Waimate Inventory Of Emissions

E Foster, R Wood

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58 Kilmore Street
P O Box 345
CHRISTCHURCH
Phone: (03) 365 3828
Fax: (03) 365 3194

CANTERBURY REGIONAL COUNCIL

75 Church Street
P O Box 550
TIMARU
Phone: (03) 688 9069
Fax: (03) 688 9067

Executive Summary

An inventory of emissions to air was conducted during 1997 for the urban area of Waimate. Wintertime emissions of suspended particulate (PM_{10}), carbon monoxide (CO), nitrogen oxides (NOx), sulphur oxides (SOx), volatile organic compounds (VOCs), and carbon dioxide (CO_2) from domestic heating, transport and industry were examined. Surveying, traffic modelling, resource consent information and the application of emission factors were used to derive emissions.

From the domestic heating survey approximately 42% of Waimate households use electricity, 14% use gas and 65% use solid fuel to heat their main living area on a typical winter's night. Wood burners are used by almost half of Waimate households while open fires are used by ~9% of Waimate households. Many households use more than one method of heating in their main living area.

Wood burners are responsible for ~40% of the PM_{10} emissions from domestic heating with the remainder coming from open fires (25%) and coal and multi-fuel burners (36%). Three quarters of the PM_{10} emissions come from the burning of wood with the remainder coming from coal burning. Approximately half of the PM_{10} emissions occur during the evening (4pm to 10pm) period.

Passenger cars are responsible for the majority of PM_{10}, CO, NOx, VOC, and CO_2 emissions from transport. Just under half of the emissions from transport occur during the 10am to 4pm period.

Combustion processes are responsible for the majority of PM_{10}, CO, NOx, SOx, and CO_2 emissions from industry in Waimate. The majority of VOC emissions from the industrial sector come from spray painting.

Overall the domestic heating sector is responsible for 97% of the PM_{10}, ~80% of the CO, ~60% of the SOx and almost 90% of the CO_2. The transport sector contributes ~40% of the NOx, ~20% of the SOx and less than 10% of emissions of all other contaminants. Industry emits ~30% of the SOx, 15% of the NOx emissions and less than 10% of emissions of all other contaminants.

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1. Introduction

1.1 Purpose and Scope

This report describes the results of an air emissions inventory for the town of Waimate. It provides an estimate of quantities of specific contaminants released into the air from major sources within the urban area of the town.

Emission inventories are an important air quality management tool for determining the relative contribution of different sources to emissions to air. Emission inventories are used in conjunction with air quality monitoring data and results of meteorological investigations to assess the effectiveness of different management options.

The scope of this emissions inventory was as follows:

- Contaminants include suspended particulate (PM_{10}), carbon monoxide (CO), nitrogen oxides (NOx), sulphur oxides (SOx), volatile organic compounds (VOCs), and carbon dioxide (CO_2)
- Sources include domestic home heating, transport and industry
- The area under investigation includes the urban areas of Waimate
- Wintertime daily emissions including a breakdown for the following periods; 6am-10am, 10am-4pm, 4pm-10pm, 10pm-6am.

1.2 Background

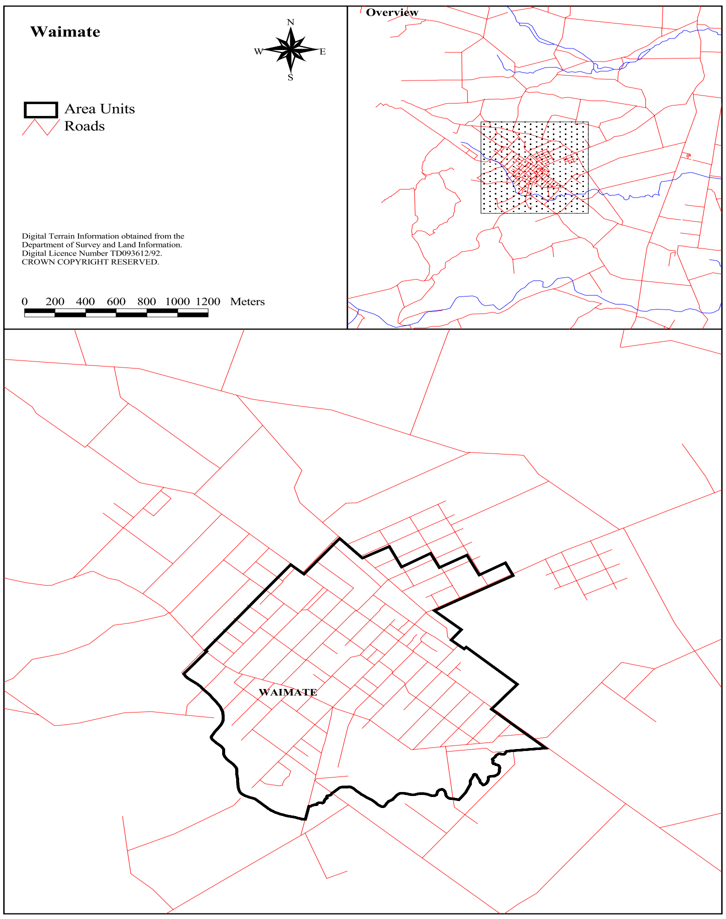


Figure 1.1 Urban areas of Waimate

Waimate is a district centre and small rural service town situated in South Canterbury between the Hunter Hills and the coast. It has a population of approximately 3260 housed in 1320 dwellings.

For the purpose of this investigation the urban area of Waimate was defined by the census area Waimate (figure 1).

Waimate has a single retail and business centre, local government centre, secondary school, primary schools, and a number of district social and recreational facilities.

Its road network is connected to the major state highway route in the South Island, S.H 1, by State Highway 82 which passes through the township and provides access to the Waitaki River valley and State Highway 8 at Omarama. The rural hinterland to the northeast side gives access to the local road network via Parsonage Road while a second connection, via High Street, to S.H. 1 in the southeast is near Willowbridge.

Domestic home heating, transport and industrial discharges are likely to be the main sources of air contaminants discharging into the Waimate area during the winter months. However, agricultural burning in the nearby rural areas is likely to be a significant source at other times of the year. This burning is typically carried out during the autumn. Backyard rubbish burning is also a potential source of air contaminants. There are currently no restrictions on backyard rubbish burning in Waimate.

The major land transport connections to the remainder of the South Island's road and rail networks are via State Highway 1, the principal intercity road link, and via State Highway 77 to the inland Canterbury road network. The South Island main trunk railway parallels State Highway 1 through the town and connects Waimate by rail to all the major communities in the South Island, with the exception of Nelson and places within central and west Otago.

As a result of the linear development based on these connections, through traffic concentrates near the town's commercial and retail centre. It was this concentration of traffic, and in particular the high proportion of heavy goods vehicles which led to the relocation of the state highway route from East to West Street in the mid 1980s.

There are a few industrial or trade activities discharging to air in Waimate. These include industrial and school boilers, spray painting operations and activities involving seed/ grain handling.

No restrictions are currently imposed on home heating methods in Waimate. Open fires and wood and multi-fuel burners can be installed into new houses and there are no restrictions relating to the fuels burnt.

No monitoring of air quality in Waimate has yet to be carried out by the Canterbury Regional Council. However, monitoring of PM_{10}, CO and SO_2 is scheduled for the year 2001.

2. Domestic Home Heating

2.1 Home heating survey

During July 1997 Business Improvements Ltd conducted a telephone survey of households to determine domestic home heating methods and fuels. This assessed the methods of home heating i.e., open fires, electricity, gas, log burners, multi-fuel burners, and oil fired heating systems; the quantity of fuel, wood or coal, used over a 24 hour period, and the times of the day the method of home heating was used. A total of 171 households were surveyed, giving a margin of error of approximately 7%. Because of the higher emissions during the winter months, surveys targeted use on a typical winter's day (i.e. 24-hour period) with the area of interest being the main living area only. If multiple methods e.g., electricity and a wood burner, were both used on a typical winter's night, details relating to both methods were included.

The quantity of gas used was derived from an assessment of the frequency with which gas bottles were refilled. Respondents using gas were also asked whether or not their gas appliances were flued.

Those respondents who had either log burners or multi-fuel burners were required to give an indication of the age of their appliance, and in the case of multi-fuel burners, the type (brand or model) of appliance they were using.

A copy of the questionnaire is contained in appendix 1. The survey was based on 1991 census data. All tables and emission calculations in this report include an extrapolation of the initial survey to reflect household numbers indicated in the 1996 census. Further details of the home heating survey based on 1991 census data are contained in CRC report no. U97/80 (Lamb, 1997).

Details of the survey area and sampling are contained in table 2.1.

Home heating methods and fuels

Table 2.2 outlines the percentage of households using the different home heating methods in Waimate. Table 2.3 describes the percentage use of different methods in more detail including the age of burners, the use of multi-fuel versus wood burners and open fires, and the percentage of gas appliances that are flued.

An analysis of survey results found that about 4% of households in Waimate use both electricity and gas to heat their main living area on a typical winter's night.

Solid fuel burners are considered in terms of the type of burner and the age of the burner because these factors influence the amount of contaminants emitted from the appliance. For the purpose of this assessment solid fuel burners have been classified as follows:

- A log burner is a burner of any age that does not burn coal;

Table 2.1 Survey area for Waimate

Survey area for Waimate (based on census areas)	Area (ha)	Total number of households	Housing density (houses/ha)	Total houses surveyed	Error Level %
Waimate	314	1308	4.1	171	~7%

Table 2.2: Home heating methods in Waimate

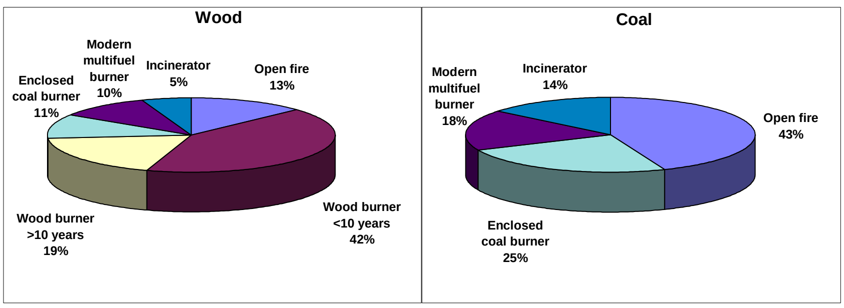
Home heating method	% of households*	Number of households
Electricity or gas (or both)	50.9	665
Solid fuel burners (incl. open fires)	64.9	849
Oil fired heating	0.6	8

*Note: The percentage of households is greater than 100% because of households using multiple methods of home heating e.g., gas and solid fuel burning, on a typical winter's night.

