in Section 29.

25.1 Releases to land

25.1.1 Chlorinated phenoxy herbicides

Phenoxy herbicides may be applied either directly to land or via aerial application. In the latter case, this is not considered a direct emission to air, but rather a transport pathway, and therefore no estimate of PCDD and PCDF emissions to air from the use of these herbicides has been made.

The herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) is used in New Zealand, mainly on hill country pastoral land, to control thistles and other broadleaf weeds. This agrichemical, which is no longer manufactured in New Zealand but imported primarily from the United States, is known to contain PCDD and PCDF residues as by-products from its production process. Industry data indicate that approximately 180 to 220 tonnes of 2,4-D acid equivalents were sold in New Zealand during 1998.

There are no PCDD and PCDF concentration data available for the 2,4-D used in New Zealand. The US Inventory reports an average concentration of 0.7 µg TEQ kg^{-1} for technical 2,4-D used in the United States, although it should be noted that this figure does not take into account any contribution from OCDD or OCDF congeners to the TEQ of the material (US EPA, 1998). Nevertheless, in the absence of any local data, this concentration has been used in the current inventory.

National release estimate

Assuming all of the 2,4-D product sold in New Zealand was used in the agricultural sector, and was applied to land for weed control, this would equate to an annual release to the environment of 0.13 – 0.15 g TEQ yr^{-1}. The estimated PCDD and PCDF release from phenoxy herbicides is summarised in Table 25.1.

Table 25.1 PCDD and PCDF releases to land from the use of phenoxy herbicides

Herbicide	Herbicide use (tonne yr^{-1})	PCDD/PCDF concentration (µg TEQ kg^{-1})	Annual release range (g TEQ yr^{-1})
2,4-D	180 – 220	0.7	0.13 – 0.15

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a ‘high’ certainty ranking because it is based on industry data for the total amount of 2,4-D (acid equivalents) sold. Although there is no information on how this material is used or applied nationally, it can be reasonably assumed that most of it is ultimately released to the environment. The emission factor is assigned a ‘low’ certainty ranking because there are no data available on the concentration of PCDDs and PCDFs present in 2,4-D used in New Zealand. The emission factor adopted is based on data reported for 2,4-D used in the United States.

25.1.2 Other New Zealand registered pesticides

The US Inventory has reported that a number of other pesticides have been suspected of being contaminated with PCDDs and PCDFs (US EPA, 1998). These include some pesticides that are currently registered in New Zealand, including chlorothalonil, dicamba, endosulphan, and oxadiazon. A listing of all pesticides registered in New Zealand has been published by the Ministry of Agriculture and Fisheries (MAF, 1999).

In 1987, the US EPA's Office of Pesticide Programmes issued the first of two data call-ins related to PCDD and PCDF contamination of pesticides registered in the United States. The first data call-in required information to be provided on the raw materials and chemistry of the manufacturing process for pesticides suspected of having the potential to become contaminated if synthesised under conditions favouring PCDD and PCDF formation. The second data call-in, also issued in 1987, sought analytical data on PCDDs and PCDFs for specific pesticides or active ingredients. Aside from data on phenoxy herbicides (see Section 25.1.1), no information became available as a result of the data call-ins to support PCDD and PCDF contamination of almost all of the pesticides investigated, including endosulphan and chlorothalonil. At the time of publication of the US Inventory, data generation and evaluation of dicamba and oxadiazon was still ongoing. No other data on PCDD and PCDF residues in these or other New Zealand registered pesticides is known to have been published, and therefore no estimate of PCDD and PCDF releases to the environment from the use of these pesticides in New Zealand can be made.

26 Landfills

There are a number of potential sources of PCDDs and PCDFs in the waste streams that enter landfills. These include wastes such as ash from incinerators and boilers, ash and slag from industrial manufacturing processes, treated wood waste and wastewater solids. In addition residential solid waste has been shown to contain PCDDs and PCDFs. Their origin in residential waste is not fully understood, but they may be introduced through the disposal of contaminated products, and from residues (i.e. ash) from combustion processes such as domestic heating.

26.1 Emissions to air

26.1.1 Landfill gas

The gas generated in landfills may be collected for use in engines or may be flared without energy recovery. In New Zealand, landfill gas recovery is not a widely adopted practice (although this is slowly changing), with most landfill gas simply escaping into the air, uncontrolled, as fugitive emissions.

The total landfill gas production in New Zealand is currently estimated to be about 240 million Nm^3 per year (EECA and CAE, 1996). Information from landfill resource consent applications indicates that nine landfills in New Zealand collect landfill gas. This is then either flared or utilised in reciprocating engines for the generation of electricity. Most of the flares used are the candle type. An estimated 5.5 million Nm^3 of landfill gas is used in reciprocating engines and a further 4.5 million Nm^3 is flared. Given the uncertainty of these figures, these have not been deducted from the total 240 million Nm^3 of landfill gas that is assumed to escape by way of fugitive emissions.

There are no New Zealand data on PCDD and PCDF concentrations in raw landfill gas, or in the emissions from combusted landfill gas. There are also only limited data internationally, as has been noted by the US Inventory (US EPA, 1998). Based on data from the Netherlands, Germany and the United Kingdom, the UK Review derived the following concentration ranges (HMIP, 1995):

Fugitive gas emissions	0.32 – 0.36 ng I-TEQ m^{-3} of raw landfill gas discharged;
Flared gas	0.022 ng I-TEQ m^{-3} of flue gas (at 11% oxygen);
Gas combusted in engine	0.006 – 1.2 ng I-TEQ m^{-3} of flue gas (at 11% oxygen).

To derive emission factors for flared gas and landfill gas combusted in an engine, it is assumed that landfill gas comprises 50% methane and that approximately 10 m^3 of flue gas is produced per cubic metre of gas combusted (assumptions as per the UK Review). The temperature is not specified in the UK Review. However, it would appear that it is at 0°C on a dry gas basis, and this has also therefore been assumed. On this basis, the following emission factors are calculated:

Fugitive gas emissions	0.32 – 0.36 ng I-TEQ Nm^{-3} of landfill gas discharged;
Flared gas	0.22 ng I-TEQ Nm^{-3} of landfill gas discharged;
Gas combusted in engine	0.06 – 12 ng I-TEQ Nm^{-3} of landfill gas discharged.

The US Inventory reports the results of PCDD and PCDF emissions from a landfill flare in the United States, and calculates an emission factor of 2.4 ng I-TEQ m^{-3} of landfill gas combusted (US EPA, 1998). This is an order of magnitude higher than that reported in the UK Review. The emission factors reported in both the UK Review and the US Inventory are used in the current study.

National emission estimate

PCDD and PCDF emissions from landfill gas are summarised in Table 26.1. The total annual emission from fugitive gas, flared gas and gas combusted in engines is estimated to be in the range 0.078 – 0.16 g I-TEQ yr^{-1}.

Table 26.1 PCDD and PCDF emissions from landfill gas

Source	Gas emitted (10^6 Nm^3 yr^{-1})	Emission factor (ng I-TEQ Nm^{-3})	Annual emission range (g I-TEQ yr^{-1})
Fugitive emissions	240	0.32 – 0.36	0.077 – 0.086
Flared gas	4.5	0.22 – 2.4	0.00099 – 0.011
Gas combusted in engines	5.5	0.06 – 12	0.00033 – 0.066
Total			0.078 – 0.16

While these estimates currently indicate a low level of PCDD and PCDF emissions from landfill gas, it is clear that there is great uncertainty in the emission factors available for this source. This is illustrated by the top end emission factors of 2.4 ng I-TEQ m^{-3} for a landfill flare and 12 ng I-TEQ Nm^{-3} for a gas engine that come from single United States (US EPA, 1998) and United Kingdom (HMIP, 1995) studies respectively. Nevertheless, it should noted that the total current estimate of emissions is low, in part as a result of the small volumes of gas currently flared and burnt in engines in New Zealand.

Certainty

Activity statistic	L (fugitive emissions)
	M (flared gas and gas combusted in engines)
Emission factor	L (fugitive emissions, flared gas and gas combusted in engines)

The activity statistic for landfill gas fugitive emissions is assigned a ‘low’ certainty ranking because of the uncertainty in estimating landfill gas production and leaks from capped landfills. The activity statistics for flared landfill gas and gas combusted in engines are both assigned a ‘medium’ certainty ranking because although this information is generally available from the few landfill operators where landfill gas is collected, there are some uncertainties in the data. The emission factors for fugitive emissions, flared gas and landfill gas combusted in engines are all assigned a ‘low’ certainty ranking because no New Zealand emissions test data are available. The factors used are taken from overseas data which were themselves derived from a limited number of direct measurement studies.

26.1.2 Flaring of landfill leachate vapour

The flaring of landfill leachate vapour occurs in the Auckland region at a large sanitary landfill that accepts industrial wastes (Tonkin and Taylor, 1999). The leachate is evaporated at low temperatures (80 – 90 °C) and the vapour is injected into the base of a flare where it is combusted, along with landfill gas, at a temperature of > 760 °C. Up to 60 m^3 of leachate is evaporated per day. The concentrated residues from the evaporation are returned to the landfill. Although no assessment of PCDD and PCDF emissions has been carried out for this activity, the composition of landfill leachate is such that its evaporation will lead to enhanced levels of chlorinated organics entering the flare. This, in turn, can be expected to result in enhanced PCDD and PCDF emissions over that from the flaring of leachate gas alone. However, insufficient data are currently available to estimate the magnitude of these emissions. There are currently proposals to operate similar systems to handle landfill leachate at other Auckland landfills.

26.1.3 Landfill fires

Any uncontrolled burning of waste material of the type found at landfills can be expected to lead to the formation and emission of PCDDs and PCDFs. The 1995 National Landfill Census indicates that there were at least 142 fires at landfills during the preceding 12 months (MfE, 1997c). Of these, approximately two thirds were reported as accidental fires and one third were reported as being intentionally lit. These data compare with a recorded 288 fires at landfills (246 public and 42 private fires) and 59 fires at rubbish transfer stations that were attended to by the New Zealand Fire Service during the period July 1997 to June 1998 (NZFS, 1999).

No New Zealand emission factors are available for the release of PCDDs and PCDFs from landfill fires. PCDDs and PCDFs have been measured in ambient air at a site that was impacted by the plume of a smouldering landfill fire in the Waikato at a concentration of 1,750 fg I-TEQ m^{-3} (Olivine, 1998), indicating the potential for such uncontrolled fires to be a significant source of PCDDs and PCDFs in New Zealand.

Studies have been carried out in experimental fires designed to simulate surface landfill fires and deep landfill fires in Sweden (Persson and Bergström, 1991). The experiments used 9-month old domestic waste. The tests showed no differences in the PCDD and PCDF content of the fire gas produced by the simulated surface and deep seated fires. The average emission factor was reported to be 1,000 µg Nordic-TEQ tonne^{-1} of waste burnt. Based on these data and the total number of landfill fires in Sweden, and an assumed quantity of waste burned for each surface and deep seated fire, it was estimated that the PCDD and PCDF emission from landfill fires in Sweden was 35 g Nordic-TEQ yr^{-1} (Persson and Bergström, 1991).

The US Inventory used this figure on a pro-rata basis to derive an annual estimate of emissions by assuming a direct correlation of emissions to population size in the United States and Sweden. The same approach can be applied to New Zealand. Similarly, an annual estimate of emissions can be made on a pro-rata basis from the relative quantities of waste that are landfilled in Sweden and New Zealand.

National emission estimate

Sweden has a population of 8,822,000 (1995 data as per US EPA, 1998). New Zealand's population at mid-1998 was 3,790,000 (Statistics NZ, 1998). On a pro-rata population basis, the potential PCDD and PCDF emissions from landfill fires in New Zealand is estimated to be 15 g I-TEQ yr^{-1}. About 11 million tonnes of household waste (including waste from commercial activities and small businesses) and non-hazardous industrial waste was landfilled in Sweden in 1990 (OECD, 1996). Similarly, the quantity of solid waste landfilled in New Zealand in 1995 has been estimated at approximately 3.18 million tonnes (see Section 26.2; MfE, 1997c). Therefore, on a pro-rata quantity of waste landfilled basis, the potential PCDD and PCDF emissions from landfill fires in New Zealand is estimated to be 10 g I-TEQ yr^{-1}. There are only minor differences between the Nordic TEFs (the basis of the Swedish data) and I-TEFs, and these are ignored in the current estimate of emissions.

PCDD and PCDF emissions from uncontrolled landfill fires are estimated to be between 10 – 15 g I-TEQ yr^{-1}. Because of the paucity of information available, including the lack of data on the quantity of waste burnt at landfill fires in New Zealand, and the pro-rata approach followed in this current estimate of emissions, this estimate should be regarded as a preliminary indication only.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic and the emission factor are assigned a 'low' certainty ranking because the estimate of emissions is based on pro-rata population and landfill data. A pro-rata approach assumes that the composition of the wastes going to landfills is similar between New Zealand and Sweden, and that the quantities of waste burnt in landfill fires in the two countries are also similar.

26.2 Releases to land

It has been estimated that approximately 3.18 million tonnes of solid waste was landfilled in New Zealand in 1995, of which approximately 1.42 million tonnes was residential waste and 1.76 million tonnes was industrial waste (MfE, 1997c). For this inventory, these quantities of waste are assumed to reflect the waste streams in 1998.

The composition of residential landfilled waste is primarily organic (50%), paper (19%) and construction and demolition waste (10%). Other components include plastic (7%), metal (6%) and glass (3%). Potentially hazardous waste comprises approximately 1% of the total residential waste stream. Of the industrial waste landfilled in New Zealand, organic (24%), construction and demolition (22%) and paper (18%) were again the major components. Potentially hazardous waste accounted for approximately 15% of the total industrial waste stream (MfE, 1997c).