- An enclosed coal burner is an older model coal burner designed during or before the 1980s;
- A modern multi-fuel burner is a more recent burner in which either wood or coal can be burnt.

The following are the models or brands from the survey responses[1] included as either enclosed coal burners, modern multi-fuel burners, potbellies and incinerators:

1. Enclosed coal burners: McKay space heater, Gilles Juno, Bosca, Bellmac, Schooner, Warmaire, Rayburn, Glowburn, Wellstood, New Wonder, Speedway, Dougherty Boiler.
2. Modern multi-fuel burners: Masport, Jayline, Stack, Contessa, Magnum, Lady Kitchener, Kent, Fisher, Yunca, Siesta.
3. Incinerator: Atlas, Shacklock, Orion



Figures 2.1 & 2.2: Wood use and coal use across appliances

4. Potbelly: Potbelly

Included in the list of makes and models for 2 above (multi-fuels) are wood burners that are designed to burn wood only e.g., Lady Kitchener, Magnum, Fisher. The inclusion of these models in 2 above indicates that in some instances these wood burners are being used (inappropriately) to burn coal.

Table 2.3: Breakdown of home heating methods in Waimate

	Number of house holds	Percentage*
Electricity	543	41.5
Total Gas	183	14
-flued gas		-
-unflued gas	183	14
Oil	8	0.6
Open fire/ visor	123	9.4
Log burner	574	43.9
-10 years and older	177	13.5
-less than 10 years	375	28.7
Enclosed coal burner	115	8.8
Modern multi-fuelburner	76	5.8
Pot belly	16	1.2
Incinerator	46	3.5

* The total percentage is greater than 100% because some households use more than one method of home heating.

Table 2.3 indicates that 9% of households in Waimate use an open fire and table 2.4 shows that 8% of households burn wood on their open fire. This indicates that less than 1% of households burn coal alone on an open fire. Similarly all users of modern multi-fuel burners burn wood with a small percentage also is burning coal.

Figures 2.1 and 2.2 illustrate the distribution of wood (kg) and coal (kg) burnt on different appliances. The greatest amount of wood is burnt on the older model wood burners. Multi-fuel burners are the appliances in which the greatest quantity of coal is burnt.

The relative weight of each fuel used for domestic home heating in Waimate on a

[1] Four areas were surveyed for home heating methods during July 1997. In addition to Ashburton, Rangiora, Kaiapoi and Waimate were surveyed. Model and brand classifications were based on responses from all four areas.

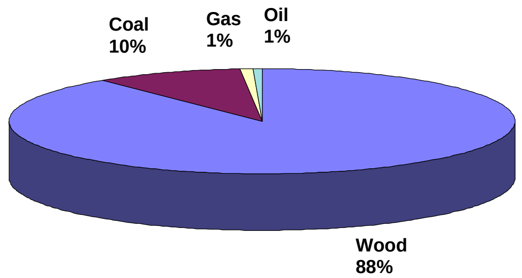


Figure 2.3: Proportion of fuel (kg) burnt in Waimate on a typical winter's night

Table 2.4: fuel consumption across appliances

	Wood		Coal	
	% hh	**kg**	**% hh**	**kg**
Open fire	8.2	2615	5.8	957
Wood burner 10yrs or older	13.5	3726	-	-
Wood burner <10 yrs old	28.7	8408	-	-
Enclosed coal burner	8.8	2190	4.7	529
Modern multi-fuel burner	5.8	1415	1.8	227
Potbelly	1.2	242	0.5	76
Incinerator	3.5	1089	1.8	302
Total	**63**	**19685**	**6.9**	**2091**

typical winter's day is illustrated in figure 2.3.

Approximately 70% of wood burnt in Waimate is purchased from a wood merchant. and 30% is self collected.

Wood burners are the most common method used to heat the home during the 10pm to 6am period (table 2.5). Open fires and gas are rarely used during this period. Less than 20% of households using open fires light them in the early morning (6am-10am) compared to 76% for gas, 62% for electricity and 50-60% for wood and multi-fuel burners. On average, wood burners, multi-fuels are used to heat households for longer periods than other methods of home heating.

Home heating methods in Waimate compared to other urban centres

Table 2.5 compares home heating methods used in Waimate with those of other urban centres. The use of open fires in Waimate is similar to Ashburton and Timaru. The use of gas in Waimate is significantly less than in Kaiapoi (99% CI).

2.2 Home heating emissions

Emissions from domestic home heating were calculated by multiplying the amount of fuel used per day/night by an emission factor which takes into account the appliance on which the fuel is burnt i.e.,

$$CE\ (g/day) = EF\ (g/kg) \times FB\ (kg/day) \qquad \mathbf{(1)}$$

where CE = contaminant emission
EF = emission factor
FF = fuel burnt

An assessment of emissions from domestic home heating for different periods of the day was also conducted. This breakdown was based on a survey question regarding the time of day, for a typical winter's day, the main living area of a house was heated. Times of the day were specified as follows:

- Morning (between 6am and 10am)
- Day time (between 10am and 4pm)
- Evening (between 4pm and 10pm)
- Overnight (between 10pm and 6am)

Emissions for each period were assessed as follows:

$$CE\ (g/\text{time period}) = EF\ (g/kg) \times FF\ (kg/\text{time period}) \qquad (2)$$

where

$$FF\ (kg/\text{time period}) = \text{no. of hours in time period} \times \frac{\text{total fuel use/day}}{\text{no. of hours in all time periods}}$$

For example, the amount of fuel burnt from 4 pm to 10 pm for a household that heats the main living area from 4 pm -10 pm and from 10 am - 4 pm and burns a total of 20 kg wood per day is as follows:

$$FF(kg/4pm\text{-}10pm) = 6\ hrs \times \frac{20kg}{12\ hrs} = 10kg \qquad (3)$$

Table 2.5: Home heating methods used at different times of the day (as a proportion of the total number of households using that method of home heating)

Time of day	Electricity %	Gas %	Oil %	Wood burner %	Open fire %	Multi -fuel %
6am - 10am	62	76	0	57	19	54
10am - 4pm	32	39	0	53	38	64
4pm - 10pm	64	67	100	92	94	100
10pm - 6am	34	13	0	67	6	22
Average over 4 time periods	48	49	25	67	39	69

Table 2.6: Home heating methods in Waimate compared to other urban centres

	% for Waimate	**% for Rangiora**	**% for Kaiapoi**	**% for Ashburton**	**% for Timaru[1]**	**% for Chch[1]**
Electricity	41.5	51.3	40.6	44.2	63	68
Total Gas	14	13.4	32.6	13.2	24	17
-flued gas	-	1.1	3.2	1.1		
-unflued gas	14	12.3	29.4	12.1		
Oil	0.6	0.5	-	2.6	3	5
Open fire/ visor	9.4	5.9	5.9	10.5	10	14
Log burner	43.9	62.0	50.8	33.2	43	28
-10 yrs and older	13.5	22.5	16.6	13.7	23[2]	14[2]
-less than 10 yrs	28.7	39.0	34.2	19.5	20[3]	14[3]
Enclosed coal burner	8.8	2.1	0.5	6.8	2	3
Modern multi-fuel burner	5.8	1.1	3.2	11.1	n/a	
Potbelly	1.2	1.1	2	1.6	1	0.3
Incinerator	3.5	-	4	-	-	1

[1] Emission inventories for Christchurch and Timaru were designed differently to account for the effect of different regulations in the Christchurch Clean Air Zones. This work was conducted by a different organisation using an alternative questionnaire. With the exception of the classifications of appliances, which aren't specified in the Christchurch/Timaru inventories, the results can be interpreted in a similar manner.
[2] Appliances recorded in the <1989 category for the Christchurch and Timaru emission inventories.
[3] Appliances recorded in the 1989-1992 and post 1993 categories for the Christchurch and Timaru emission inventories.

Emission factors

Actual emissions of air contaminants for a given appliance are dependent on a number of factors including: properties of the fuel (e.g., wetness, chemical composition, density) the amount of oxygen supporting the combustion process (e.g., high, medium or low setting on a wood burner), and the temperature of the fire and fire box (higher emissions are expected during the initial stages of the fire). Because it is not possible to quantify actual emissions from

Table 2.7: Emission factors for domestic home heating appliances (g/kg)

Appliance	PM_{10}	CO	NOx	SOx	VOC	CO_2
Gas burner	0.1	0.4	2	0.01	0.2	2500
Oil burner	1.3	0.6	2.2	3.8	0.25	3200
Open fire - wood	15	120	1.6	0.2	30	1700
Open fire - coal	33	60	1.5	18	15	2800
Old (10yr +) burner - wood	12.8	10	1.4	0.2	26	1700
Newer (< 10 yr) burner -wood	7.1	57	0.8	0.2	29	1700
Enclosed coal burner - wood	14.3	114	1.6	0.2	29	1700
Enclosed coal burner - coal	31	57	1.4	18	14	2800
Multi-fuel burner - wood	8	64	0.9	0.2	16	1700
Multi-fuel burner - coal	17.6	32	0.8	18	8	2800
Incinerator - wood	15.6	125	1.7	0.2	31	1700
Incinerator - coal	34.3	62	1.6	18	16	2800
Potbelly - wood	14.3	114	1.6	0.2	31	1700
Potbelly - coal	31.5	57	1.4	18	14	2800

Table 2.8: Home heating emissions by appliance type

	Daily fuel quantity (kg/day)	PM_{10} kg	CO kg	NOx kg	SOx kg	VOC kg	CO2 kg
Gas	167	0	0	0	0	0	417
Oil	131	0	0	0	1	0	418
Open fire - wood	2687	40	323	4	1	81	4568
Open fire - coal	981	32	59	2	18	15	2747
Wood burner (10yr+)	8686	50	396	5	1	99	6575
Wood burner (<10yr)	3868	62	493	7	2	123	14765
Enclosed coal burner -wood	2185	31	250	3	0	63	3714
Enclosed coal burner - coal	550	17	31	1	10	8	1539
Modern multi-fuel - wood	2172	17	139	2	0	35	3693
Modern multi-fuel -coal	393	7	13	0	7	3	1099
Potbelly – wood	251	4	29	0	0	7	427
Potbelly - coal	78	3	5	0	1	1	220
Incinerator - wood	1130	18	141	2	0	35	1921
Incinerator - coal	314	11	20	1	6	5	879
Total – wood	20979	221	1770	24	4	442	35664
Total - coal	2315	70	127	3	42	32	6484
Total	23294	291	1899	28	46	474	42984

all appliances in an area average emissions based on appliance and fuel type are used. These are referred to as emission factors and are based on the amount of contaminant in grams e.g., PM_{10}, CO, emitted per kg of fuel burnt. Emission factors are summarised in table 2.7.

The home heating emission factors used in the emission inventory were those derived by NIWA (CRC, 1997) for the Clean Air Zones of Christchurch. These were developed from a literature survey including: United States Environmental Protection Agency (1994) and take into account the nature of the fuels and appliances in use in Christchurch. Slightly higher emission factors for newer (<10yr) woodburners and multi-fuel burners were used for Waimate. This is because limitations regarding the installation of these appliances that exist in Christchurch which are likely to impact on emissions do not exist in Waimate.

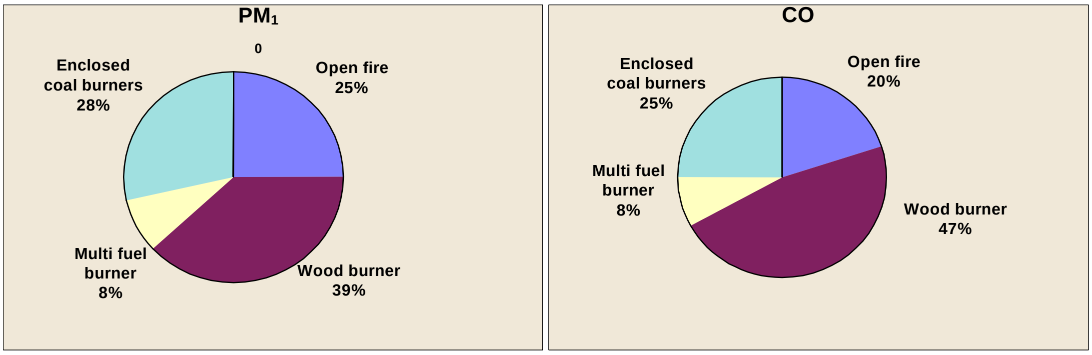


Figure 2.4 & Figure 2.5: PM_{10} & CO emissions by appliance type

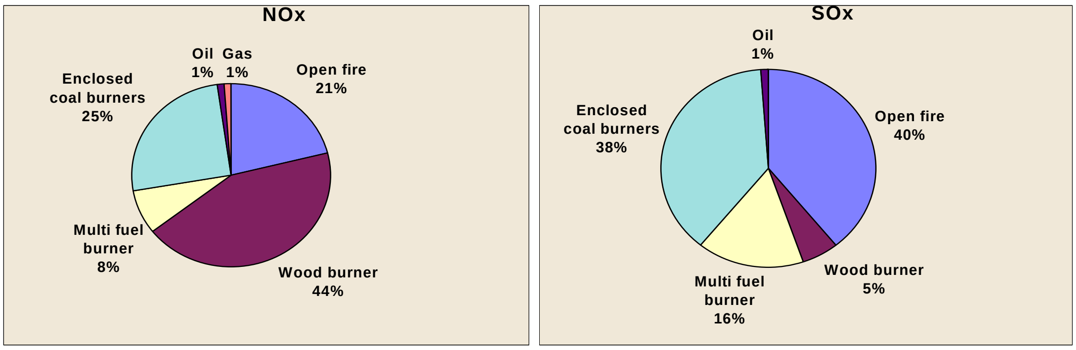


Figure 2.6 & 2.7: NOx and SOx emissions by appliance type

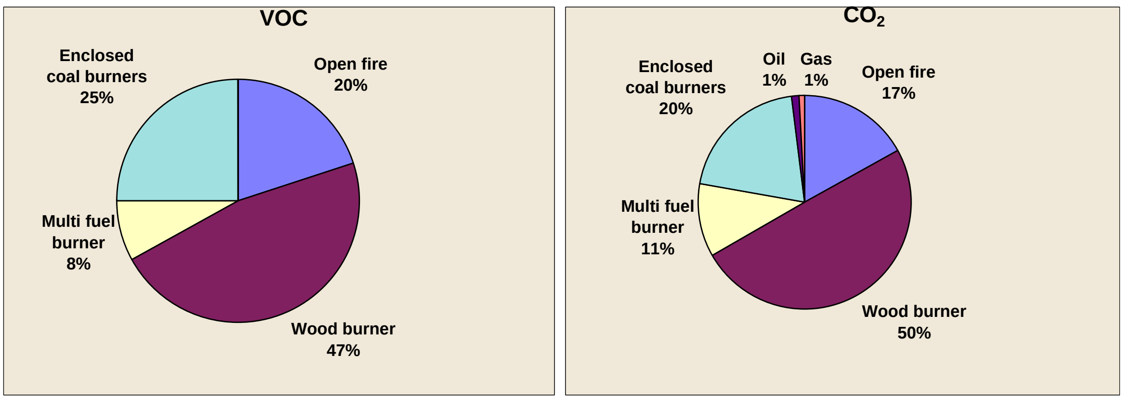


Figure 2.8 & 2.9: VOC and CO_2 emissions by appliance type

Daily home heating emissions by appliance type

The approximate amount of fuel burnt on a typical winter's day by appliance type, and the resulting emissions are shown in table 2.8. Emissions of each contaminant by appliance type are also illustrated in figures 2.4 to 2.9.

Open fires and wood burners each contribute to ~1/3 of the PM_{10} emissions. Wood burners contribute over 40% of the CO, NOx, VOC and CO_2 emissions. Multi-fuel burners and open fires each result in >30% of SOx emissions.

Home heating emissions by fuel type

Figures 2.10 to 2.15 illustrate the contributions of the fuels wood, coal, oil and gas to the total emissions of each contaminant from domestic home heating. The burning of wood results in over 80% of the CO, NOx, and VOC emissions. Coal burning results in 94% of the SOx emissions and 33% of the PM_{10}. Gas and oil contribute to 3% of the NOx, 1% of the