No New Zealand data are available on the concentration of PCDDs and PCDFs in residential waste deposited in landfills. The UK Land and Water Review cites a concentration for household waste of 6.3 ng I-TEQ kg^{-1} (wet weight basis) as the mean of 13 samples (Environment Agency, 1997). This value is probably higher than would be expected for New Zealand as, in general, New Zealand has low PCDD and PCDF emissions relative to the United Kingdom. However, in the absence of alternative data, it is used as a conservative indication of the PCDD and PCDF concentration of residential waste going to New Zealand landfills.

This inventory also assumes that the PCDD and PCDF concentration in household waste in the United Kingdom will reflect their concentration in New Zealand's industrial waste stream. This assumption is made on the basis of:

- The small number and size of New Zealand industries that produce PCDD and PCDF contaminated wastes (e.g. incinerator ash and similar contaminated solid waste residue streams) compared to other more industrialised countries;
- The composition of New Zealand's industrial waste, which is primarily organic, construction, demolition and paper materials, with a smaller percentage of potentially hazardous waste (MfE, 1997c).

Accordingly, the same concentration data have been used to estimate the release of PCDDs and PCDFs from industrial waste in New Zealand as for domestic waste.

National release estimate

PCDD and PCDF releases from residential and industrial solid waste are summarised in Table 26.2. The total annual release from these sources is estimated to be 20 g I-TEQ yr^{-1}. This estimate represents the quantity of PCDDs and PCDFs that are added each year to the already existing PCDD and PCDF reservoir within landfills. For an estimate of the PCDD and PCDF reservoir already present within landfills, see Section 26.4.

Table 26.2 PCDD and PCDF releases to landfills

Source	Quantity of waste (10^6 tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Annual release (g I-TEQ yr^{-1})
Residential solid waste	1.42	6.3	8.9
Industrial solid waste	1.76	6.3	11.1
Total	3.18		20

Certainty

Activity statistic	H
Emission factor	L

The activity statistic is assigned a ‘high’ certainty ranking for both residential and industrial waste because it is based on industry census data. The emission factor is assigned a ‘low’ certainty ranking for both residential and industrial waste because no New Zealand data are available. The emission factor used is based solely on concentration data for PCDDs and PCDFs in household waste in the United Kingdom.

26.3 Releases to water

National releases of PCDDs and PCDFs in leachate from landfills were estimated as:

1. A release from the quantity of new refuse placed in landfills annually;
2. An annual emission from the quantity of refuse placed in landfills over the preceding 50 year period. This will represent the ongoing annual discharge from the reservoir of PCDDs and PCDFs held in landfills.

PCDD and PCDF releases from landfill leachate are assessed in terms of small (≤ 500 tonne waste deposited yr^{-1}), medium (501 to 5,000 tonne yr^{-1}) and large landfills (≥ 5,000 tonne yr^{-1}). These categories are based on the landfill size developed in the 1995 National Landfill Census (MfE, 1997c). These categories are likely to reflect the quality of the landfill capping, and the level of operational management, both of which will affect the amount of leachate produced.

Leachate is generated primarily by the infiltration of rainfall through the landfill cover. The volume of leachate produced at a landfill is dependent on the refuse volume, site area, rainfall and the percentage rainfall infiltration. For the current inventory, the volume of leachate produced from refuse placed annually in landfills was estimated as follows:

- The refuse volume. The numbers of operational small, medium and large landfills in New Zealand were estimated from the information reported in the 1995 landfill census (MfE, 1997c). These estimates were 197 small landfills, 140 medium landfills and 48 large landfills. Using an assumed average tonnage for each landfill size (500 tonne yr^{-1} for small landfills, 3,500 tonne yr^{-1} for medium landfills and 50,000 tonne yr^{-1} for large landfills), the volume of refuse disposed of in each category of landfill size was calculated. The tonnage for each landfill size was then adjusted proportionally so that the total quantity of new refuse placed annually was 3.18 million tonnes per year as determined by the landfill census (MfE, 1997c);
- The site area. The refuse volume for each landfill size was converted to a landfill area by assuming an average landfill depth of 10 m for small and medium sized landfills and an average depth of 20 m for large landfills;
- Rainfall. The mean annual rainfall for each region was obtained from New Zealand Meteorological Service data for 1951 - 1980;
- Percentage rainfall infiltration. It was assumed that 20% of rainfall will generate leachate for small and medium sized landfills as these sites generally have poorer cover, and 10% of rainfall will generate leachate for large landfills which tend to have more highly engineered covers.

On the basis of the above approach, the estimated quantities of refuse placed annually in small, medium, and large landfills and the volumes of leachate produced annually for each landfill size are summarised in Table 26.3. The total volume of leachate produced from new refuse placed annually is estimated to be 68,500 m^3 yr^{-1}.

To estimate the volume of leachate produced from the refuse already present within landfills, a quantity of 159 million tonnes of refuse was assumed. This represents the quantity of refuse that has been placed in landfills over the preceding 50 years (see Section 26.4). It is not possible to break this quantity down between the various size categories of landfills, since the relative distribution between the size categories would likely be different for historic and current landfilling practices. It can be expected that historically, relatively more waste would have gone to the small and medium sized landfills than currently occurs. The refuse is assumed to be distributed at an average landfill depth of 10 – 20 m, and assumptions for rainfall and rain infiltration are as previously given. On this basis, the total volume of leachate produced from the refuse in place in closed and operating landfills is estimated to be $1.1 \times 10^6 – 4.3 \times 10^6$ m^3 yr^{-1}. This is summarised in Table 26.4.

The following calculation was undertaken to provide a reality check on this estimate. The 1995 landfill census (MfE, 1997a) records leachate volumes discharged from 17 operational landfills. From the data provided, it is estimated that a leachate volume of 180,000 m^3 yr^{-1} of leachate is being discharged from these 17 landfills that represent approximately 5 % of the currently operating landfills. If this volume is pro-rated across all operational landfills, the total volume of leachate produced is estimated to be 3.6×10^6 m^3 yr^{-1}. This estimate falls within the range estimated above. Whilst this calculation makes no allowance for closed landfills that will also produce leachate, it can be reasonably assumed that the 180,000 m^3 of leachate collected is derived from more than 5% of the refuse volume, since it will be the larger more modern landfills that will have leachate collection systems.

PCDD and PCDF data are available for landfill leachate from five New Zealand landfills, with concentrations in the range 7.5 - 221 pg I-TEQ L^{-1}. The highest leachate concentration of 221 pg I-TEQ L^{-1} is for a landfill that receives a large component of industrial and potentially hazardous wastes.

For the current study, the annual estimate of release of PCDDs and PCDFs from landfill leachate produced from new refuse placed annually was calculated assuming a range of concentrations of 14 – 48.3 pg I-TEQ L^{-1} in leachate for small and medium sized landfills (n=3) and 7.5 – 221 pg I-TEQ L^{-1} for large landfills (n=2). To estimate the annual release of PCDDs and PCDFs in leachate produced from the total volume of refuse already in place in landfills, a concentration range of 7.5 – 221 pg I-TEQ L^{-1} was applied.

National release estimate

PCDD and PCDF releases from landfill leachate from new refuse placed annually are summarised in Table 26.3. The total annual release from this source is estimated to be 0.00074 – 0.0093 g I-TEQ yr^{-1}.

Table 26.3 PCDD and PCDF releases from landfill leachate produced from new refuse placed annually

Landfill size	Volume of refuse placed annually (10^3 m^3 yr^{-1})	Landfilled area (ha)	Leachate produced (m^3 yr^{-1})	PCDD/PCDF concentration (pg I-TEQ L^{-1})	Annual release range (g I-TEQ yr^{-1})
Large	5,100	25.5	34,600	7.5 – 221	0.00026 – 0.0076
Medium	1,050	10.5	28,300	14 – 48.3	0.00040 – 0.0014
Small	210	2.1	5,700	14 – 48.3	0.000080 – 0.00028
Total	6,360 [1]	38.1	68,500		0.00074 – 0.0093

1. Equivalent to 3.18 million tonnes of solid waste deposited annually (assuming 1m^3 = 0.5 tonne [MfE, 1997c]).

PCDD and PCDF releases from landfill leachate from the refuse that has been placed in landfills over a preceding 50 year period are summarised in Table 26.4. The total annual release from this reservoir source is estimated to be 0.0083 – 0.95 g I-TEQ yr^{-1}.

Table 26.4 PCDD and PCDF releases from landfill leachate produced from the total refuse volume already in place in landfills

Source	Volume of refuse in place (10^3 m^3)	Landfilled area (ha)	Leachate produced (10^6 m^3 yr^{-1})	PCDD/PCDF concentration (pg I-TEQ L^{-1})	Annual release range (g I-TEQ yr^{-1})
Closed and operating landfills	159,000 [1]	795 – 1,590	1.1 – 4.3	7.5 - 221	0.0083 – 0.95

1. This is the total volume of refuse in landfills that has been generated over the last 50 years (see Section 26.4). Equivalent to 79.5 million tonnes of solid waste deposited annually (assuming 1m^3 = 0.5 tonne [MfE, 1997c]).

It should be noted that these estimates do not necessarily reflect the level of PCDD and PCDF release to water. Thus, the leachate may be re-circulated back through the landfill, or there may be contaminant absorption onto solids and land before the leachate enters water.

The 1995 National Landfill Census (MfE, 1997c) indicates that 13% of operational landfills currently collect leachate. This leachate is typically discharged to trade waste, treated, or recirculated back into the landfill. Information is not available as to what proportion of leachate is handled in each manner. Leachate collection tends to take place at the more modern and larger landfills. As such, the proportion of actual leachate production that is collected from operational landfills may be significantly more than 13%. It can also be inferred that for the remaining 87% of operational landfills that do not have leachate collection systems, their leachate is discharged to land and, as a result, to groundwater and/or surface water. Furthermore, it is likely that the majority of closed landfills also discharge their leachate to groundwater or surface water. However, for any leachate that is discharged to land, the extent to which the PCDDs and PCDFs enter groundwater or surface water is unknown given the partitioning that will occur with soil during infiltration.

Certainty

Activity statistic	L
Emission factor	M

The activity statistic is assigned a ‘low’ certainty ranking because the amount of landfill leachate produced has been modelled based on estimated volumes of refuse, landfill areas and rates of leachate generation for various landfill sizes. It is not based on actual measured data at New Zealand landfills. The emission factor is assigned a ‘medium’ certainty ranking because it is based on test data for PCDDs and PCDFs in leachate from a number of New Zealand landfills of varying sizes, including a landfill that receives a large component of industrial and potentially hazardous wastes.

26.4 Reservoirs

Landfills represent a reservoir of PCDDs and PCDFs. The release of PCDDs and PCDFs from this reservoir is through landfill gas, uncontrolled landfill fires or landfill leachate.

It is generally accepted that environmental loading of PCDDs and PCDFs increased rapidly from the 1930s due to the development of industries that synthesised organic materials and more particularly certain organochlorine chemicals and products. Although PCDDs and PCDFs would have been present in older wastes due to combustion, levels would have risen to a peak probably in the 1960s or 1970s. To estimate the size of the reservoir in landfills, a 50 year timeframe has been adopted over which waste containing PCDDs and PCDFs would have been disposed of to landfills.

The total quantity of refuse generated over the last 50 years can be determined from:

- The timeframe;
- The mean annual population of New Zealand over the last 50 years. This was estimated, by region, by extrapolation of the mean population data between 1961 and 1995 (Statistics NZ, 1996);
- The rate of refuse generation. A mean rate of 0.65 tonnes of waste per person per year was used, which included both residential and industrial waste. This was based on per capita waste data for Christchurch for the period 1986 to 1993 (CCC, 1994) and extrapolated to give a mean for the last 50 years. As would be expected, this mean rate is lower than the current rate of refuse generation (0.85 tonnes person^{-1} year^{-1}) which reflects increasing consumption in today’s consumer society.

On this basis, the total refuse tonnage residing in landfills is calculated to be 79.5 million tonnes (equivalent to 159 x 10^6 m^3 assuming $1m^3$ = 0.5 tonne [MfE, 1997c]). This encompasses refuse in operating landfills and closed landfills.

The following estimate was undertaken to provide a check on this calculation. The 1995 National Landfill Census indicated that there were in excess of 385 operating landfills and 865 known closed landfills within New Zealand (MfE, 1997a). The median size of these landfills is likely to be around 60,000 tonnes (120,000 m^3) based on the data provided in the landfill census. This would equate to a total refuse tonnage in place within landfills of approximately 75 million tonnes (150 x 10^6 m^3). Although the actual total tonnage of refuse within landfills will be greater than this, as there are likely to be more than 865 closed landfills, the estimate made is in reasonable agreement with that calculated from the mean rate of refuse generation and the mean population for the last 50 years.

National reservoir estimate

Based on a derived refuse quantity of 79.5 million tonnes and a PCDD and PCDF concentration for household waste of 6.3 ng I-TEQ kg^{-1} (Environment Agency, 1997), the reservoir of PCDDs and PCDFs associated with landfills is estimated to be 500 g I-TEQ. This is summarised in Table 26.5.

Table 26.5 PCDD and PCDF reservoir at landfills

	Quantity of waste (10^6 tonnes)	PCDD/PCDF concentration (ng I-TEQ kg^{-1})	Reservoir (g I-TEQ)
Residential and industrial solid waste	79.5	6.3	500

This estimate of the PCDD and PCDF reservoir assumes that there has been no loss or degradation of PCDDs and PCDFs present within landfills. This assumption is considered appropriately conservative as PCDDs and PCDFs may historically have been present at greater concentrations than the 6.3 ng I-TEQ kg^{-1} used in this assessment.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a ‘medium’ certainty ranking because the amount of refuse generated over a 50 year period, which constitutes the reservoir, has been derived from actual refuse tonnages per capita for an eight year period but extrapolated back over 50 years. The emission factor is assigned a ‘low’ certainty ranking because no New Zealand data are available for PCDD and PCDF concentrations in the waste stream deposited within landfills. The reservoir estimate made is based on data for household waste reported in the UK Land and Water Review.

27 Wastewater treatment

27.1 Introduction

PCDDs and PCDFs are present in wastewater and consequently in treated effluent, wastewater solids and biosolids as a result of:

- Point source discharges by industry;
- Diffuse discharges from industrial, commercial and domestic sources;
- Atmospheric deposition and surface runoff.

In addition, studies in Sweden have provided convincing evidence that the more highly chlorinated PCDDs (heptachloro- and octachloro- congeners) may be formed by enzymatic action on chlorophenol precursors during sewage treatment processes (Öberg *et al.*, 1992).

It has also been suggested that sludge drying technologies in which there is significant heating of the sludge (i.e. to temperatures of 200 °C or above) may lead to additional PCDD and PCDF formation (Environment Agency, 1997). Although there were no sludge drying technologies in operation in New Zealand as at 1998, this treatment process was being actively considered in one city. A sludge drying plant is now being commissioned in this city, and other thermal technologies are also being considered elsewhere in New Zealand.

There is one wastewater solids incinerator in New Zealand. The release of PCDDs and PCDFs from wastewater solids incineration is discussed in Section 6.

Treatment processes

A variety of treatment processes operate in New Zealand. Estimates of PCDD and PCDF releases to land and water are made for each of the following categories:

Pretreatment:
Pretreatment refers to processes that discharge the wastewater effluent to the environment with minimal treatment or screening. As such there is no sludge produced by these processes. Effluent that has only been pretreated will have a higher suspended solids level than wastewater effluent that has been subject to other treatment processes.

Primary and secondary treatment:
Primary treatment involves the removal of a portion of the solids from the wastewater effluent by screening or settlement. Secondary treatment involves the further treatment of primary effluent to remove organic matter and residual suspended material. Secondary treatment generally involves biological processes.

Oxidation ponds:
The use of oxidation ponds is widespread within New Zealand. Oxidation ponds may be present as a polishing stage for treatment plants with other primary and/or secondary treatment, or they may provide the only treatment stage within a water treatment plant. Where oxidation ponds are the only treatment stage, concentrations of PCDDs and PCDFs in sludge are likely to be low. Where oxidation ponds are used after primary or secondary treatment, the wastewater solids that settle out will tend to be fine grained. A significant component of the PCDDs and PCDFs is likely to be associated with this fine grained material and hence PCDD and PCDF concentrations can

potentially be more elevated. Oxidation pond sludges are therefore likely to have highly variable PCDD and PCDF concentrations depending upon the nature of other treatment processes involved.

It should also be noted that there is typically a greater level of variability in the collection of samples from oxidation ponds in terms of the suspended solids content, and this can markedly affect the PCDD and PCDF concentrations measured.

Anaerobic digestion:

Anaerobic digestion of wastewater solids from primary and secondary treatment is considered separately as this process removes a significant component of the volatile solids as biogas. This will reduce the level of organic carbon within wastewater solids, and this, in turn, can be expected to affect the concentration of PCDDs and PCDFs in the sludge.

Treatment plants with primary treatment, secondary treatment or anaerobic digestion of wastewater solids may also have oxidation ponds and therefore generate oxidation pond sludge in addition to other forms of wastewater solids.

27.2 Releases to land

The quantity of wastewater solids produced from each of the treatment processes was used to estimate the total annual release of PCDDs and PCDFs from this sector. Where available, wastewater solid volumes for each wastewater treatment plant and treatment process were taken from the New Zealand Water and Waste Association (NZWWA) sewage treatment plant database. For treatment plants and processes with no wastewater solids volumes recorded in the database, an estimate of solids volumes was made from the suspended solids removal and BOD_5 reduction for each stage of treatment. For this estimate, either actual data from the NZWWA sewage treatment plant database for effluent or influent suspended solids and BOD_5 were used or, in the absence of such data, the following assumptions were made:

- No PCDDs and PCDFs were associated with screenings and grit removed during pretreatment;
- Influent suspended solids and BOD_5 concentrations were assumed to be 270 g m^{-3};
- Primary treatment achieves a suspended solids removal efficiency of 50 – 70%, and a BOD_5 removal efficiency of 24 – 40% (Metcalfe and Eddy, 1991);
- The secondary treatment process most commonly used in New Zealand is extended aeration. Extended aeration was assumed to achieve an effluent quality of 30 g m^{-3} for suspended solids and 20 g m^{-3} for BOD_5;
- Oxidation pond effluent was assumed to have suspended solids and BOD_5 levels of 20 g m^{-3}.

The total wastewater solids volumes (i.e. actual plus estimated volumes) that were determined by following this approach are reported for each of the treatment processes in Table 27.1. The total annual production of wastewater solids is estimated to be 87,800 tonnes DW per year.

Based on a population of 3,790,000 and with 85% of the population being on reticulated sewage collection, this is equivalent to an estimated wastewater solids production of 82 g DW $person^{-1}$ day^{-1}. This is in reasonable agreement with the Department of Health figures for wastewater solids production of 88 g DW $person^{-1}$ day^{-1} for Auckland, 75 g DW $person^{-1}$ day^{-1} for Christchurch and an average of 55 g DW $person^{-1}$ day^{-1} for other parts of New Zealand (DoH, 1992b).

Concentrations of PCDDs and PCDFs in New Zealand wastewater solids have been measured in the range 5.64 – 108 ng I-TEQ kg^{-1} DW (n=10) (NZWWA, 1998). These data are within the range of concentrations that have been reported in wastewater solids overseas. A useful compilation of international data for wastewater solids has been published by Jones and Sewart (1996). Using the New Zealand data, the following concentration ranges were applied to estimate PCDD and PCDF releases to land for each of the treatment processes:

- 5.64 – 18.7 ng I-TEQ kg^{-1} DW for sludge from primary and secondary treatment;
- 6.84 – 108 ng I-TEQ kg^{-1} DW for oxidation pond sludges;
- 11.5 – 35.6 ng I-TEQ kg^{-1} DW for sludge from anaerobic digestion.

National release estimate

The annual release of PCDDs and PCDFs in wastewater solids, by treatment process, is summarised in Table 27.1. The total annual release from this source is estimated to be in the range 0.61 – 5.2 g I-TEQ yr^{-1}.

Table 27.1 PCDD and PCDF releases to land from wastewater treatment

Treatment process	Sludge production (dry tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1} DW)	Annual release range (g I-TEQ yr^{-1})
Pretreatment [1]	0	-	0
Primary and secondary treatment	38,900	5.64 – 18.7	0.22 – 0.73
Oxidation ponds	36,600	6.84 – 108	0.25 – 4.0
Anaerobic digestion	12,300	11.5 – 35.6	0.14 – 0.44
Total	87,800		0.61 – 5.2

1. It is assumed that no sludge is collected following pretreatment and therefore there is no PCDD and PCDF release to land for this treatment process.

Some wastewater treatment plant solids are deposited to landfill, and some of this material is applied directly to land for its nutrient content and soil conditioning properties. A small quantity is incinerated as discussed in Section 6. There is a growing interest in New Zealand to process (e.g. compost, heat stabilise) and beneficially reuse wastewater treatment plant solids, while other disposal technologies are also becoming available, such as sludge vitrification.

Certainty

Activity statistic	M
Emission factor	M

The activity statistic is assigned a ‘medium’ certainty ranking because it is based partly on industry data from the NZWWA sewage treatment plant database and partly on sludge volumes calculated from suspended solid levels and BOD_5 removal rates. The total annual sludge volume estimated is in good agreement with earlier Department of Health data. The emission factor is assigned a ‘medium’ certainty ranking because it is based on New Zealand data for sludge from a variety of treatment processes.

27.3 Releases to water

The quantity and quality of effluent discharges from wastewater treatment will depend on the site, the nature of the influent streams and the treatment processes applied. Studies have shown that almost all of the PCDDs and PCDFs measured at the entry point to a wastewater treatment plant are associated with the solid material rather than the aqueous component. It is therefore reasonable to assume that the release of PCDDs and PCDFs to water will depend to a large degree on the amount of solids in the effluent discharge. On this basis, the release of PCDDs and PCDFs to water have been estimated, for the current inventory, from the volume of effluent discharged and the suspended solids content of the discharge.

The effluent discharge volumes used were based on influent volumes detailed in the NZWWA sewage treatment plant database. In general influent volumes will exceed effluent volumes for a treatment plant due to evaporative losses, discharges to groundwater from oxidation ponds and the removal of liquid associated with the wastewater solids removed during treatment. These loses will vary between treatment plants and between treatment processes, but are generally considered to be relatively minor.

Suspended solids data from the NZWWA sewage treatment plant database were used to calculate the average suspended solids level in effluent for each treatment type. From the effluent discharge volumes and the average suspended solids content, the quantities of solids released in aqueous discharges were estimated. This is reported for each treatment process in Table 27.2.

Whilst there are considerable data in the literature on PCDDs and PCDFs in wastewater solids (Jones and Sewart, 1996; NZWWA, 1998), data on their concentrations within effluent are more limited. In New Zealand, PCDDs and PCDFs have been measured at a concentration of 4.5 pg I-TEQ L^{-1} in treated effluent from one large wastewater treatment plant. It is uncertain how representative this may be of other New Zealand wastewater treatment plants, particularly as the plant for which the data are available receives a significant component of industrial wastewater.

As noted previously, PCDDs and PCDFs tend to associate strongly with particulate material and consequently are likely to be found in the solid fraction rather than the effluent. The PCDD and PCDF effluent concentration of 4.5 pg I-TEQ L^{-1} is therefore likely to be primarily associated with the suspended solids concentration in the effluent, which was measured as 44 g m^{-3}. Assuming all the PCDDs and PCDFs present in the effluent were associated with the suspended solids, this would equate to a dry solids concentration of 102 ng I-TEQ kg^{-1}. This is within the range of PCDD and PCDF concentrations found in oxidation pond sludges (NZWWA, 1998). For this inventory, PCDD and PCDF releases in effluent are therefore calculated assuming the range of concentrations in oxidation pond sludges of 6.84 – 108 ng I-TEQ kg^{-1} DW represents the concentration of PCDDs and PCDFs associated with the fine grained suspended solids within wastewater effluents. This concentration is therefore applied to primary, secondary and oxidation pond effluents.

This concentration range is not, however, appropriate for pretreated effluent. As previously noted, pretreatment does not remove any wastewater solids from the influent wastewater stream. The concentration of PCDDs and PCDFs in pretreated effluents is therefore likely to be comparable to the settlable solids concentration of typical wastewater solids. This is effectively the concentration of PCDDs and PCDFs in primary and secondary wastewater solids, which were measured in the range 5.64 – 18.7 ng I-TEQ kg^{-1} DW.

National release estimate

The annual release of PCDDs and PCDFs in wastewater effluent, by treatment process, is summarised in Table 27.2. The total annual release from this source is estimated to be in the range 0.34 – 2.6 g I-TEQ yr^{-1}.

Table 27.2 PCDD and PCDF releases to water from wastewater treatment

Treatment process	Effluent discharged (10^6 m^3 yr^{-1})	Average SS (g m^{-3})	Solids released with effluent (dry tonne yr^{-1})	PCDD/PCDF concentration (ng I-TEQ kg^{-1} DW)	Annual release range (g I-TEQ yr^{-1})
Pretreatment	95.8	407	39,000	5.64 – 18.7	0.22 – 0.73
Primary treatment	36.4	168	6,100	6.84 – 108	0.042 – 0.66
Secondary treatment	51.8	13	670	6.84 – 108	0.0046 – 0.073
Oxidation ponds	270	39	10,500	6.84 – 108	0.072 – 1.1
Total	454		56,300		0.34 – 2.6

SS Suspended solids.

This release seems relatively high when compared to the release estimated for wastewater solids (0.61 – 5.2 g I-TEQ yr^{-1}), and this is unexpected given that most of the PCDDs and PCDFs are expected to be associated with the solid discharge rather than the aqueous discharge. However, this comparatively elevated estimate for wastewater effluent appears to be, in part, as a result of the mass of suspended solids that are released in the effluent streams from New Zealand wastewater treatment plants.

As New Zealand's wastewater management practices develop and the quality of wastewater treatment processes improves, the release of PCDDs and PCDFs to water will be expected to fall with the removal of wastewater solids from the effluent stream. This will, however, lead to a concomitant increase in the release of PCDDs and PCDFs to the environment from wastewater solids, although decreasing PCDD and PCDF levels entering wastewater treatment plants in the future may offset this.

Certainty

Activity statistic	M
Emission factor	L

The activity statistic is assigned a 'medium' certainty ranking because it is based on influent volumes from the NZWWA sewage treatment plant database, and it is assumed that the effluent volumes are likely to be similar to influent volumes. The emission factor is assigned a 'low' certainty ranking because it is based on PCDD and PCDF concentrations in wastewater solids which are then applied to the suspended solid levels in the effluent stream.

28 Historic pesticide manufacture

Pesticides are no longer manufactured in New Zealand. Contamination from historic pesticide manufacture and disposal of pesticide wastes from agricultural use represents a potentially significant reservoir of PCDDs and PCDFs. However, releases to land and water from such reservoirs are difficult to quantify given the general scarcity of information.

This Section assesses the PCDDs and PCDFs present in a reservoir associated with the historic manufacture of phenoxy herbicides. An estimate of PCDD and PCDF releases to land from the ongoing use of 2,4-D is given in Section 25, and from the historic use of 2,4,5-T in Section 29.

28.1 Reservoirs

The Waireka Landfill, located in the Taranaki Region, was constructed in 1985 and contains waste from the now ceased manufacture of phenoxy herbicides, including 2,4-D and 2,4,5-T. Since the accumulated wastes were deposited in 1985 no further material has been added to this landfill, and the landfill has now been closed. The Waireka Landfill is a secure landfill, fully lined and capped, with leak detection wells that are routinely monitored. Any leachate from the landfill is collected and incinerated in a hazardous waste incinerator. PCDD and PCDF emissions to air from this waste incinerator are estimated in Section 5.