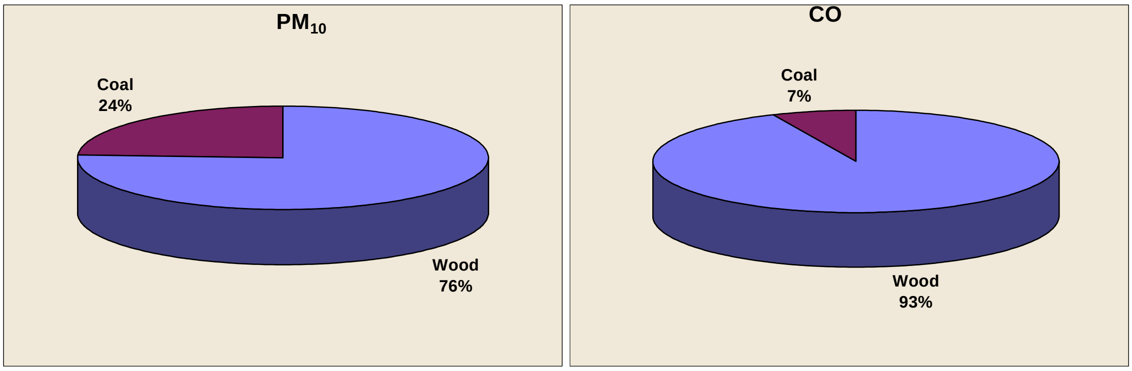


Figure 2.10 & 2.11: PM_{10} and CO emissions by fuel type

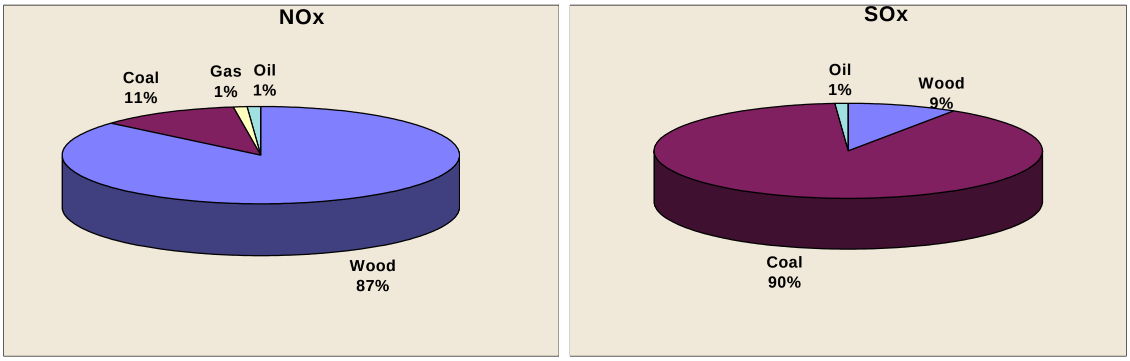


Figure 2.12 & 2.13: NOx and SOx emissions by fuel type

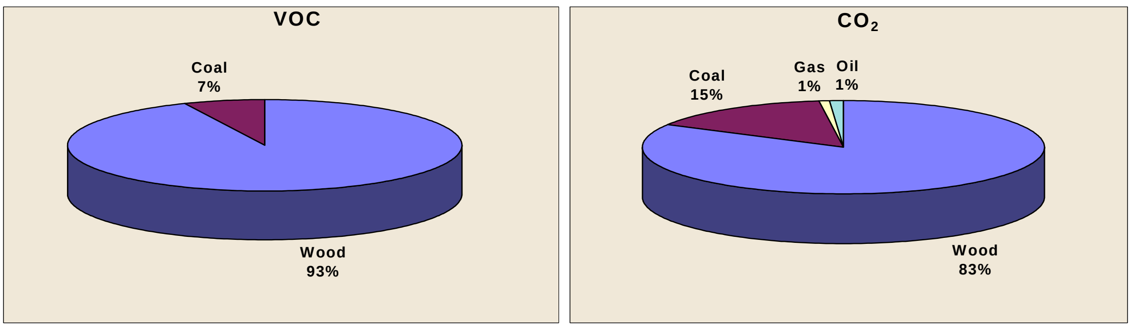


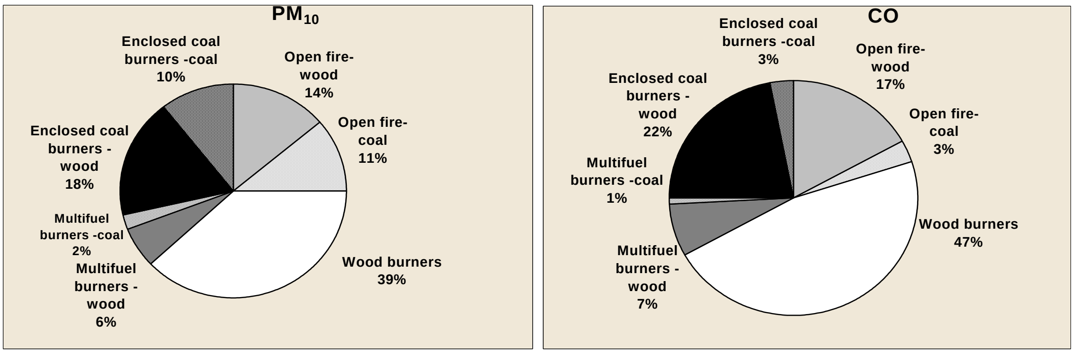
Figure 2.14 & 2.15: VOC and CO_2 emissions by fuel type

SOx, and 2% of the CO_2 emissions. They are also responsible for less than 0.5% of PM_{10}, CO and VOC emissions.

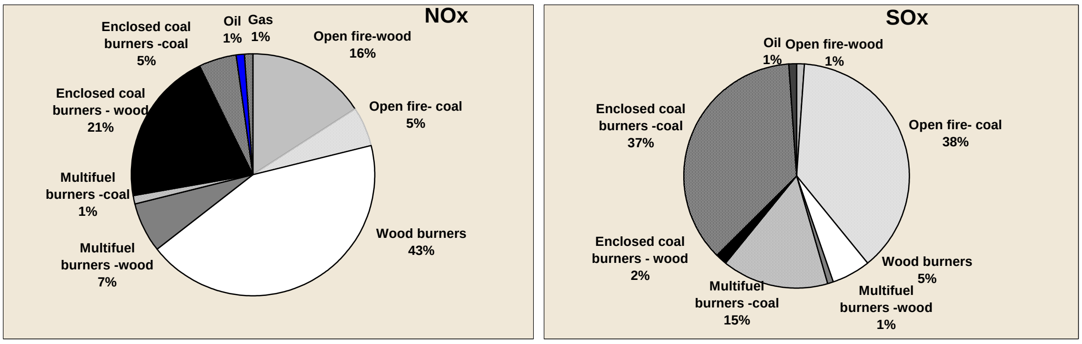
Home heating emissions by fuel and appliance type

Home heating emissions by fuel and appliance type are illustrated in figures 2.16 to 2.21. PM_{10} emissions on an appliance basis indicate an even contribution across fuels. Although coal has greater PM_{10} emissions per kg burnt a greater quantity of wood is burnt on each appliance type. Overall more emissions come from the burning of wood.

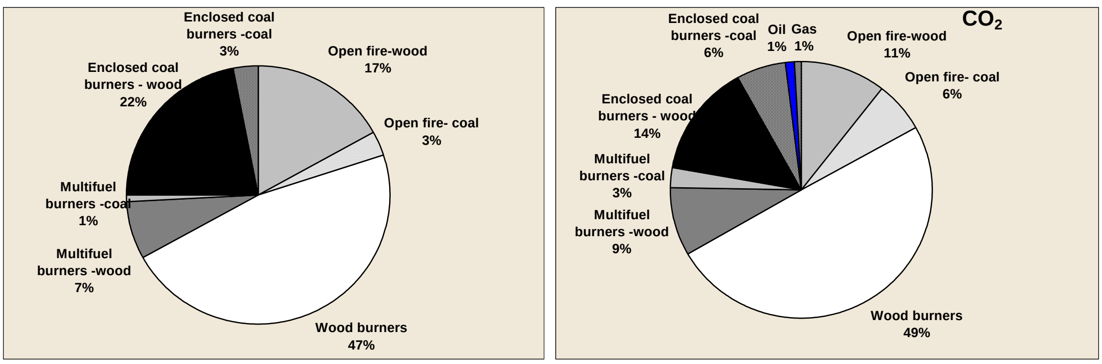
The majority of CO, NOx and VOC emissions from an open fire come from burning wood. Similar trends are observed for these contaminants with the multi-fuel and enclosed coal burners.



Figures 2.16 & 2.17: PM_{10} and CO emissions by fuel and appliance type



Figures 2.18 & 2.19 SOx and NOx emissions by fuel and appliance type



Figures 2.20 & 2.21 VOC and CO_2 emissions by fuel and appliance type

Home heating emissions by time of day and emission density

For the purpose of allowing comparisons of emissions in Waimate to those of other areas of the region the total kg of emissions was divided by the number of hectares in the study area. This allows a comparison of weight of emission per area volume. The Waimate area comprises of 314 ha. Emissions of contaminants from the domestic home heating sector on a g/kg basis is illustrated in table 2.9.

Emissions were also examined in terms of the time of day during which they occur for a typical winter's day. This allows for an assessment of emissions relative to times in which there may be variations in meteorological conditions. For example, if meteorological measurements indicated that the wind was much stronger during the daytime, emissions that occurred at this time may have little effect on the 24 hour average concentration.

Table 2.10 shows the variations in emissions over a 24 hour period. The distribution of PM_{10} emissions over the period is also illustrated in figure 2.22. The division of the day into these four time periods is not an even distribution, with the morning period being represented by four hours, the daytime and evening by six hours and the night-time by eight hours. Variations on this distribution are minimal for other contaminants.

Table 2.9: Grams of emissions per hectare

No. of Ha	Daily fuel quantity (kg/ha)	PM_{10} g/ha	CO g/ha	NOx g/ha	SOx g/ha	VOC g/ha	CO2 g/ha
314	74	800	5020	76	146	1255	122422

Table 2.10: Variations in emissions with time of day

	PM_{10}		CO		NOx		SOx		VOC		CO_2	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
6am-10am	30	87	199	576	3	9	4	13	50	144	4706	14163
10am-4pm	58	157	376	967	6	14	10	30	94	242	8323	23233
4pm-10pm	146	378	918	2226	14	35	25	79	9	557	20568	55656
10pm-6am	57	178	405	1251	6	18	7	24	101	313	9387	29370
Total	291	800	1898	5020	28	76	46	146	474	1255	42985	122422

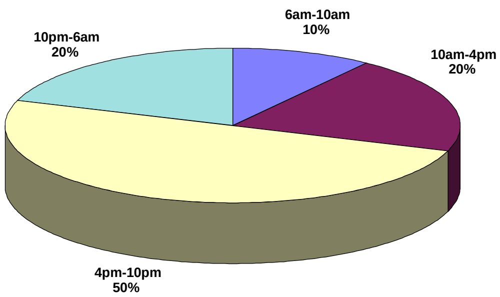


Figure 2.22: PM_{10} emissions by time of day

Assessment of the effect of emissions on the 24-hour average contaminant concentrations requires a characterisation of the meteorological conditions. Such an analysis is not yet available for Waimate. The collection of the data presented in this report via the emission inventory allows for this assessment to be made once the appropriate meteorological model is available.

3. Transport

Air pollution from motor vehicles results from the oxidation of components of the fuel and air used in the internal combustion engines that power them. The incidence of particular forms of pollution depend on the amount of fuel consumed, the concentration of the elements in the fuel which define the pollution, and to a lesser extent the operational characteristics of the engine at the time of their formation.

This means that the quantities of pollution produced in a selected area will depend on the number of vehicle kilometres run within the area over a defined period of time, and to a lesser extent the amount of delay to vehicle movement produced by vehicle interaction and intersection control.

The air pollutants discharged are principally oxides of carbon, nitrogen, and sulphur as gases; carbon and hydrocarbons as particulate material; and other hydrocarbons as fumes. While all these pollutants result from the combustion of hydrocarbon fuels such as petrol and diesel, higher concentrations of carbon monoxide are associated with petrol combustion, whereas higher concentration of particulate is characteristic of diesel combustion.

Emissions relate to the amount of vehicle travel in a road network. However, the quantities of the various emissions are notably non-linear with respect to vehicle speed. High emissions generally occur at low vehicle speeds, but also at very high speeds. Typically emissions reduce as speeds increase and are generally at a minimum at relatively high cruising speeds. Carbon dioxide, carbon monoxide, volatile organic compounds, and sulphur oxides all fit this pattern. For vehicles with reasonably tuned motors, nitrogen oxides emissions can differ slightly with emissions decreasing at speeds less than about 35 kilometres per hour, and then increase as speeds increase.

A further complication is that some of the pollutants are particularly associated with one fuel, whereas others are more associated with the particular engine configuration at the time the pollutants are being produced. Sulphur oxides and black smoke are particularly characteristic of the use of diesel fuels and as stated above, carbon monoxide is characteristic of petrol burning engines. In the case of black smoke (diesel) and carbon monoxide (petrol) the amount of pollutant produced is maximised during short periods of high acceleration.