Although PCDDs and PCDFs are present in the Waireka Landfill, insufficient data are available to enable an accurate estimate to be made of the quantity present in this reservoir.

29 Historic use of 2,4,5-T

29.1 Reservoirs

The herbicide 2,4,5-T was once widely used in New Zealand for the control of gorse, blackberry and other woody weeds. Its manufacture ceased in late 1987, although some stocks remained which were likely to have been used after this date.

2,4,5-Trichlorophenol (TCP) was the key intermediate in the production of 2,4,5-T. PCDDs and PCDFs, primarily 2,3,7,8-TCDD (TCDD), were formed during the production of 2,4,5-TCP from 1,2,4,5-tetrachlorobenzene. Depending upon the manufacturing conditions and purification efficiency, levels of TCDD in the final product varied greatly. Partly as a result of requirements imposed by the Agricultural Chemicals Board, the level of contamination decreased over the years. Prior to 1973 the level of TCDD was about 1,000 $\mu g\ kg^{-1}$. In 1973 this was reduced to 100 $\mu g\ kg^{-1}$ as a result of a legal requirement set by the Agricultural Chemicals Notice 1973, falling in 1982 to 10 $\mu g\ kg^{-1}$ according to an amendment to the Notice of 1973 (Coster *et al.*, 1986). Actual concentrations of TCDD in New Zealand produced 2,4,5-T have been published by Smith and Pearce (1986). They reported that for 2,4,5-T produced in 1971, the average concentration of 2,3,7,8-TCDD was 950 $\mu g\ kg^{-1}$, falling to 470 $\mu g\ kg^{-1}$ in 1972 then to between 47 – 7.3 $\mu g\ kg^{-1}$ for product produced between 1973 – 1981 and 8.5 – 4.7 $\mu g\ kg^{-1}$ for product produced between 1982 – 1985.

The annual production of 2,4,5-T from 1948 when manufacturing commenced in New Zealand through to 1985 has been reported by Coster *et al.* (1986). During this period, a total of over 10,600 tonnes of 2,4,5-T had been manufactured. Assuming the production in 1986 and 1987 was the same as in 1985, the total quantity of 2,4,5-T manufactured can be estimated to be 11,640 tonnes at the time production ceased in 1987. Up to 15% of this product is believed to have been exported (Coster *et al.*, 1986). Based on these production figures, and using the residue limits set by the Agricultural Chemicals Notice 1973 and the TCDD residue concentrations reported by Smith and Pearce (1986), it can be estimated that between 2,710 – 3,380 g of TCDD has been distributed on the land surface of New Zealand (Table 29.1).

TCDD degradation

In order to estimate the size of the reservoir from 2,4,5-T usage that exists at 1998, an allowance needs to be made for TCDD degradation. This is appropriate because:

1. The bulk of the application to land occurred during the 1950s and 1960s (see Table 29.1) when TCDD contamination of 2,4,5-T was at its maximum;
2. It can be reasonably assumed that most of the 2,4,5-T used (and therefore TCDD) would have been applied to plant and land surfaces, which would favour degradation.

Studies have shown that TCDD is very labile in sunlight (Freeman and Schroy, 1986). For example, McCrady and Maggard (1993) have reported a half-life for the photodegradation of TCDD on grass of 44 hours. In soil, it is believed that TCDD loss is predominantly through volatilisation and photodegradation at the soil surface. It would appear that microbial and chemical degradation of TCDD under virtually all soil conditions is negligible (Arthur and Frea, 1989). Paustenbach *et al.* (1992) have reviewed many major published studies on TCDD persistence in soil. They concluded that 2,3,7,8-TCDD probably has a half-life of 9 – 15 years at the soil surface (i.e. the top 0.1 cm that can be penetrated by ultraviolet radiation) and 25 – 100 years in subsurface soil.

For the current study, a half-life of 15 years is assumed, but no allowance is made for photodegradation on grass or plant surfaces.

National reservoir estimate

On the basis of the estimates made for the quantity of TCDD distributed on New Zealand's land surface and using assumptions for degradation as outlined above, the TCDD reservoir in soils from the historic use of 2,4,5-T is estimated to be in the range 620 – 860 g. This is summarised in Table 29.1.

Table 29.1 2,3,7,8-TCDD reservoir from historic 2,4,5-T use

Year	Total production (tonnes)	TCDD concentration ($\mu g\ kg^{-1}$)	Deposition to soil [1] (g)	Reservoir [3] (g)
1948 – 1972	3,400	(950 – 470) [2] – 1,000	2,590 – 2,890	570 – 660
1973 – 1981	5,520	(47 – 7.3) [2] – 100	110 – 470	41 – 190
1982 – 1987	2,720	(8.5 – 4.7) [2] – 10	13 – 23	8 – 13
Total	11,640		2,710 – 3,380	620 – 860

1. Assuming 15% of the 2,4,5-T produced is exported.
2. Concentration range from Smith and Pearce (1986). The annual concentration reported was used to derive each annual estimate of the quantity of TCDD deposited to soil. The annual estimates were then summed for each period of 2,4,5-T production given in the table.
3. Assuming a 15 year half-life.

It is known that, annually, 2,4,5-T was sprayed over several hundred thousand hectares of pastoral land, as well as forestry and other land blocks (Coster *et al*., 1986), and therefore the estimated reservoir of TCDD given in Table 29.1 is likely to represent a diffuse reservoir source. Nevertheless, during a major environmental survey of PCDDs and PCDFs in New Zealand soils, an elevated concentration was measured at one hill country pastoral site at a concentration of 9.14 ng I-TEQ kg^{-1}, with TCDD being the major contributor (> 95%) to the toxic equivalents (Buckland *et al*., 1998a,b). The study noted that this soil residue level could not have been obtained from the application of 2,4,5-T at recommended spraying rates and operations, and the source of the contamination was therefore attributed to the accidental spillage of 2,4,5-T formulation or concentrate. Notwithstanding the pathway of contamination, the study also noted that there might be other localised areas of soil contamination throughout the farming lands of New Zealand where 2,4,5-T was historically used (Buckland *et al*., 1998a).

Certainty

Activity statistic	M
Emission factor	M

The activity statistic is assigned a 'medium' certainty ranking because it is based on industry data for the total amount of 2,4,5-T produced in New Zealand and some allowance is made for material exported overseas. The emission factor is assigned a 'medium' certainty ranking because it is based on residue limits that were typical for concentrations of TCDD in 2,4,5-T reported overseas, and is supported by limited data for TCDD levels in New Zealand produced 2,4,5-T. However, uncertainty arises from the adjustment made to account for degradation of TCDD in soil, as the half-life of TCDD in surface and subsurface soil under New Zealand conditions is unknown.

30 Timber treatment and historic pentachlorophenol use

30.1 Introduction

The primary use of PCP in New Zealand was in the timber industry, either as NaPCP in antisapstain treatment or as a preservative in diesel oil. PCP was also used to a relatively minor extent as a slimicide in the pulp and paper industry, as a soil and timber sterilant in mushroom culture and in a variety of applications for the control of moss and algae. A previous assessment of PCDD and PCDF releases from PCP and NaPCP use has been made by Bingham (1992), and this is summarised in Section 1.3. The use of PCP in the timber industry ceased in 1988, and it was deregistered by the Pesticides Board in 1991. Health and environmental guidelines have been published for PCP and other timber treatment chemicals to assist with the assessment and management of contaminants on sawmill and timber treatment sites in New Zealand (MfE and MoH, 1997).

Although no complete records were ever kept, it is estimated that, commencing in the mid to late 1950s and over the next 35 years, about 5,500 tonnes of PCP was imported into New Zealand for use in the timber industry. At the height of its use, approximately 200 tonnes per year was used for antisapstain treatment (Shaw, 1990), and 100 tonnes per year was used for preservative treatment (Bingham, 1992). No PCP was ever manufactured in New Zealand.

Bingham (1991) has reported PCDD and PCDF data for the four NaPCP antisapstain formulations marketed in New Zealand in 1986. Concentrations were measured between 0.21 – 1.85 mg I-TEQ kg^{-1}, with a mean concentration of 0.9 mg I-TEQ kg^{-1}. Assuming these concentrations were typical of levels present in material imported prior to 1986, then for a total quantity of 5,500 tonnes, the total input of PCDDs and PCDFs into the New Zealand environment from PCP use in the timber industry was between 1.2 – 10.2 kg I-TEQ. Whilst the exact fate of this PCDD and PCDF contamination is unknown, residues in a variety of materials and wastes can be identified.

The use of PCP in diesel oil as a permanent timber preservative involved a pressure process (known as the Rueping process) to force active ingredient into the heart of the wood. In addition to solution drippage, which would have resulted in immediate localised contamination at a timber site, much of the PCDDs and PCDFs present in the formulation would have been effectively locked into the timber itself. The most common use of PCP preserved timber was for telegraph poles and railway sleepers. These, and other structures made from PCP treated timber, are reservoirs for PCDDs and PCDFs, and have the potential to release these contaminants into the environment through slow evaporation, or more rapidly if the timber is burnt. The US Inventory has also identified PCP treated timber structures as a reservoir for, and diffuse source of, PCDDs and PCDFs (US EPA, 1998).

Where NaPCP was used as an antisapstain treatment for the interim protection of timber against fungal staining, a variety of waste streams would have been produced, resulting in a number of possible routes for environmental exposure (Bingham and Bettany, 1991). Simple drippage from freshly dipped timber would again lead to localised exposure at the site. However, significant sinks for the PCDD and PCDF contaminants were, firstly, the sludge that settled in formulation storage or dilution tanks and, secondly, the sawdust, bark and soil that settled in the bottom of the troughs used to dip the timber. Varying methods of disposal have been used for these wastes. These include their burial on or off site, and disposal in tips and landfills. Another possible disposal route was the use of the waste as a fuel in recovery boilers at the timber site.

Because the timber was typically dipped in a rough sawn state, some of the timber would subsequently have been gauged to produce dressed timber products. These shavings, which would also have contained PCDDs and PCDFs, would have been either burnt in waste recovery boilers or buried on or off site. Some PCDD and PCDF contaminants would also have remained on the surface of the timber when it was sold.

No information is available to estimate the quantities of PCDDs and PCDFs present in vectors leaving timber sites during the period of PCP use. However, a number of studies have been undertaken into the level of residual contamination in soil at timber sites as a result of historic PCP and NaPCP use (MfE and DoH, 1992; Royds and CMPS&F, 1994; CMPS&F, 1995). These studies have been summarised by Ellis (1997) and Roberts *et al.* (1996). Bingham and Bettany (1991) have also reported PCDD and PCDF concentrations measured in sludges and other wastes generated from PCP use. Data from these studies can be used to estimate the size of the PCDD and PCDF reservoir in soils at timber treatment sites in New Zealand. To assess the reservoir, contamination arising from the antisapstain and preservative use of PCP is treated separately.

30.2 Reservoirs in soil at timber treatment sites

To estimate the quantity of PCDDs and PCDFs in soils at timber treatment sites resulting from the antisapstain and preservative use of PCP, the soil burdens were calculated for each area of the sites where contaminant concentration data were available. These burdens were then summed to give a total PCDD and PCDF burden per site, and this burden was multiplied by the number of sites where either NaPCP or PCP was used.

The estimates made in the following Sections have incorporated conservative assumptions with regards to potentially contaminated areas and depths of contamination. In addition, no allowance has been made for any PCDD and PCDF degradation in the soil, although it is likely that such degradation would be minor given the long half-life of PCDDs and PCDFs in subsurface soil. The estimates of the quantities of PCDDs and PCDFs present within the reservoir are therefore likely to represent an upper limit.

30.2.1 Antisapstain use of NaPCP

The assessment of the reservoir of PCDDs and PCDFs from the use of NaPCP for antisapstain treatment is particularly problematical owing to:

1. The large number of sites where the chemical was used and the different scale of use at these sites; and
2. The relative paucity of data on the concentrations of PCDDs and PCDFs remaining at these sites.

As previously noted, no complete records were kept of the quantities of PCP imported into New Zealand, or its transport to, and use at, timber treatment sites. A best approximation is that about:

- 270 sites used less than 20 tonnes of NaPCP (referred to as “small NaPCP users”; a mean quantity of 4 tonnes use is assumed for this inventory);
- 11 sites used 20 to 100 tonnes (“moderate NaPCP users”; assumed mean use of 40 tonnes);
- 4 sites used more than 100 tonnes (“large NaPCP users”; assumed mean use of 140 tonnes);
- 1 site used about 1,000 tonnes (the Waipa Mill, referred to as the “very large NaPCP user”).

Some PCDD and PCDF concentration data were available for three “small NaPCP users” from the Canterbury Region (CMPS&F, 1995) along with more comprehensive data for a number of site areas for the “very large NaPCP user” (i.e. the Waipa Mill; MfE and DoH, 1992). These data, summarised in Table 30.1, were used to calculate the contaminant burden at these sites.