As a result of the different fuels and the engine configurations that burn them, the emission types are split by fuel type to reflect the different reactions.

Those splits between petrol and diesel are for CO 5:1, for NOx 1:2, for SOx 1:10, VOCs 2:1, and PM_{10} 1:30. In the case of PM_{10} the lopsided nature of the ratio and the size of the amounts involved, means no value for PM_{10} from petrol engines has been assessed.

In the road network of Waimate almost all of the motor vehicle running is on the flat. Therefore emissions are related primarily to vehicle kilometres run and secondly to the degree of congestion in the road network. In modern road vehicles powered by normally aspirated engines

(90% of the current fleet), oxides of carbon and sulphur will be minimised at a constant speed of between 70-80 km/h and increase slightly for speeds above that. When the speed is highly variable and slower than the stated speed, the discharges of carbon oxides, sulphur oxides, etc. will be significantly greater. For the purposes of this work the variability of the speeds increases as the mean speed value falls below 45 km/h.

Table 3.1 shows estimates of emissions by time of day. This was calculated by multiplying the total vehicle kilometres driven by the proportion of vehicles moving during that period of the day and by the appropriate emission factor. Further details of the calculations of transport emissions are contained in appendix 2.

Table 3.2 shows estimates of emissions by vehicle class and emission type. This was calculated by multiplying total vehicle kilometres travelled by the proportion of vehicles in that vehicle class and by the appropriate emission factor.

3.1 Transport emissions

Figures 3.1 to 3.12 illustrate that petrol vehicles are responsible for the majority of CO, NOx, VOC and CO_2 emissions. Diesel vehicles contribute 60% of the SO_2 and the majority of the PM_{10} emissions. No illustration of the latter is provided as only PM_{10} emissions from diesel fuel were considered.

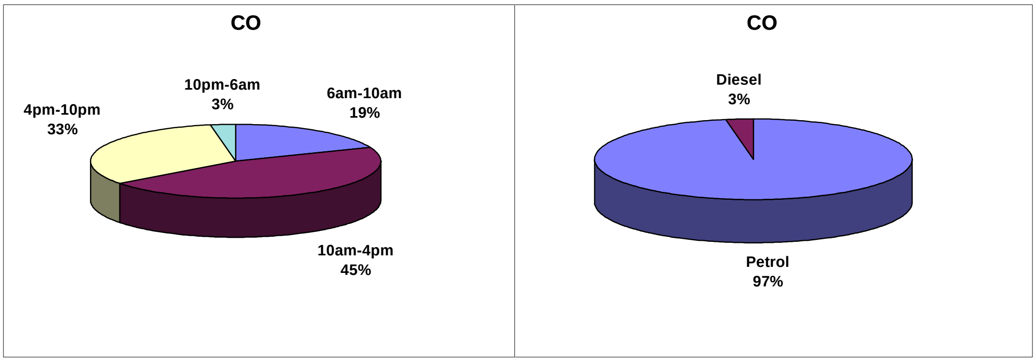
Passenger car emissions were found to contribute the majority of the CO, VOC, NOx and CO_2 emissions and over 40% of the SOx emissions from the transport sector. Heavy goods vehicles produced approximately half of the PM_{10} emissions and 30% of the SOx emissions.

Table 3.1: Transport Emissions by Time of Day

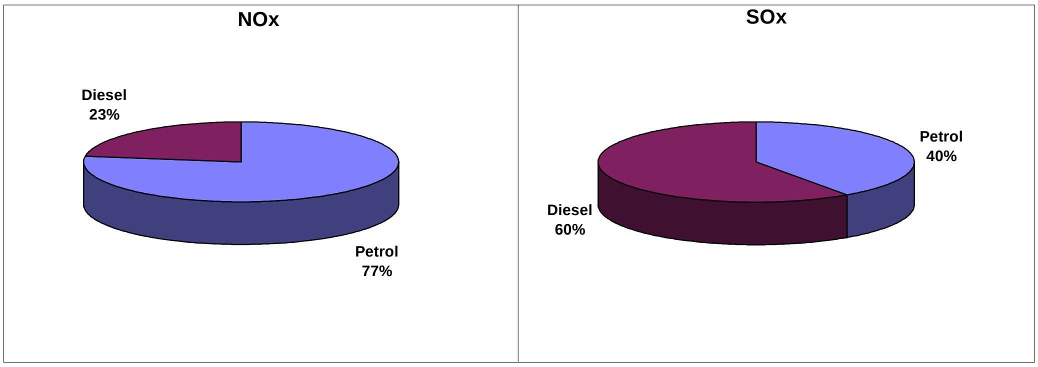
	PM_{10}	CO		NOx		SOx		VOC		CO_2	
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg
6am-10am	0	68	2	4	1	0	1	8	1	500	74
10am-4pm	1	165	5	10	3	1	2	19	1	1222	180
4pm-10pm	1	117	3	7	2	1	1	13	1	860	127
10pm-6am	0	10	0	1	0	0	0.1	1	0.1	70	10
Total	**1.5**	**360**	**10.3**	**21.6**	**6.2**	**2.2**	**3.7**	**41**	**2.7**	**2650**	**391**

Table 3.2 Transport emissions by vehicle type

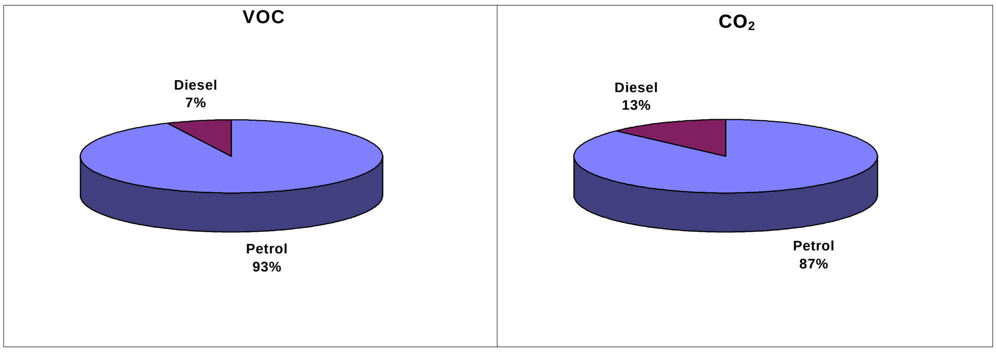
	PM_{10}	CO		NOx		SOx		VOC		CO_2	
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg
Passenger Car	0	300	2	18	1	2	1	34	1	2210	75
Light goods	0	48	4	3	2	0	1	6	1	360	131
Heavy goods	1	12	5	1	3	0.1	2	1	1	90	186
Total	**1.4**	**360**	**11**	**21.7**	**6**	**2.37**	**3.6**	**41**	**2.6**	**2660**	**392**



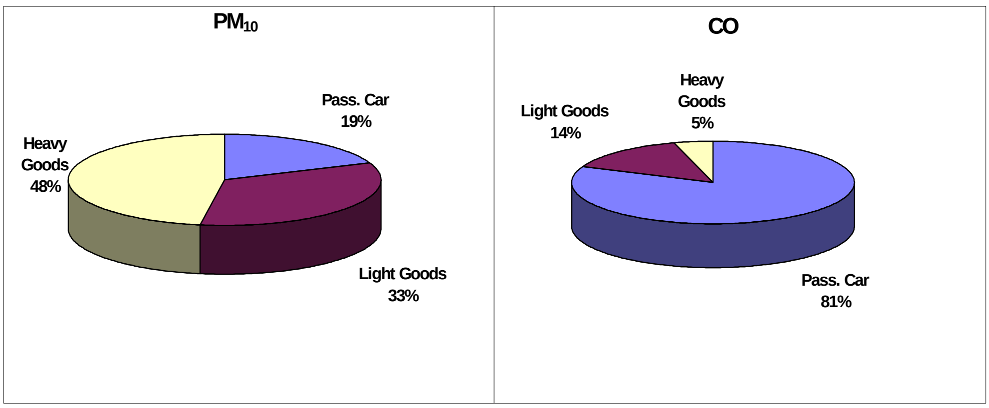
Figures 3.1 & 3.2: CO transport emissions by time of day and by fuel type



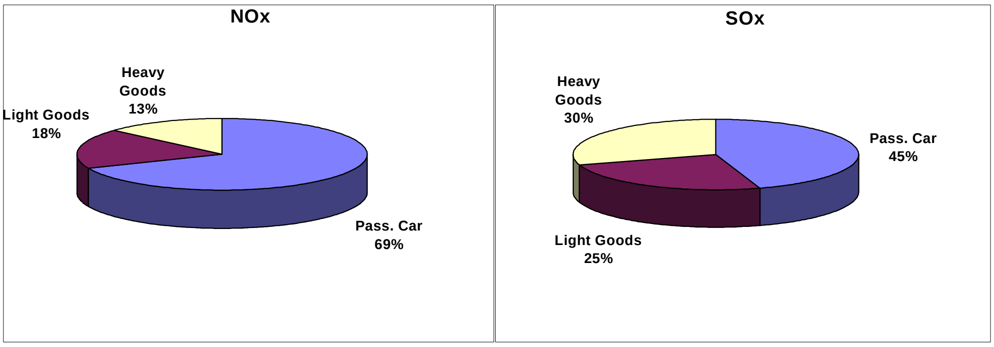
Figures 3.3 & 3.4: NOx and SOx transport emissions by fuel type



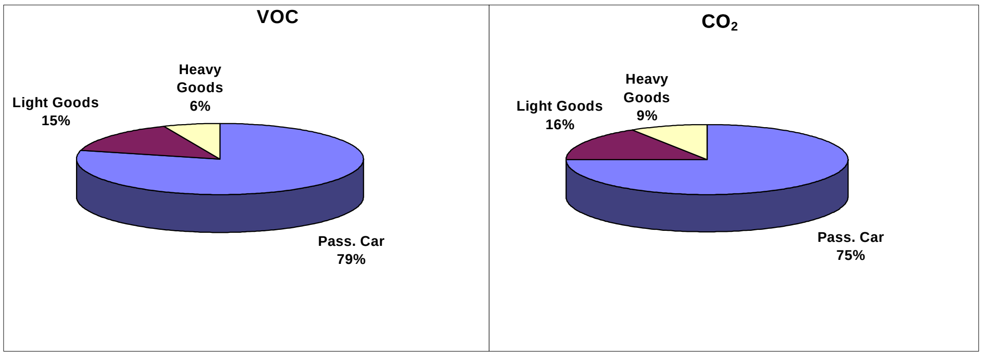
Figures 3.5 & 3.6: VOC and CO_2 transport emissions by fuel type



Figures 3.7 & 3.8: PM_{10} and CO transport emissions by vehicle type



Figures 3.9 & 3.10: NOx and SOx transport emissions by vehicle type



Figures 3.11 & 3.12: VOC and CO_2 transport emissions by vehicle type

4. Industry

4.1 Industrial Processes

Identification of industrial activities

A search of the Canterbury Regional Council's resource consent database was conducted using GIS to identify industries with resource consents for "discharges to air" in the urban areas of Waimate. Only one resource consent was found. This was for the kiln drying of wood and is classified as a "Part B" process for having a raw material capacity of more than 250kg/hour. The primary discharge from this process are products of combustion from a 150kW coal fired boiler.