Table 30.1 Parameters used to estimate the total PCDD and PCDF reservoir in soil at timber treatment sites

Treatment type	PCDD/PCDF soil concentration [1] (µg I-TEQ kg^{-1})	Area affected [1] (m^2)	Depth affected (m)	Reference
ANTISAPSTAIN TREATMENT (NaPCP)				
“Small NaPCP users”				
Average surface concentration beneath and immediately adjacent to dip tanks	3.37	100	0.2	CMPS&F, 1995
Average surface concentration beneath sorting tables	0.62	500	0.2	CMPS&F, 1995
“Very large NaPCP user” (Waipa Mill)				
Surface concentrations associated with				
➢ Circular mill green chain	1.17	2,400	1.05	MfE and DoH, 1992
➢ Band mill green chain	1.3	2,400	1.05	MfE and DoH, 1992
➢ Hot spot under mix room	3,300	1	1.05	MfE and DoH, 1992
➢ Jap square	3.1	375	1.05	MfE and DoH, 1992
➢ Boron dip	0.6	800	1.05	MfE and DoH, 1992
➢ Burn pit	4	100	1.05	MfE and DoH, 1992
➢ Other areas	0.12	162,000	1.05	MfE and DoH, 1992
PRESERVATIVE TREATMENT (PCP IN OIL)				
Waipa Mill				
Surface concentrations associated with				
➢ Rueping plant	18.3	1,600	1.26	MfE and DoH, 1992
➢ Pole yard	21.3	10,000	1.26	MfE and DoH, 1992
Hanmer Springs				
Mean concentration over depth	12.4	2,420	1.26	Roberts *et al.*, 1996

1. Based on site specific data.

The areas at the sites estimated to be affected by PCDD and PCDF residues are also provided in Table 30.1. For the “small NaPCP users”, no site data were available for PCDD and PCDF concentrations with depth. The soils analysed for PCDDs and PCDFs were composites that were sampled to a depth of 0.2 m. The PCP depth concentration profiles for these three sites indicated that PCP concentrations extended to approximately 0.5 m below the soil surface. It is well documented that the PCDDs and PCDFs, and particularly the more highly chlorinated heptachloro- and octachloro- congeners, are significantly less mobile in soil than PCP. On this basis, the PCDDs and PCDFs were unlikely to have migrated deeper than the upper few centimetres of the soil profile, and it is therefore reasonable to assume that they will be completely contained within the 0.2 m sampling depth.

For the “very large NaPCP user”, the depth of contamination was estimated from a plot of PCDD and PCDF concentrations as a function of depth for each of the affected areas listed in Table 30.1. The surface concentrations given in Table 30.1 were then used to calculate the average soil concentrations up to the depth at which the PCDDs and PCDFs were estimated to have declined to zero.

From the soil concentrations, and the affected area and depth, the total PCDD and PCDF burden was estimated to be 0.15 g I-TEQ per site for “small NaPCP users” and 19.2 g I-TEQ for the “very large NaPCP user” (Table 30.2).

Unfortunately, no site information is available for the “moderate NaPCP users” or the “large NaPCP users” with respect to either the concentration of PCDD and PCDF residues present at the sites, or the likely areas affected by PCDD and PCDF contamination. Soil burdens for these sites could not therefore be calculated directly.

Using the soil burdens for the “small NaPCP users” and the “very large NaPCP user” previously described, the PCDD and PCDF burdens for the “moderate NaPCP users” and “large NaPCP users” were estimated from a linear regression of PCDD and PCDF burden versus PCP use (Figure 30.1). On this basis, the total PCDD and PCDF burden was estimated to be 0.77 g I-TEQ per site for “moderate NaPCP users” and 2.7 g I-TEQ per site for “large NaPCP users” (Table 30.2).

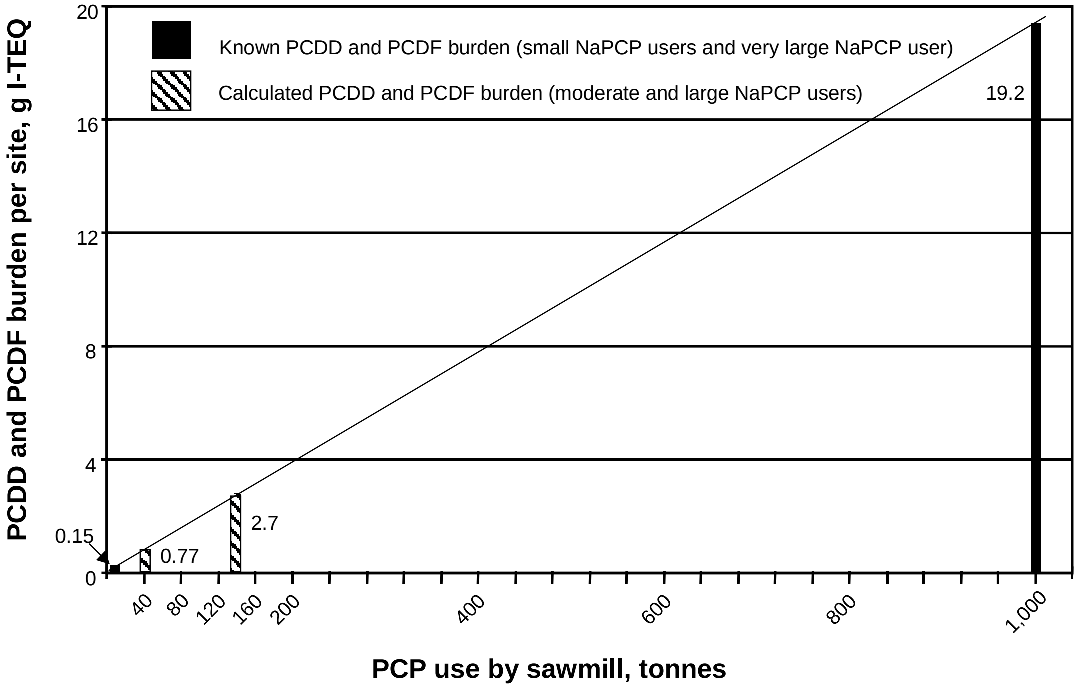

Figure 30.1 PCDD and PCDF reservoir in soil from antisapstain use of PCP

National reservoir estimate

For 270 “small users”, 11 “moderate user”, 4 “large users” and 1 “very large user’, the total PCDD and PCDF reservoir in soils at timber treatment sites from antisapstain use of NaPCP is estimated to be approximately 80 g I-TEQ. This is summarised in Table 30.2.

Table 30.2 PCDD and PCDF reservoir in soil from antisapstain treatment

Site category	**PCDD/PCDF burden in soil** [1] (g I-TEQ)				**PCDD/PCDF burden** (g I-TEQ site^{-1})	**No. of sites**	**Reservoir** (g I-TEQ)
	Dip tanks	Sorting tables	Green chain	Other areas			
Small NaPCP users	0.080	0.075			0.15	270	42
Moderate NaPCP users					0.77 [2]	11	8.5
Large NaPCP users					2.7 [2]	4	11
Very large NaPCP user	0.30		5.80	13.1	19.2	1	19
Total							80

1. PCDD and PCDF burden = (surface concentration/2) x affected area x depth x soil density. The surface concentration is divided by 2 to provide for a linear decrease to zero over the depth of contamination. This is applied for the “very large NaPCP user” only (i.e. not for the “small NaPCP users”). The concentrations, affected area and depth are given in Table 30.1. A mean soil bulk density of 1.2 tonne m^{-3} was assumed.

2. PCDD and PCDF burdens for the “moderate NaPCP users” and the “large NaPCP users” were obtained from a linear regression plot as shown in Figure 30.1.

Certainty

Activity statistic	L
Emission factor	L

The activity statistic is assigned a ‘low’ certainty ranking because the number of sites where NaPCP was used has been approximated and the quantity of NaPCP use at these sites is uncertain. The emission factor is assigned a ‘low’ certainty ranking because the area of contamination and soil PCDD and PCDF concentrations are based on only a limited amount of site specific data which have then been extrapolated over the whole sector.

30.2.2 Preservative use of PCP in diesel

PCP use as a preservative in diesel oil was only undertaken at three sites in New Zealand, namely the Waipa Mill (where antisapstain treatment also occurred), Hanmer Springs and a third site in Christchurch, which was a comparatively small user. The usage of PCP at the two major sites is estimated to be approximately 2,000 tonnes at the Waipa Mill and 420 tonnes at Hanmer.

Concentration data for PCDDs and PCDFs at these sites have been reported, and are summarised in Table 30.1 (MfE and DoH, 1992; Roberts *et al.*, 1996.) The areas estimated to be affected by PCDD and PCDF residues at both of these sites are also detailed in Table 30.1.

As previously noted, for the Waipa site, the depth of contamination was estimated from a plot of PCDD and PCDF concentrations as a function of depth for each of the affected areas listed in Table 30.1. The surface concentrations given in Table 30.1 were then used to calculate the average soil concentrations up to the depth at which the PCDDs and PCDFs were estimated to have declined to zero. The depth of contamination at Hanmer was assumed to be the same as that at the Waipa Mill.

National reservoir estimate

The estimated burden of PCDDs and PCDFs at the Waipa Mill is estimated to be 184 g I-TEQ and at Hanmer 45 g I-TEQ, as summarised in Table 30.3. The total PCDD and PCDF reservoir in soils at timber treatment sites from preservative use of PCP in oil is estimated to be approximately 230 g I-TEQ.

Table 30.3 PCDD and PCDF reservoir in soil from preservative treatment

Timber treatment site	PCDD/PCDF burden (g I-TEQ site^{-1})	No. of sites	Reservoir (g I-TEQ)
Waipa Mill	184	1	184
Hanmer Springs	45.3	1	45
Total			230

1. PCDD and PCDF burden = (surface concentration/2) x affected area x depth x soil density. The surface concentration is divided by 2 to provide for a linear decrease to zero over the depth of contamination. This is applied for the Waipa Mill only, not for Hanmer. The concentrations, affected area and depth are given in Table 30.1. A mean soil bulk density of 1.2 tonne m^{-3} was assumed.

Certainty

Activity statistic	M
Emission factor	M

The activity statistic is assigned a medium certainty ranking because PCP use for preservative treatment was predominantly undertaken at only two sites. However, there is some uncertainty in the amounts of PCP that were actually used at the sites. The emission factor is also assigned a ‘medium’ certainty ranking because detailed site assessments have been undertaken at both sites.

30.3 Emissions to air from reservoir sources

PCDDs and PCDFs may be emitted to air from reservoir sources via direct volatilisation from the soil surface and from scouring by wind where material may be carried from the site. The latter is likely to be the more significant of the two processes, particularly from exposed soil surfaces at sites that are still in active use (such as where the soil may be disturbed by vehicle movement). Earth movement at contaminated timber sites (e.g. during site remediation) may also lead to the generation of windblown dust. No data are available from which to estimate the quantities of PCDDs or PCDFs that may enter the atmosphere and be carried off site from any of these processes, and therefore no estimate of emissions to air can be made from this source.

30.4 Releases to water from reservoir sources

PCDDs and PCDFs may be released to water either through the direct contamination of groundwater or, as a result of rain events, via site runoff and the migration of contaminated soil and other materials to surface water. The contamination of surface waters is likely to be the more significant of the two processes.

A study by Campin *et al*. (1991) (see Section 22.3.1) has illustrated the potential for releases to water to occur from timber treatment sites. Similarly, PCDDs and PCDFs have been detected in sediment from streams adjacent to other timber milling sites in New Zealand (Gifford *et al*., 1996; MfE and DoH, 1992; Royds & CMPS&F, 1994). At one major timber processing site, clean-up activity has involved the diversion of all contaminated groundwater and stormwater and its treatment with ultra violet light and hydrogen peroxide (Ellis, 1997; Roberts *et al*., 1996). PCDD and PCDF concentrations of the intercepted water are reduced from 12 ng I-TEQ L^{-1} to 4 ng I-TEQ L^{-1} by this process.

Insufficient information is available to estimate the quantities of PCDDs and PCDFs that may be released to water from reservoirs at timber sites. Nevertheless, it can be assumed that these transportation processes, unless adequately managed, will result in the ongoing release of these contaminants to the wider aquatic environment.

31 Coal gasification

Internationally, PCDDs and PCDFs have not been generally recognised as a priority contaminant of gasworks waste. New Zealand studies, however, have found that PCDDs and PCDFs may be present in wastes produced during the gasification of coal, and at sites where gasworks were located.

31.1 Reservoirs

There are believed to be approximately 54 gasworks sites in New Zealand, which operated between the 1800s and 1988 (MfE, 1997d). Waste products typically include coal and oil tar, tar/oil/water emulsions, hydrocarbon sludges, coke and ash, as well as other inorganic wastes such as spent oxides and clinker. Recent industry studies have found that PCDDs and PCDFs may be present in coal tar and contaminated soil at gasworks sites.

The amount of coal tar and contaminated soil at gasworks sites varies considerably, typically being dependent upon the size of the gasworks and the length of time over which the gasworks operated. Based on environmental site assessment data for a number of sites within New Zealand, the quantities of gasworks waste will generally be in excess of 1,000 tonnes per site. Although there is insufficient information to accurately determine the exact tonnage, it is estimated that the average is likely to be between 500 and 10,000 tonnes of coal tar and highly contaminated soil per gasworks site. Of the approximately 54 gasworks sites in New Zealand, it is known that at least five have been remediated.

Studies undertaken at four gasworks sites have measured PCDDs and PCDFs in coal tar and contaminated soil in the range 1.13 – 13.1 ng I-TEQ kg^{-1}. As a comparison, the lower end of this range is comparable to background PCDD and PCDF concentrations measured in urban New Zealand soils, whilst the upper end of the range is typically 5 to 10 times higher than levels measured in urban soils (Buckland *et al.*, 1998a,b).

National reservoir estimate

The quantity of PCDDs and PCDFs associated with coal gasification is summarised in Table 31.1. Based on the available New Zealand data, this reservoir is estimated to be in the range 0.028 – 6.4 g I-TEQ.

Table 31.1 PCDD and PCDF reservoir at gasworks sites

	Quantity of coal tar and contaminated soil (tonnes site^{-1})	**Number of unremediated sites[1]**	**Total quantity of coal tar and contaminated soil (tonnes)**	**PCDD/PCDF concentration (ng I-TEQ kg^{-1})**	**Reservoir (g I-TEQ)**
Gasworks sites	500 – 10,000	49	24,500 – 490,000	1.13 – 13.1	0.028 – 6.4

1. Assumes coal tar and contaminated soil have been removed from 5 sites.

Contaminated coal tar, soil and other wastes from the five gasworks sites that are known to have been remediated now reside within landfills.