Other potential discharges classified as "Part C" processes[2] were identified through a search of the Waimate telephone directory.

Activities identified as potential dischargers to air were examined in terms of the contaminants PM_{10}, CO, SOx, NOx, CO_2, and VOCs, specified for the emission inventory. Activities such as landfills and processes less not meeting the specifications of part A, B or C's of the former Clean Air Act were excluded from the analysis due to relatively low emissions of the contaminants concerned.

Assessment of emissions from industrial processes

Discharges to air from industrial activities arise generally arise from either combustion processes or as a result of the use or handling of materials which can generate emissions e.g., paint in spray painting. For the purpose of this report the latter are referred to as process emissions and include all non-combustion sources.

Emissions from combustion

A number of industries use the combustion of fuels such as LPG, oil, and coal to

[2] and therefore not currently requiring consents from the CRC.

produce energy. The following equation illustrates the chemical reaction required for complete combustion:

$$C_xH_y + O_2 = xCO_2 + yH_20 \qquad \textbf{(5)}$$

where C_xH_y represents the fuel being burnt. The reaction is exothermic, resulting in the production of heat.

The formation of air contaminants resulting from the combustion process varies depending on the chemical and physical properties of the fuels. From the above equation it is apparent that carbon dioxide (CO_2) is produced as product of combustion while CO is produced when combustion is incomplete. Because sulphur dioxide emissions occur as a result of oxidation of sulphur in the fuel fuels with a greater proportion of sulphur will result in higher emissions of sulphur oxides. Nitrogen oxides form as a result of N_2, which is present in the air we breathe, reacting with the oxygen (O_2) under high temperatures. Suspended particulate, particles in the air less than 10 microns in diameter are also produced during the combustion process.

Emission factors for emissions from combustion processes were those used in the Christchurch emission inventory. The Christchurch emission factors were derived by National Institute of Water and Atmospheric Research from international literature (United States Environmental Protection Agency (USEPA) 1994, Economopoulos, 1993, International Panel on Climate Change, 1995 and Air Pollution Engineering Manual, 1992). The emission factors are based on typical operation for an average boiler and do not account for variations in technology or age of the boilers. Emission factors used for the Christchurch inventory for the different fuels are contained in table 4.1.

Emissions of contaminants from the domestic sector, as a result of domestic home heating, primarily occur during the winter months. As domestic home heating emissions are likely to be significant during the winter, the daily emissions across all sectors were examined in terms of wintertime loading.

A small number of industries had adequate information contained on the resource consent to ascertain the daily fuel use and time of day variations. The remaining data was obtained via a telephone survey of industries in the area.

Emissions are also examined on a time of day basis. This allows for an assessment of the effect of any variations in meteorological conditions over a 24-hour period that may impact on contaminant concentrations.

Daily and annual emissions were calculated as follows:

*Contaminant emission (kg/day) = fuel use (tonnes/day) * contaminant emission factor (kg/tonne)* **(6)**

For example, calculations for PM_{10} emissions from an industry using 1.5 tonnes of coal per day are shown in equation 7.

*PM_{10} emission = 1.5 tonnes/day * 5 kg/tonne = 7.5 kg PM_{10} per day* **(7)**

Process emissions

Spraypainting was the only non-combustion source of industrial emissions identified for the Waimate area.

Processes emissions for spraypainting operations were calculated as follows:

Emissions (kg/day) = quantity of paint used (litres/day) x emission factor (kg/litre) **(8)**

The emission factor used for spraypainting is 560 kg of VOC per litre of paint (CRC, 1997).

4.2 Industrial Emissions

For the purpose of allowing comparisons of emissions in Waimate to those of other areas of the region, the total mass of emissions was divided by the number of hectares in the study area. This allows a comparison of mass of emission per area volume. Table 4.2 shows total emissions from the industrial sector, on g/ha basis and a breakdown for different periods of the day.

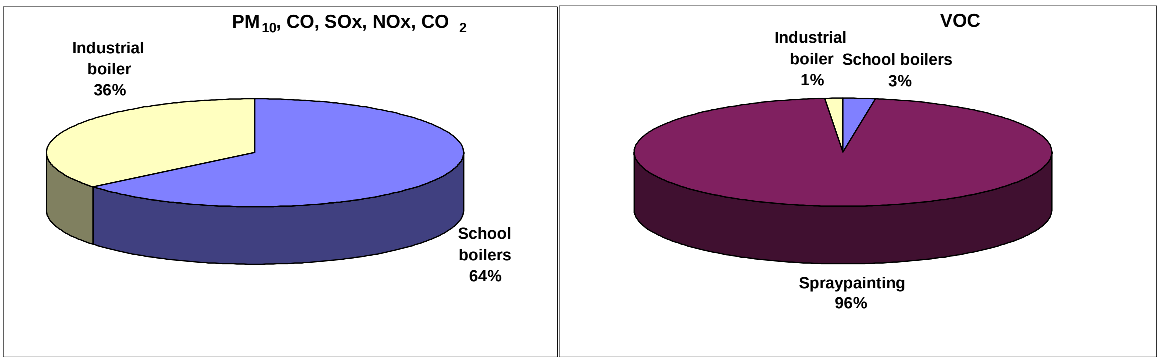
Figures 4.1 and 4.2 show the sources of industrial emissions in Waimate. It is estimated that two thirds of the industrial PM_{10}, CO, NOx, SOx and CO_2 during the winter comes from school boilers. The majority of the industrial VOC comes from spraypainting. However, it is apparent from table 4.2 that the total quantities emitted is small.

Table 4.1: Emission factors used for industrial combustion processes (from Christchurch emission inventory)

Fuel	Boiler size	PM_{10} kg/tonne	CO kg/tonne	NOx kg/tonne	SOx kg/tonne	VOC kg/tonne	CO2 kg/tonne
LPG	5 MW	0.06	0.71	2.6	0.007	0.12	2885
	50 MW	0.06	0.71	2.6	0.007	0.12	2885
Oil	40 kW	0.28	0.64	2.8	4.0	0.18	3010
	10 MW	0.28	0.64	2.8	4.0	0.18	3010
Coal	40kW	5.00	2.3	8.2	17.5	0.06	2355
	10MW	5.00	2.5	9.0	17.5	0.06	2355
Wood	40kW	1.3	2.0	0.33	0.037	0.15	1100
	10 MW	1.3	13.0	1.15	0.037	0.15	1100

Table 4.2: Industrial emissions by time of day

	PM_{10}		CO		NOx		SOx		VOC		CO_2	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
6am-10am	4	13	2	6	7	22	15	47	0	0	2021	6440
10am-4pm	1	2	0	1	1	3	2	6	2	5	259	826
4pm-10pm	1	2	0	1	1	3	2	6	0	0	259	826
10pm-6am	1	2	0	1	1	4	3	8	0	0	346	1101
Total	6	19	3	9	10	31	21	67	2	6	2885	9193



Figures 4.1 & 4.2: Industrial PM_{10}, CO, NOx, SOx, CO_2, and VOC emissions by source

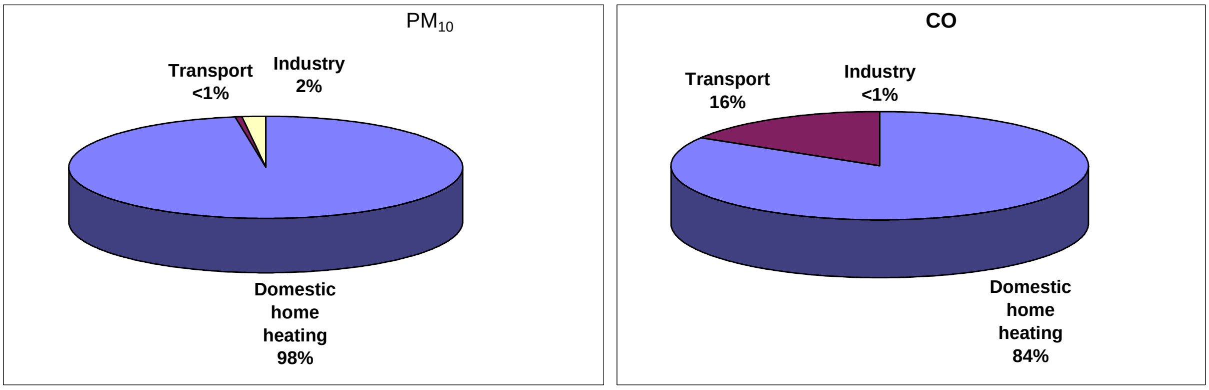
5. Total emissions for Waimate

The proportional contribution of each sector to the total emissions in Waimate is shown in table 5.1. Figures 5.1 to 5.6 compare the proportion of PM_{10}, CO, NOx, SOx, VOCs and CO_2 emissions arising from each sector.