Certainty

Activity statistic	L
Emission factor	M

The activity statistic is assigned a ‘low’ certainty ranking because, whilst the approximate number of gasworks sites in New Zealand is known, the total quantity of wastes and contaminated soil has been estimated using data from only a few of these sites. The emission factor is assigned a ‘medium’ certainty ranking because PCDD and PCDF concentration data are available for wastes and contaminated soil from four New Zealand gasworks sites.

31.2 Releases to water

As noted in Section 31.1, coal tar/water emulsions may be present at gasworks sites, and, as such, there is the potential for PCDD and PCDF releases to water. However, there is no information available to enable any estimate of releases to water from gasworks sites in New Zealand to be made. Nonetheless, given the small quantity of PCDDs and PCDFs that are present as a reservoir source at gasworks sites (estimated upper range of 6.4 g I-TEQ), any release to water that may occur is likely to be very small.

32 Summary of PCDD and PCDF emissions and reservoir sources

A tabulated summary of PCDD and PCDF emission estimates to air, releases to land and water, and reservoir sources is presented in Table 32.1.

Summaries of the activity statistics and emission factors used to derive these estimates are provided in Table 32.2 for emissions to air, and Tables 32.3 and 32.4 for releases to land and water respectively. The source of the emission factor data used to derive each estimate is also noted in the summary tables. This is indicated as either New Zealand (NZ) data or a reference is provided to the published literature.

Table 32.1 Summary of PCDD and PCDF emission sources

Source	Emission to air (g I-TEQ yr^{-1})	Cert. [1]	Release to land (g I-TEQ yr^{-1})	Cert. [1]	Release to water (g I-TEQ yr^{-1})	Cert. [1]	Reservoir (g I-TEQ)	Cert. [1]
Incineration and combustion processes								
Clinical, pathological and quarantine waste incineration	0.38 – 3.5	M, M	0.43 – 3.2	M, L	No direct releases		–	
Hazardous waste incineration	0.00054 – 0.0039	H, H	0.25×10^{-6} – 85×10^{-6}	H, L	No direct releases		–	
Wastewater solids incineration	0.009	H, L	0.024	M, L	Insufficient data		–	
Crematoria	0.0080 – 0.45	H, L	Insufficient data				–	
Power generation	0.059 – 0.11	H, M	0.0016 – 0.12	H, L	Insufficient data		–	
Industrial, commercial and agricultural coal combustion								
Industrial and commercial appliances	0.032 – 3.8	H, M	0.00045 – 0.30	M, L	Insufficient data		–	
Agricultural appliances	0.0017 – 0.20	H, L	0.000023 – 0.016	M, L	Insufficient data		–	
Domestic coal burning	0.36 – 0.59	H, L	0.00072	M, L	No direct releases		–	
Industrial wood combustion								
Wood processing wastes	0.28 – 1.2	M, M	0.0012 – 0.017	M, L	Insufficient data		–	
Contaminated wood wastes	0.57 – 1.2	M, L	0.33 – 1.9	M, L	Insufficient data		–	
Domestic wood burning	0.71 – 8.7	H, L	0.48 – 9.7	M, L	No direct releases		–	
Domestic waste burning								
Organic waste (including green waste)	0.041 – 1.2	L, L	Insufficient data		No direct releases		–	
“House” waste (including paper and plastics)	0.50 – 5.2	L, L	5.7	L, L	No direct releases		–	
Land transport								
Unleaded petrol	0.010 – 0.59	H, L	No direct releases		No direct releases		–	
Diesel	0.10 – 0.57	H, L	No direct releases		No direct releases		–	
Uncontrolled fires								
Forest and herbage fires	0.080 – 1.1	L, L	Insufficient data		No direct releases		–	
Structure fires	0.27 – 2.7	L, L	Insufficient data		Insufficient data		–	
Vehicle fires	0.10 – 0.14	L, L	Insufficient data		Insufficient data		–	

Source	Emission to air (g I-TEQ yr^{-1})	Cert. [1]	Release to land (g I-TEQ yr^{-1})	Cert. [1]	Release to water (g I-TEQ yr^{-1})	Cert. [1]	Reservoir (g I-TEQ)	Cert. [1]
Manufacturing and production processes								
Cement and lime manufacture								
Cement manufacture	0.10 – 0.65	H, M	1.3 x 10^{-5} – 1.4	H, L	No direct releases		–	
Lime manufacture	0.0030 – 0.16	H, L	5.0 x 10^{-6} – 0.15	M, L	No direct releases		–	
Iron and steel production								
Primary steel production	0.10	H, H	0.67	H, M	0.015	H, M	–	
Secondary steel production	0.017 – 0.063	H, H	1.4	H, M	Insufficient data		–	
Non-ferrous metal production	0.10 – 1.3	L, L	0.19 – 2.2	L, L	Insufficient data		–	
Aluminium production								
Primary aluminium production	Insufficient data [2]		0.0017	H, L	Insufficient data		–	
Secondary aluminium production	0.0091 – 1.8	M, L	0.67 – 6.8	L, L	Insufficient data		–	
Glass production	0.00024 – 0.0038	H, L	Insufficient data		Insufficient data		–	
Pulp and paper production								
Bleached kraft mills	0.033 – 0.045	H, M	0.56	H, M	0.20 – 0.35	H, M	24	M, M
Non-kraft mills (paper recycling)	No BLS [5]		0.0050	M, L	Insufficient data		Insufficient data	
Miscellaneous activities								
Cigarette smoking	0.00029 – 0.0084	H, L	Insufficient data		No direct releases		–	
Used oil use and disposal	0.00068 – 0.024	L, L	0.012 – 0.53	L, L	Insufficient data		–	
Use of halogenated pesticides	No direct releases [3]		0.13 – 0.15	H, L	No direct releases		–	
Landfills	0.078 – 0.16 [6] and 10 – 15 [7]	L/M, L L, L	20	H, L	0.00074 – 0.0093 [8] and 0.0083 – 0.95 [9]	L, M L, M	500	M, L
Wastewater treatment	See Wastewater solids incineration		0.61 – 5.2	M, M	0.34 – 2.6	M, L	–	

Source	Emission to air (g I-TEQ yr^{-1})	Cert. [1]	Release to land (g I-TEQ yr^{-1})	Cert. [1]	Release to water (g I-TEQ yr^{-1})	Cert. [1]	Reservoir (g I-TEQ)	Cert. [1]
Historic activities [4]								
Historic pesticide manufacture	Not assessed		None		Not assessed		Insufficient data	
Historic use of 2,4,5-T	Not assessed		None		Not assessed		620 – 860 [10]	M, M
Timber treatment and historic pentachlorophenol use	Not assessed		Not assessed		Not assessed		80 [11] and	L, L
							230 [12]	M, M
Coal gasification	Not assessed		None		Not assessed		0.028 – 6.4	L, M
Total annual estimate of emissions for 1998	**14 – 51**		**26 – 54**		**0.56 – 3.9**		**–**	
Total estimate of reservoir source at 1998	**–**		**–**		**–**		**1,450 – 1,700**	

1. Certainty rankings are presented as *activity ranking*, *emission factor ranking*. H = High certainty; M = Medium certainty; L = Low certainty. See Section 3.3.
2. Insufficient data are available to make any estimate of PCDD and PCDF emissions from this source.
3. No direct releases of PCDDs and PCDFs occur from this activity.
4. Ongoing PCDD and PCDF emissions to air and releases to water were not assessed from historic activities. Emissions to air may occur from, for example, wind scouring of soil and dust from contaminated sites, or via volatilisation from PCP treated structures. Similarly, releases to water may occur via runoff from contaminated sites. No ongoing relases to land are expected from historic pesticide manufacture, the historic use of 2,4,5-T or coal gasification. PCDD and PCDF releases to land may occur via migration from PCP treated structures, but are not assessed in this inventory.
5. No black liquor solids (BLS) recovery occurs at non-kraft mills. Emissions from heat/power generation are covered under coal/wood fired combustion.
6. From fugitive landfill gas emissions, landfill gas flaring and gas combusted in engines.
7. Emissions from landfill fires.
8. From annual refuse placed.
9. Release from reservoir.
10. Reservoir estimate for 2,3,7,8-TCDD.
11. From NaPCP for antisapstain treatment.
12. From PCP in oil for preservative treatment.

Table 32.2 Summary of activity statistics and emission factors for emissions to air

Source	Measure	Activity statistic (tonne yr^{-1})	Emission factor (µg I-TEQ $tonne^{-1}$)	Data source
Clinical, pathological and quarantine waste incineration				
Incinerators with measured emissions	Waste	9,200	0.37 – 617	NZ
Incinerators without measured emissions	Waste	3,800	62.5 – 617	NZ
Hazardous waste incineration	Waste	302	0.09 – 179	NZ
Wastewater solids incineration	Dry solids	1,000	9	HMIP, 1995
Crematoria	Bodies	15,900 [1]	0.5 – 28 [2]	Bremmer *et al*., 1995; US EPA, 1998
Power generation	Coal	294,000	0.2 – 0.36	NZ
Industrial, commercial and agricultural coal combustion				
Industrial and commercial appliances	Coal	798,000	0.04 – 4.8	HMIP, 1995
Agricultural appliances	Coal	42,000	0.04 – 4.8	HMIP, 1995
Domestic coal burning	Coal	63,000	5.7 – 9.3	HMIP, 1995
Industrial wood combustion				
Wood processing wastes	Wood	567,000	0.50 – 2.2	HMIP, 1995; US EPA, 1998
Contaminated wood wastes	Wood	63,000	9 – 19	HMIP, 1995
Domestic wood burning				
Enclosed appliances	Wood	463,000	1 – 3	HMIP, 1995
Open fires	Wood	250,000	1 – 29	HMIP, 1995
Domestic waste burning				
Organic waste (including green waste)	Waste	40,600	1 – 29	HMIP, 1995
"House" waste (including paper and plastics)	Waste	17,400	29 – 300	HMIP, 1995; Lemieux, 1997
Land transport				
Unleaded petrol	VKT	28,770 x 10^6 [3]	0.36 – 21 [4]	HMIP, 1995
Light diesel	VKT	4,920 x 10^6 [3]	3.7 – 12.7 [4]	Essers *et al*., 1992; IFEU, 1998
Heavy diesel	VKT	2,910 x 10^6 [3]	29 – 174 [4]	Gertler *et al*., 1997; Gullett and Ryan, 1997

Source	**Measure**	**Activity statistic (tonne yr^{-1})**	**Emission factor (µg I-TEQ $tonne^{-1}$)**	**Data source**
Uncontrolled fires				
Forest and herbage fires	Material burnt	39,780	2 – 29	Bremmer *et al*., 1995; US EPA, 1998
Structure fires	Material burnt	2,680 – 6,690	100 – 400	From consideration of published studies. See Section 16.1
Vehicle fires	Vehicles burnt	3,200 [5]	32 – 44 [6]	Wichmann *et al*., 1995
Cement and lime manufacture				
Cement manufacture kilns with measured emission	Clinker	475,000	0.20 – 0.25	NZ
Cement manufacture kilns without measured emission	Clinker	494,000	0.02 – 1.08	HMIP, 1995
Lime manufacture	Product	151,000	0.02 – 1.08	HMIP, 1995
Iron and steel production				
Primary steel production	Steel	650,000	0.16	NZ
Secondary steel production	Steel	170,000	0.098 – 0.37	NZ
Non-ferrous metal production	Product	20,000 – 36,000	5 – 35	HMIP, 1995
Aluminium production				
Secondary aluminium production	Aluminium	35,000	0.26 – 52.2	US EPA, 1998
Glass production	Product	120,000	0.002 – 0.032	HMIP, 1995; IFEU, 1998; US EPA, 1998
Pulp and paper production (black liquor recovery boilers)	BLS	1,260,000	0.026 – 0.036	NZ
Cigarette smoking	Cigarettes	4,200 x 10^6 [7]	0.07 – 2 [8]	Löfroth and Zebühr, 1992; Matsueda *et al*., 1994
Used oil use and disposal	Used oil	340 – 4,000	2 – 6	Bremmer *et al*., 1994
Landfills				
Landfill gas, fugitive emissions	Gas	240 x 10^6 [9]	0.32 – 0.36 [10]	HMIP, 1995
Landfill gas, flared gas	Gas	4.5 x 10^6 [9]	0.22 – 2.4 [10]	HMIP, 1995; US EPA, 1998
Landfill gas, gas combusted in engines	Gas	5.5 x 10^6 [9]	0.06 – 12 [10]	HMIP, 1995
Landfill fires	Pro-rata from Swedish data (Persson and Bergström, 1991). See Section 26.1.2			

1. Bodies yr^{-1}
2. µg I-TEQ $body^{-1}$
3. km yr^{-1}
4. pg I-TEQ km^{-1}
5. fires yr^{-1}
6. µg I-TEQ $fire^{-1}$
7. Cigarettes yr^{-1}
8. pg I-TEQ $cigarette^{-1}$
9. Nm^3 yr^{-1}
10. ng I-TEQ Nm^{-3}

VKT	Vehicle kilometres travelled
BLS	Black liquor solids

Table 32.3 Summary of activity statistics and emission factors for releases to land