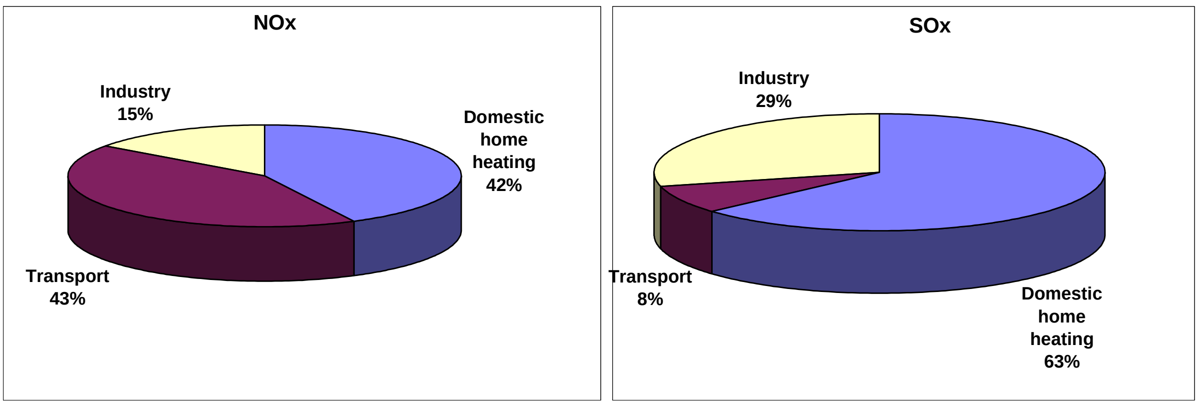
Table 5.1: Total emissions by sector

	PM_{10}		CO		NOx		SOx		VOC		CO_2	
	kg	g/ha	kg	g/ha	kg	g/ha	Kg	g/ha	kg	g/ha	kg	g/ha
Home heating	291	928	1898	6048	28	90	46	148	474	1512	42985	136981
Transport	1	5	371	1183	28	90	6	18	44	141	3042	9694
Industry	6	19	3	9	10	31	21	67	2	6	2885	9193
Total	299	952	2272	7240	66	211	73	233	521	1659	48911	155868

and 15% of the NOx emissions. Industrial



Figures 5.1 & 5.2: PM_{10} and CO emissions by sector



Figures 5.3 & 5.4: NOx and SOx emissions by sector

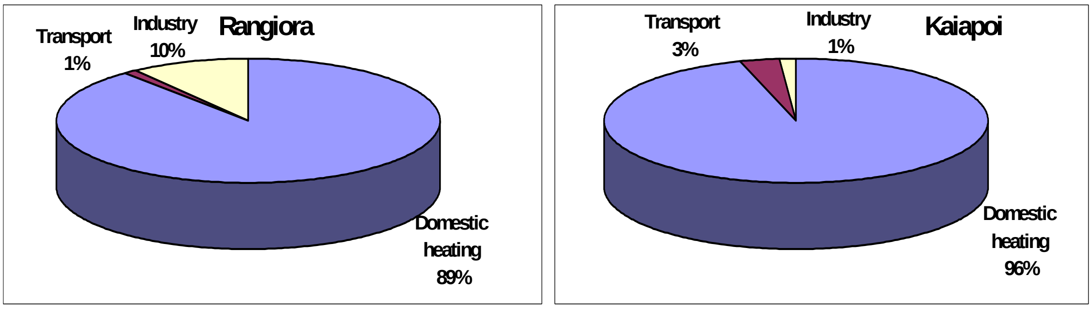


Figure 5.7 & 5.8: Contribution to PM_{10} emissions in Rangiora and Kaiapoi

Figure 5.5 &

Table 5.2: Total emissions by time of day

	PM_{10}		CO		NOx		SOx		VOC		CO_2	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
6am-10am	34	108	272	865	15	49	20	63	58	186	7303	23272
10am-4pm	60	190	547	1743	19	62	14	45	116	370	9979	31799
4pm-10pm	147	468	1039	3310	24	76	29	92	244	777	21816	69523
10pm-6am	58	185	415	1322	8	25	10	32	102	326	9814	31274

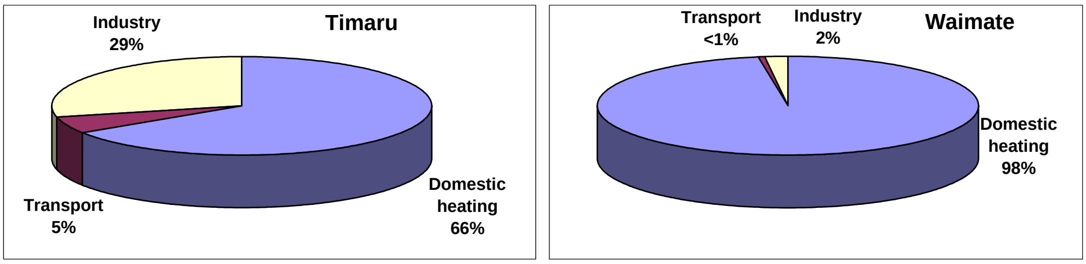


Figure 5.11 & 5.12: Contributions to PM_{10} in Timaru and Waimate

5.1 Total compared w

Table 5.3 c Rangiora e household to region. This basis:

- Waimate has the highest PM_{10} emissions per household
- Christchurch has the highest CO and VOC emissions per household

heat their main living area and because of the greater proportion of older appliances that are used.

Table 5.3 Grams of emissions per household compared with other urban areas

	hh	PM_{10} g/hh	CO g/hh	NOx g/hh	SOx g/hh	VOC g/hh	CO_2 g/hh
Rangiora	3692	166	1719	128	37	357	33134
Kaiapoi	3188	110	1646	163	34	301	28090
Timaru	9732	209	1765	305	170	436	70110
Christchurch	94856	141	1982	274	70	473	51316
Ashburton	5791	176	1755	129	86	347	37386
Waimate	1308	224	1711	50	55	392	36900

The relative contribution of different sectors to PM_{10} emissions in Waimate compared to Timaru, Waimate, Rangiora, Kaiapoi, and Christchurch are illustrated in figures 5.7 to 5.12.

These illustrate that in Waimate almost all of the PM_{10} emissions are from the domestic and that the percentage contribution is higher than in Ashburton, Christchurch, Rangiora and Timaru.

6. Summary

Wintertime emissions from domestic heating, transport and industry were estimated for the urban areas of Waimate. Estimates were based on surveying, traffic modelling, resource consent information and the application of emission factors.

- Survey results showed that approximately 42% of Waimate households use electricity to heat their main living area on a typical winter's night. This compares to 14% that use gas and 65% that use solid fuel heating methods.
- Results indicate that many households use more than one method of domestic heating in their main living area.
- Wood burners were found to contribute approximately 40% of the PM_{10} emissions from domestic heating with the remainder coming from open fires (25%) and coal and multi-fuel burners (36%).
- Three-quarters of the PM_{10} emissions come from the burning of wood with the remaining quarter coming from coal burning.
- Approximately half of the PM_{10} emissions occur during the evening (4 p.m. to 10 p.m.) period.
- Passenger cars are responsible for the majority of the PM_{10}, CO, NOx, VOC and CO_2. About half of the CO emissions from transport occur during the evening (4 p.m. – 10 p.m.) period.
- Combustion processes are responsible for the majority of the PM_{10}, CO, NOx, SOx and CO_2 emissions from industry in Waimate. The majority of VOC emissions from the industrial sector come from spray painting operations.
- Overall the domestic heating sector is responsible for 97% of the PM_{10}, 80% of the CO, approximately 60% of the SOx and almost 90% of the CO_2. The transport sector contributes approximately 40% of the CO, approximately 20% of the SOx, and less than 10% of emissions of all other contaminants.
- Industry emits 30% of the SOx emissions, 15% of the NOx and less than 10% of emissions of other contaminants.

7. References

Canterbury Regional Council; 1997. Christchurch Inventory of Total Emissions. Canterbury Regional Council Report No. R97/7.

Lamb, C G; 1997. Home Heating Methods Survey: A survey of heating methods used in Ashburton, Waimate, Kaiapoi and Rangiora. Canterbury Regional Council U97/80.

United States Environmental Protection Agency (USEPA); 1996. Compilation of Air Pollution Emission Factors (AP-42), Research Triangle Park, North Carolina, United States of America

Table 5.4: Total emissions in Waimate compared to other urban centres

		Waimate		Ashburton		Timaru		Rangiora		Kaiapoi		Christchurch	
	Source	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha*	kg	g/ha	kg	g/ha
PM_{10}	home heating	285	928	897	724	1340	652	543	985	334	594	10971	618
PM_{10}	transport	1	5	18	14	110	54	8	14	12	22	1365	77
PM_{10}	industry	6	19	106	86	585	285	61	130	5	8	1018	57
	Total	**293**	**952**	**1021**	**824**	**2035**	**991**	**612**	**1129**	**351**	**624**	**13354**	**752**
CO	home heating	1865	6048	5345	4315	8559	4167	2316	7083	2316	4120	61962	3489
CO	transport	371	1183	4780	3859	8438	4108	2437	4420	2929	5209	125591	7073
CO	industry	3	9	44	35	185	90	6	13	3	5	478	27
	Total	**2239**	**7240**	**10169**	**8209**	**17182**	**8365**	**4759**	**11516**	**5248**	**9334**	**188031**	**10589**
NOx	home heating	28	90	82	66	125	61	56	102	34	61	937	53
NOx	transport	28	90	517	417	2161	1052	398	722	486	864	23655	1332
NOx	industry	10	31	147	119	681	331	20	43	11	20	1452	82
	Total	**66**	**211**	**746**	**602**	**2967**	**1444**	**474**	**867**	**531**	**945**	**26044**	**1467**
SOx	home heating	45	148	214	173	239	116	52	94	44	78	2490	140
SOx	transport	6	18	84	67	93	45	40	73	64	114	1130	64
SOx	industry	21	67	199	160	1321	643	43	92	21	37	3055	172
	Total	**72**	**233**	**497**	**400**	**1653**	**805**	**135**	**259**	**129**	**229**	**6675**	**376**
VOC	home heating	466	1512	1336	1079	2140	1042	976	1771	579	1030	15490	872
VOC	transport	44	141	634	512	2071	1008	322	584	388	689	28608	1611
VOC	industry	2	6	37	30	35	17	19	41	1727	3072	798	45
	Total	**512**	**1659**	**2007**	**1621**	**4246**	**2067**	**1317**	**2396**	**2694**	**4791**	**44896**	**2528**
CO_2	home heating	42338	136981	131965	106535	186822	90955	93774	170112	55854	99350	1375853	77482
CO_2	transport	3042	9694	44636	36035	235391	114601	22296	40447	33695	59934	2802943	157849
CO_2	industry	2885	9193	39901	32212	260096	126629	6261	13363	6406	11394	688883	38794
	Total	**48265**	**155868**	**216502**	**174782**	**682309**	**332186**	**122331**	**223923**	**95955**	**170678**	**4867679**	**274122**

* For Rangiora the analysis assumes that 85% of the transport and domestic emissions occur within the urban area of 469 ha and that 100% of the industrial emissions occur within the urban area. The Rangiora analysis has been reviewed to include this assumption because of the large quantity of rural land within the area defined as Rangiora.