Source	Measure	Activity statistic (tonne yr^{-1})	Emission factor (ng I-TEQ kg^{-1})	Data source
Clinical, pathological and quarantine waste incineration	Gas scrubbing residues	585	680 – 4,500	Environment Agency, 1997
	Grate ash	1,950	15 – 300	Environment Agency, 1997
Hazardous waste incineration	Grate ash	2.50	0.1 - 34	Environment Agency, 1997
Wastewater solids incineration	Grate ash	430	39	Environment Agency, 1997
	Fly ash	14	473	Environment Agency, 1997
Power generation	Grate ash	2,280 – 3,010	0.02 – 13.5	Environment Agency, 1997
	Fly ash	6,820 – 9,020	0.23 – 8.7	Environment Agency, 1997
Industrial, commercial and agricultural coal combustion				
Industrial and commercial appliances	Grate ash	22,260	0.02 – 13.5	Environment Agency, 1997
Agricultural appliances	Grate ash	1,170	0.02 – 13.5	Environment Agency, 1997
Domestic coal burning	Grate ash	1,760	0.41	Environment Agency, 1997
Industrial wood combustion				
Wood processing wastes	Grate ash	5,100 – 15,300	0.23 – 1.12	Environment Agency, 1997
Contaminated wood wastes	Grate ash	570 – 1,700	584 – 1,090	Environment Agency, 1997
Domestic wood burning	Grate ash	6,400 – 19,300	75 - 500	Environment Agency, 1997
Domestic waste burning ("House" waste, inc paper/plastics)	Ash	17,400	326	Lemieux *et al*., 1997
Cement and lime manufacture	Clinker	969,000	< 1	Reiner *et al*., 1995
	ESP dust (cement manufacture)	13,200	0.001 - 30	Environment Agency, 1997
	Dust (lime manufacture)	5,000	0.001 - 30	Environment Agency, 1997
Iron and steel production				
Primary steel production	Steel making baghouse dust	3,000	36.5	NZ
	Sand/char	30,000	3.3	NZ
	Arc furnace baghouse dust	1,300	357	NZ
	Gas scrubber sludge	13,140	0.045	NZ
Secondary steel production	Arc furnace baghouse dust	2,000	700	NZ
Non-ferrous metal production	Filter fines and dust	1,000 – 2,000	190 – 1,100	NZ; Bremmer *et al*., 1994

Source	**Measure**	**Activity statistic (tonne yr^{-1})**	**Emission factor (ng I-TEQ kg^{-1})**	**Data source**
Aluminium production				
Primary aluminium production	Metal reclaim fines	2,000	0.85	NZ
Secondary aluminium production	Filter fines and dust	1,400 – 1,700	480 – 4,000	Environment Agency, 1997
Pulp and paper production				
Bleached kraft mills	Primary sludge	36,700	4.5	NZ
	Secondary sludge	11,400	34	NZ
Used oil use and disposal	Used oil	8,800	14 – 60	Environment Agency, 1997
Use of halogenated pesticides	2,4-D product	180 – 220	0.7 [1]	US EPA, 1998
Landfills	Residential solid waste	1.42 x 10^6	6.3	Environment Agency, 1997
	Industrial solid waste	1.76 x 10^6	6.3	Environment Agency, 1997
Wastewater treatment	Wastewater solids	87,800	5.64 – 108	NZ

1. µg TEQ kg^{-1}

Table 32.4 Summary of activity statistics and emission factors for releases to water

Source	**Measure**	**Activity statistic (m^3 yr^{-1})**	**Emission factor (pg I-TEQ L^{-1})**	**Data source**
Primary steel production	Wastewater	3.1 x 10^6	4.7	NZ
Pulp and paper production (bleached kraft mills)	Wastewater	96 x 10^6	2.1 – 5.5	NZ
Landfills				
From annual refuse placed	Leachate	68,500	7.5 – 221	NZ
From the reservoir	Leachate	1.1 x 10^6 – 4.3 x 10^6	7.5 – 221	NZ
Wastewater treatment	Wastewater effluent	454 x 10^6 [1]	5.64 – 108 [2]	NZ

1. Total solids released in the effluent discharge calculated from the effluent volume and the average suspended solids content.
2 ng I-TEQ kg^{-1}. Release to water calculated from the total solids released and the PCDD and PCDF concentrations in the dry solids.

33 Comparison of the New Zealand emissions inventory with other countrywide inventories

33.1 Overview

A number of national inventory studies for releases of PCDDs and PCDFs on a country by country basis have now been published. However, making comparisons from one country to another is not simple. In particular, the available studies have not always been compiled using the same approach and, equally importantly, the industrial infrastructure and levels of pollution abatement technologies that are used to control emissions vary considerably from one country to another. Furthermore, the emissions of PCDDs and PCDFs change as industries upgrade pollution controls or shut down old plants or indeed open new processes. It is therefore important to consider the year that the inventory refers to and to bear in mind that the situation may have changed. New categories of sources are being identified as more work is carried out and an inventory will always be, at best, a snapshot of how things were.

In a recent review of PCDD and PCDF inventories, UNEP (1999) found that inventories of emissions to air had been established for fifteen countries (11 in Europe, Canada, the United States, Japan and Australia). Some of the existing inventories were relatively old and would require updating, while others such as the United States inventory (US EPA, 1998) are still in draft format. UNEP (1999) reported that other national inventories were in preparation. In addition to national inventories, for some countries, regional inventories have also been undertaken, such as those reported for the city of Hamburg (Lau *et al*., 1996) and Washington State (Washington State Department of Ecology, 1998).

The estimate of emissions to air for the countrywide inventory studies as reviewed by UNEP (1999) are reported in Table 33.1 and shown in Figure 33.1. It should be noted that some estimates are expressed as a single emission value, whereas others are expressed as a range of emissions. For comparative purposes, the estimate of emissions to air for the current New Zealand inventory is also included.

It is impractical, and of limited usefulness, to reproduce in detail the inventories from many diverse countries in this report. However, it is interesting to make comparisons against selected countries. Similarly, it is not possible to examine the methodological differences between inventories and it should be borne in mind that these will affect the results.

It is clear that until a systematic approach to assembling national inventories is established, meaningful comparisons can only be made with care and covering only limited aspects of the data. In particular, it should be noted that the sources addressed could be significantly different between countries. For example, few inventories consider accidental fires, the domestic burning of waste and fires at landfills. The exclusion of these sources may markedly underestimate the total PCDD and PCDF emission estimates made for a country. Furthermore, most international inventories address only releases to air, with very few countries considering releases to land and water.

For illustration, and to place the New Zealand inventory into an international context, key points from the inventories for Austria, the United Kingdom, the United States, Japan and Australia are considered in Sections 33.2 to 33.6, and an overall summary provided in Section 33.7.

Table 33.1 PCDD and PCDF emissions to air from countrywide inventories

Country	Emission estimate (g I-TEQ yr^{-1})	Reference year	Reference
Australia	150 – 2,300	Not specified	EPG, 1998
Austria	28.7	1994	UBAVIE, 1996 [1]
Belgium	662	1995	De Fré and Wewers, 1995 [1]
Canada	290	1997	Environment Canada, 1999
Denmark	37 – 45	1995	Ministry of Environment and Energy, 1997 [1]
France	674 – 2,737	1997	Adème, 1999 [1]
Germany	333	1994	IFEU, 1998 [1]
Hungry	104	1996	KGI, 1997 [1]
Japan	3,981 – 8,351	1990	Hiraoka and Okajima, 1994
The Netherlands	484	1991	Bremmer *et al*., 1994
New Zealand	**14 – 51**	**1998**	**This study**
Slovak Republic	42.5	1993	Kocan, 1994 [1]
Sweden	21.6 – 88	1993	de Wit, 1995 [1]
Switzerland	180	1995	BUWAL, 1997 [1]
United Kingdom	560 – 1,100	1993	HMIP, 1995
United States	1,026 – 7,541	1995	US EPA, 1998

1. The data reported has been taken from UNEP (1999), and not from the original publication referenced.

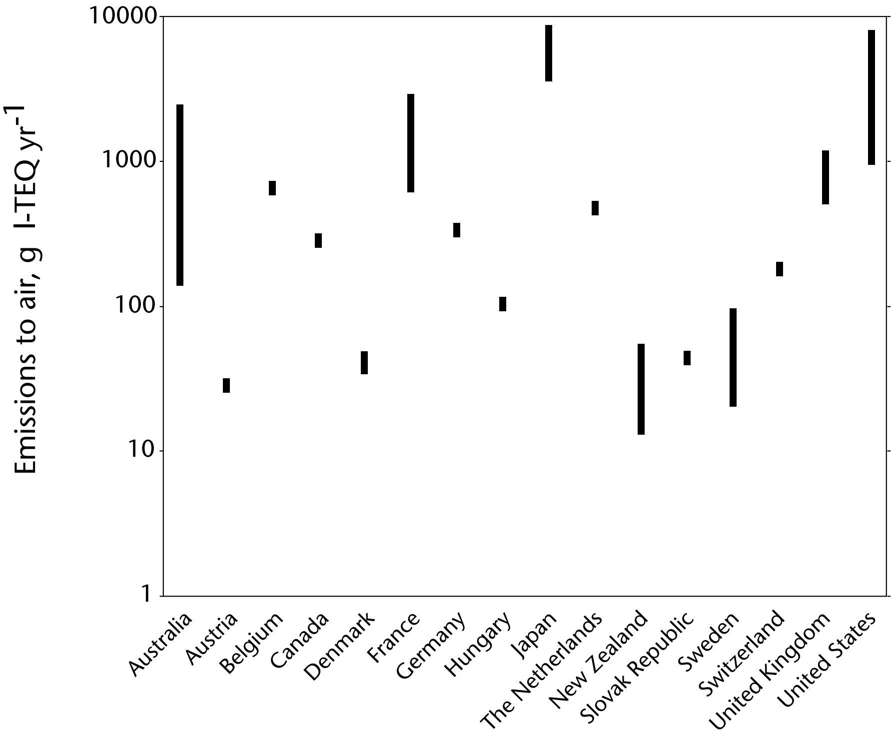

Figure 33.1 **PCDD and PCDF emissions to air from countrywide inventories**
Data as reported in Table 33.1. Estimates that are reported as a single emission value are shown as a narrow band.

33.2 Austria

Austria is a relatively small country and the inventory shows low overall emissions for the year 1994, estimated at a total of approximately 28.7 g I-TEQ yr^{-1} (Table 33.2; UBAVIE, 1996). In contrast to other countries that are reliant on incineration for waste disposal, the high standards of emissions control technology in Austria mean that waste incineration makes a minor contribution to the inventory. Non-industrial combustion plants emit approximately 16.67 g I-TEQ yr^{-1}, corresponding to 58% of the total emissions. Primarily, the emissions from this sector are from the combustion of wood and particularly from its use as a fuel for residential home heating.

Table 33.2 PCDD and PCDF emissions to air in Austria

Source	Emission (g I-TEQ yr^{-1})
Combustion in energy and transformation industries	0
Non-industrial combustion	16.67
Combustion in manufacturing industry	1.5
Production processes	10.36
Road transport	0
Waste treatment and disposal	0.179
Nature	0.024
Total	28.7

33.3 The United Kingdom

Emissions of PCDDs and PCDFs to air (HMIP, 1995), and land and water (Environment Agency, 1997) have been examined in the United Kingdom. The base year for the principal assessments was 1993. The largest sources are summarised in Table 33.3. United Kingdom data were not available for all sources and improved estimates could now be made for several sources using more recent data. Since the New Zealand inventory was compiled using a methodology based on the United Kingdom inventory, it is especially interesting to compare the principal sources identified.

Older design municipal waste incinerators were a large contributor to emissions to air, and releases to land in the form of ash and gas scrubbing residues. This is in stark contrast to New Zealand where municipal waste incineration is not carried out. It is also important to note that since new plant emission standards came into force in 1996, emissions to air in the United Kingdom from this source are estimated to have been reduced to well under 10 g I-TEQ yr^{-1}.

Some of the more important non-industrial sources such as accidental fires and the uncontrolled combustion of waste could not be quantified for the United Kingdom in 1993. As a consequence, industrial processes dominate the overall inventory. The manufacture of per- and trichloroethylene was assessed as having very high amounts of PCDDs and PCDFs in residues. However, these solvents are not manufactured in New Zealand.

Data on releases to water were limited and a ranking system was applied in the place of numerical estimates to indicate potentially important sources. The potential for releases were denoted as high (H; > 1 g I-TEQ yr^{-1}), medium (M; 0.1 – 1 g I-TEQ yr^{-1}) and low (L; < 0.1 g I-TEQ yr^{-1}).

Table 33.3 PCDD and PCDF emissions to air and releases to land and water in the United Kingdom

Source	Emissions, (g I-TEQ yr^{-1})			Comment
	air	land	water	
Municipal waste incineration	460 – 580	520 – 2,400	M/L	All plants had to meet new standards in 1996 – emissions fell drastically
Other waste incineration	20 – 100	13 – 40	H	New plant controls have drastically reduced air emissions
Coal combustion	25 – 100	1.9 – 120	L	
Metals industry	37 – 130	210 – 540	M/L	Emission controls being imposed
Traffic	1 – 45	-	-	Unleaded petrol reducing emissions
Crematoria	1 – 35	-	-	Improved operations to reduce emissions
Pesticide use (especially PCP)	-	100 – 3,200	-	Significant amounts of PCP thought to enter the UK with products such as wood and textiles
Accidental fires	Not quantified	7.5 – 2,400	H	
Pesticide production	0.1 – 0.3	8.9 – 2,000	H	Very little data and most waste is likely to be carefully disposed of reducing any environmental release
Per-, trichloroethylene production	< 0.02	350 – 630	M	Planned changes in practice will address these releases
Estimated totals [1]	560 – 1,100	1500 – 12,000		

1. Includes other sources not detailed in the table.

Recently, emissions data from large-scale industrial processes that are regulated by the Environment Agency have been assembled for 1998. The total PCDD and PCDF emissions to air from these processes are estimated at approximately 110 g I-TEQ for 1998 (Environment Agency 1999). This estimate illustrates the effect of controls on industrial sources of PCDDs and PCDFs when compared to the estimated release from industrial processes in 1993 of 430 – 840 g I-TEQ.

33.4 The United States

The US EPA has been studying the release of PCDDs and PCDFs in the United States for some years, and released a draft inventory of sources for peer review in 1998 (EPA, 1998). Although this document currently remains a draft, the central estimates for each of the source categories are summarised in Table 33.4. The emission range was estimated between 1,026 – 7,541 g I-TEQ yr^{-1}. The reference year for this inventory is 1995.

The inventory is totally dominated by estimates of the amount of PCDDs and PCDFs released from PCP treated wood, at 25,000 g I-TEQ yr^{-1}. Aside from PCP treated wood, the largest sources quantified were waste incineration (primarily municipal and medical waste incineration) and metal processing (primarily secondary copper smelting).

Further data is required for some sources such as magnesium processing and accidental fires, which were not quantified at all. Of particular interest are the poorly quantified sources that could be potentially highly significant. These include iron ore sintering, landfill fires and the domestic burning of waste, for which only order of magnitude estimates were made.

Table 33.4 PCDD and PCDF emissions to air and in products in the United States

Source	**Emission** **(g I-TEQ yr^{-1})**
Waste incineration [includes municipal, medical and hazardous waste]	1,589
Power/energy generation [includes vehicle fuels, wood, coal and oil combustion]	214
Other high temperature sources [includes cement kilns and kraft recovery boilers]	174
Minimally controlled or uncontrolled combustion [forest, bush and straw fires]	208
Metallurgical processes [secondary copper, aluminium and lead smelting]	560
Chemical manufacturing/processing sources	Expected to be negligible
Total emissions to air	2,745 (range 1,026 – 7,541)
Other sources (in product not air emissions)	
Pentachlorophenol	25,000
Order of magnitude estimates for air emissions	
Landfill fires	1,000
Backyard rubbish burning	1,000
Iron ore sintering	100

It is also relevant to note that the EPA estimate that air emissions have fallen from a central estimate of 11,274 g I-TEQ in 1987 to under 2,745 g I-TEQ in 1995 due to process changes and improvements in pollution control mainly for incineration plants (US EPA, 1998).

33.5 Japan

Several estimates of releases of PCDDs and PCDFs in Japan have been made, and intensive studies are currently underway to improve the understanding of sources in this country. Hiraoka and Okajima (1994) published an inventory for 1990, with emissions to air being assessed in the range 3,916 - 8,376 g I-TEQ yr^{-1}, as summarised in Table 33.5. Japan relies very heavily on incineration to treat municipal solid waste, as well as other waste streams such as medical and hazardous waste, and therefore has a very large number of incineration plants. However, many of the municipal waste incinerators have an intermittent operational cycle and limited pollution control equipment. Consequently, emissions of PCDDs and PCDFs are very high, and releases from incineration dominate the national inventory.

Revised estimates of emissions to air for Japan for 1998 provided a similar picture, with municipal solid waste contributing 80% of the total emissions, estimated at 5,300 g I-TEQ yr^{-1} (MITI, 1998).

Table 33.5 PCDD and PCDF emissions to air in Japan

Source	Emission (g I-TEQ yr^{-1})
Municipal solid waste incineration	3,100 – 7,400
Incineration of organic chloride waste and waste oil	460
Clinical waste incineration	80 – 240
Sewage sludge incineration	5
Paper mill sludge incineration	2
Paper mill black liquor incineration	3
Wood and waste wood incineration	0.2
Metal works	250
Cigarette smoke	16
Motor vehicles	0.07
Total	3,916 – 8,376

33.6 Australia

Australia has recently completed an inventory of air emission sources, the results of which are summarised in Table 33.6 (EPG, 1998).

Table 33.6 PCDD and PCDF emissions to air in Australia

Source	Emission (g I-TEQ yr^{-1})
Fires – prescribed burning	65 – 1,300
Bushfires	7 – 400
Cement manufacture	0.12 – 153
Residential wood combustion	15 – 98
Coal combustion	4.5 – 73
Sinter production	10.3 – 77.4
Industrial wood combustion	10 – 65
Lime	0.035 – 44
Oil combustion	21
Non-ferrous metal production	1 – 19
Medical waste incineration	0.9 – 19
Motor vehicles	0.35 – 17
Asphalt mixing	14.5
Iron and steel production	0.7 – 9.4
Landfill gas	0.8 – 2.5
Other sources	0.13 – 0.45
Total	150 – 2,300

This work was modelled closely on the United Kingdom air emission inventory methodology (HMIP, 1995), and, as such, took a similar starting point as the current New Zealand inventory. A major limitation with the Australian inventory was the almost total reliance on international data due to the lack of source measurement data for the country.

Based on the upper bound emission estimates for each source, biomass combustion from prescribed burning and bushfires are potentially the most significant sources of PCDDs and PCDFs in Australia. These two sources contributed approximately 75% to the total PCDD and PCDF emissions, which were estimated in the range 150 – 2,300 g I-TEQ yr^{-1}. However, due to the nature of these sources, there is considerable uncertainty in the estimates made.

33.7 Summary

From a review of the published countrywide inventories for PCDDs and PCDFs, the following general comments can be made:

1. The overall emissions of PCDDs and PCDFs to the environment are heavily dependent on the nature of the country, its industrial development and the levels of pollution control that are in place within the industrial sector. It would appear that emissions to air are falling, at least in several European countries and in North America, as emission controls and changes in industrial infrastructure take effect.
2. For the most part, countrywide inventories are mainly based on assessing emissions to air, with few studies addressing releases to land and water, or reservoir sources.
3. Where municipal waste incineration is heavily relied upon, the emissions of PCDDs and PCDFs can be disproportionately high if pollution controls are poor. In such instances, this category may dominate the inventory, as is the case with the United States and Japanese inventories. In contrast, in countries such as Austria where there are high standards of emission control on waste incinerators, this category may represent only a tiny fraction of the overall emissions. Other types of waste incineration, notably medical waste incineration, may also be a significant contributor to total PCDD and PCDF emissions.
4. Metal production and processing, especially secondary metal production, is becoming increasingly important to overall emissions, particularly as emissions from other industry sectors are reduced. In a number of countries, regulatory authorities are placing renewed emphasis on addressing PCDD and PCDF emissions from the metallurgical sector.
5. The combustion of wood and coal, especially at the domestic scale, is increasingly being recognised as potentially a major non-industrial source of PCDDs and PCDFs. However, this sector is highly uncertain, especially concerning the composition of wood being burnt, and the extent of co-combustion of household wastes.
6. Releases from landfill fires, from products containing PCDD and PCDF residues, from reservoirs and from non-industrial sources such as accidental fires and the domestic burning of waste are hard to quantify and are often not included in countrywide inventories, even though they may be highly significant overall.
7. Estimates for releases of PCDDs and PCDFs from bushfires and prescribed burning are highly uncertain and emission factors are hard to generate. However, in some countries this source may be very significant.

8. New Zealand would appear to have relatively low overall emissions compared to many other countries so far assessed. This can be attributed to the relatively low population compared to other developed countries, and the size and nature of the industries present in New Zealand. Industrial emissions in particular are generally low compared to other countrywide inventories.

34 Uncertainties and data gaps of the New Zealand inventory

34.1 Uncertainties

There are a number of uncertainties that need to be noted in the estimates of emissions and releases made in this inventory. These are:

1. For some industries, most notably industrial coal and wood combustion and non-ferrous metallurgical processes, there are inadequate New Zealand data for PCDD and PCDF emissions to air. Many of the emission factors used in this study have been taken from data published in the international literature. Emission factors as a tool for estimating emissions are inherently prone to uncertainties as they are typically based on limited testing of a source population. The applicability of these data to New Zealand conditions, industrial processes, fuels and waste residues is therefore subject to considerable uncertainty.

2. Similarly, data on PCDD and PCDF concentrations in solid waste streams from combustion and non-ferrous metallurgical processes are almost totally lacking. Furthermore the quantity of waste materials (e.g. ashes, sludges and slags) is generally not available. The current study has made estimates for the quantity of wastes produced based on generation rates per unit of activity undertaken (e.g. the amount of waste burnt or metal manufactured). Concentration data have generally been sourced from the published literature.

3. For a number of industrial sectors, primarily those that are defined by a multitude of small operators, there is a variety of equipment in use that operates under varying process conditions. To collect comprehensive information on all emissions and releases from all operators in this category is highly problematic with any emissions inventory.

   For the current study, collecting data from all facilities operating over the whole range of process variables was not possible. In addition, some limited New Zealand data for such sectors could not confidently be extrapolated across the whole sector. Overseas emission factors were therefore applied, with the local data being used to support the factors chosen. The use of an emission factor or concentration range does address, in part, some of this uncertainty by trying to estimate the extremes of the likely emissions and releases.

4. For data on emissions to air, most commonly the emissions tests were undertaken when the facility would have been running at optimum performance and operational control. This is unlikely to be fully representative of normal operational conditions. The likely day to day variation in PCDD and PCDF emissions from a facility over a range of operational conditions is unknown.

5. For non-industrial sources, there is considerable uncertainty in deriving emission estimates due to the almost total lack of data and the widely varying conditions under which domestic coal, wood and waste burning, and uncontrolled fires, may occur. Obtaining representative emission factors for these sources is extremely difficult. In addition, for waste burning and uncontrolled structure and vehicle fires, the quantities of the various types of material that are burnt in such fires are also highly uncertain. The lack of adequate and reliable data for non-industrial sources is particularly noteworthy due to the significant contribution that these sources appear to make to the total PCDD and PCDF emissions in New Zealand when compared with industrial sources.

6. Some estimates of releases to water, notably releases from wastewater treatment and landfills, have been derived from modelled activity statistics. In the absence of actual data, this is the best approximation that can be made. These estimates therefore remain inherently uncertain.
7. For some of the sources assessed in this inventory, emission factors span an order of magnitude or more. This is indicative of the potential variations that may be observed within a particular source category. With such large variations, it becomes particularly difficult to identify significant PCDD and PCDF contributors to the total source emissions, particularly if the upper bound of the estimated range indicates that the source may be significant, while the lower bound of the range indicates a minor contribution. In such instances, other supporting data (e.g. ambient air monitoring) may be helpful in any prioritisation of emission sources.
8. The assessment of reservoir sources, particularly those that consist of a large number of sites, such as contaminated timber treatment sites and landfills, is hindered due to the difficulty in determining the activity statistic (i.e. the quantity of contaminated soil or refuse that constitutes the reservoir). In the current study, this has been estimated using the best available data and knowledge about the particular industries that are associated with reservoir sources. Nevertheless, there remains a large degree of uncertainty. Furthermore, not only is more precise data unavailable, obtaining such data is likely to prove extremely difficult and costly, as this will require extensive assessments being undertaken at many of the sites.

34.2 Data gaps

This inventory has attempted to assess emissions, albeit with the limitations discussed above, from all industrial processes that are known to be sources of PCDDs and PCDFs in New Zealand. This includes historic sources that may now constitute a reservoir source. The robustness of the emission estimates that have been made can be enhanced by:

1. More representative emission data focused on source categories for which limited or no New Zealand data are presently available. This should also include better characterisation of these processes with respect to pollution control equipment, quantities of product produced and the nature and quantities of waste streams. This observation is particularly relevant to the non-ferrous metallurgical industry, as this industry sector has been identified as a potentially major source of PCDD and PCDF emissions internationally.
2. Better activity statistics for certain processes, most notably industrial wood combustion (quantity of contaminated wood burnt), landfill fires, landfill gas processes (fugitive emissions, flaring and combustion), landfill leachate generation and used oil use and disposal.
3. Concentration data on PCDD and PCDF residues in solid waste streams (e.g. ashes and sludges), particularly those that are deposited to land, from waste incineration, coal and wood combustion and metallurgical processes.
4. Data on PCDDs and PCDFs in domestic and industrial waste deposited in landfills, and on their emissions from landfill fires, the flaring or combustion of landfill gas and landfill leachate vapour and releases in landfill leachate. This information is particularly important to enable comparative environmental assessments to be made of the options for waste management strategies in New Zealand (i.e. landfilling vs. waste incineration).
5. Information on the quantity of leachate and run-off released from timber treatment sites where PCP was used, and the concentrations of PCDDs and PCDFs in such leachate.

With respect to non-industrial and natural sources, and uncontrolled fires, the quality of the emission estimates can be further improved by:

1. Better characterisation of the sources within this category that contribute to PCDD and PCDF emissions. For example, the current characterisation of domestic wood burning does not provide accurate data on the quantity of contaminated wood or other wastes burnt. Similarly, the amounts of the various types of materials burnt in domestic (backyard) fires and in uncontrolled fires (forest, scrub and grass fires, and structure fires) are not known with any great certainty.
2. More comprehensive emission factor data for all sources. The available data for domestic and natural sources are extremely limited and subject to considerable uncertainty, and the resultant emission estimates need to be interpreted with much caution. For example, emissions from residential wood burning appliances are used to estimate emissions from the uncontrolled burning of forest, scrub and grass, but given the highly variable nature under which such fires can occur, such emission factors may not be entirely appropriate.

35 Units and abbreviations

g	gram
µg	microgram (10^{-6} grams)
ng	nanogram (10^{-9} grams)
pg	picogram (10^{-12} grams)
ha	hectare
km	kilometre
kW	kilowatt
MW	megawatt
L	litre
m	metre
mm	millimetre
m^3	cubic metre
Nm^3	normal cubic metre of dry gas at 0 °C and 101.3 kPa
Sm^3	standard cubic metre of dry gas at 0 °C, 101.3 kPa and 11% oxygen

2,4-D	2,4-dichlorophenoxyacetic acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid
BOD_5	biological oxygen demand (5 day test)
CAE	Centre for Advanced Engineering
CRA	Coal Research Association
Dioxins	generic name for the PCDDs and PCDFs
DoH	Department of Health
DW	dry weight
EECA	Energy Efficiency and Conservation Authority
ESP	electrostatic precipitator
HMIP	Her Majesty's Inspectorate Of Pollution
I-TEF	international toxic equivalents factor
I-TEQ	international toxic equivalents
MOC	Ministry of Commerce
NaPCP	sodium pentachlorophenate
NZWWA	New Zealand Water and Waste Association
PCDD	polychlorinated dibenzo-*p*-dioxin
PCDF	polychlorinated dibenzofuran
PCP	pentachlorophenol
TCDD	tetrachlorodibenzo-*p*-dioxin
US EPA	United States Environmental Protection Agency
VKT	vehicle kilometres travelled

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