Appendix 1: Home heating survey

Good afternoon/evening my name is ______ and I am calling on behalf of the Canterbury Regional Council. May I please speak to an adult in your household who knows about your home heating.
Good afternoon/evening my name is ______ and I am calling on behalf of the Canterbury Regional Council.
We are currently undertaking a survey in your area on methods of home heating. We wish to know what you use **to heat your main living area, on a typical Winter's day, and night.**

TICK ALL THOSE WHICH APPLY

1. Respondent's Area **Ashburton [ ] Rangiora [ ] Kaiapoi [ ] Waimate [ ]**
Respondent's phone number __________________

2. (a) Do you use an open fire (includes a visor fireplace) **in your MAIN living area on a TYPICAL Winter's day or night? YES [ ] NO [ ]** ***If NO, go to Question 3***.

(b) Do you use it
- i. In the morning (between 6am and 10am) **YES** [ ] **NO** [ ]
- ii. Day time (between 10am and 4pm) **YES** [ ] **NO** [ ]
- iii. Evening (between 4pm and 10pm) **YES** [ ] **NO** [ ]
- iv. Overnight (between 10pm and 6am) **YES** [ ] **NO** [ ]

(c) Do you use wood on your open fire? **YES [ ] NO [ ]** ***If NO, go to Part (f).***

(d) How much wood do you use per day**?** ***(ask them how many pieces of wood (logs) they use on an average Winter's day)*** ______________________

(e) Do you buy your wood from a wood merchant or collect it yourself? **BUY IT [ ] COLLECT IT [ ] BOTH [ ]** ***If BOTH, ask % Collected _____% Bought ______***

(f) Do you use coal on your open fire? **YES [ ] NO [ ]** ***If NO, go to Question 3***.

(g) How much coal do you sue per day? ***(ask them how many buckets of coal they use on an average Winter's day)*** ______________________________

(h) What type of coal do you use? ____

3. (a) Do you use **any type** of electrical heating **in your MAIN living area on a TYPICAL Winter's day or night? YES [ ] NO [ ]** ***If NO, GO TO Question 4.***

(b) Do you use it
- i. In the morning (between 6am and 10am) **YES** [ ] **NO** [ ]
- ii. Day time (between 10am and 4pm) **YES** [ ] **NO** [ ]
- iii. Evening (between 4pm and 10pm) **YES** [ ] **NO** [ ]
- iv. Overnight (between 10pm and 6am) **YES** [ ] **NO** [ ]

4. (a) Do you use **any type** of gas heating **in your MAIN living area on a TYPICAL Winter's day or night? YES [ ] NO [ ]** ***If NO, GO TO Question 5***.

(b) Is it **flued or unflued** gas heating? **FLUED** [ ] **UNFLUED** [ ] **BOTH** [ ]

(c) Do you use it
i. In the morning (between 6am and 10am) **YES** [ ] **NO** [ ]
ii. Day time (between 10am and 4pm) **YES** [ ] **NO** [ ]
iii. Evening (between 4pm and 10pm) **YES** [ ] **NO** [ ]
iv. Overnight (between 10pm and 6am) **YES** [ ] **NO** [ ]

(d) How much gas do you use? ***(ask them for the size of the gas bottle(s) and how often they would refill them*** (-sizes are 2kg, 2.5kg, 3kg, 4.5kg, 9kg, 18kg, 20kg, 45kg, 90kg)
Size#1______________ Freq#1______________
Size#2______________ Freq#2______________

5. (a) Do you use a log burner ***(This is not a multi-fuel burner, i.e. does not burn coal)*** in your **MAIN living area on a TYPICAL Winter's day or night.**
YES [ ] NO [ ] ***If NO, GO TO Question 6***.

(b) How old is your log burner? **10 yrs old or older** [ ] **Less than 10 yrs old** [ ]

(c) Do you use it
i. In the morning (between 6am and 10am) **YES** [ ] **NO** [ ]
ii. Day time (between 10am and 4pm) **YES** [ ] **NO** [ ]
iii. Evening (between 4pm and 10pm) **YES** [ ] **NO** [ ]
iv. Overnight (between 10pm and 6am) **YES** [ ] **NO** [ ]

(d) How much wood do you use per day? ***(ask them how many pieces of wood (logs) they use on an average Winter's day)*** __________________

(e) Do you buy your wood from a wood merchant or collect it yourself? **BUY IT [ ]**
COLLECT IT [ ] BOTH [ ] ***If BOTH, ask % Collected _____% Bought ______***

6. (a) Do you a multi-fuel burner ***(this includes incinerators, pot belly stoves, McKay space heaters, etc. It is a burner which burns coal as well as wood)*** **in your MAIN living area on a TYPICAL Winter's day or night?**
YES [ ] NO [ ] ***If NO, GO TO Question 7.***

(b) How old is your multi-fuel burner? **10 yrs old or older** [ ] **Less than 10 yrs old** [ ]

(c) What type of multi-fuel burner is it? ____

(d) Do you use it
i. In the morning (between 6am and 10am) **YES** [ ] **NO** [ ]
ii. Day time (between 10am and 4pm) **YES** [ ] **NO** [ ]
iii. Evening (between 4pm and 10pm) **YES** [ ] **NO** [ ]
iv. Overnight (between 10pm and 6am) **YES** [ ] **NO** [ ]

(e) How much wood do you use per day? ***(ask them how many pieces of wood (logs) they use on an average Winter's day)*** ______________________

(f) Do you buy your wood from a wood merchant or collect it yourself? **BUY IT [ ]**

COLLECT IT [ ] BOTH [ ] ***If BOTH, ask % Collected _____% Bo****ught* ______

(g) Do you use coal on your multi-fuel burner? YES [ ] NO [ ] *If NO, go to Question 7.*

(h) How much coal do you use per day? ***(ask them how many buckets of coal they use on an average Winter's day)*** ______________________________

(i) What type of coal do you use? ____

7. (a) Do you use an oil-fired heating system **in your MAIN living area on a TYPICAL Winter's day or night? YES** [ ] **NO** [ ] ***If NO, go to END.***

(b) Do you use it

i.	In the morning (between 6am and 10am)	**YES** [ ]	**NO** [ ]
ii.	Day time (between 10am and 4pm)	**YES** [ ]	**NO** [ ]
iii.	Evening (between 4pm and 10pm)	**YES** [ ]	**NO** [ ]
iv.	Overnight (between 10pm and 6am)	**YES** [ ]	**NO** [ ]

(c) How much oil do you use? ____

(END) THANK YOU VERY MUCH FOR YOUR HELP WITH THIS SURVEY.

Appendix 2: Transport Model

Estimating Trip Making in Waimate.

Waimate has all of the trip movements of a small district centre which has been estimated from a survey of the trip making of a 10% sample of households drawn from the Valuation Roll. Similarly a survey was made of trip making from a 3.5 % sample of households in the rural area surrounding Waimate. The urban sample was made by including every ninth entry from the roll, except when it was obvious that the entry was from a vacant lot or commercial premises, then the next prospect was drawn, before a space of a further eight entries was made to the next drawing. The rural sample was drawn by giving approximately 25 secondary students from 3 different classes the questionnaire and asking them to complete them for their own family and their two nearest neighbours. The trip making survey day was Thursday 24 July, the same day on which numberplate surveys were made.

The urban trip sample was scaled to give a matrix of internal trips; the spatial distribution of external trips is determined from the home questionnaire responses, while the number and temporal distribution of external trips was found from automatic traffic counts. These counts were made on the principal arterial connections to Waimate, namely Timaru Road to the east northeast, Parsonage Road to the north, High Street to the southeast, and Gorge Road to the southwest.

Heavy vehicle movements are based on a classified count made in conjunction with a number plate survey, which had as an outer cordon, on the roads on which automatic traffic counts were taken. The number plate surveys were made on 24 July, close to, but on the town centre side of the automatic counts, and an internal cordon comprised of number plate surveys made on High Street (one on either side of the commercial area) and on Queen Street, west of Parsonage Road (table A.1).

Of the 130 Home Interview survey forms distributed, 10 were for addresses that were developed for industrial or commercial purposes or vacant dwellings.

Of the remaining 120 trip making information was provided for 61 different households, and another 19 households did not own a vehicle or made no trips on the day of the survey. The questionnaires returned gave the following distribution across the internal zones.

Table A1: Waimate Number-plate Survey and Traffic Counts

Waimate Number Plate Survey and Traffic Counts											
Location	Period	Observed	H.G.V	%	L.G.V	%	Matched	3_Stns	4_Stns	Tot Obs	Traf Cnts
Timaru Rd	8_10	163	16	9.82	27	16.6	134	32	4	310	253
High St.		87	16	18.4	23	26.4	37	8	3	171	194
Gorge Rd		103	12	11.7	15	14.6	36	15	8	153	
Parsonage		85	9	10.6	10	11.8	77	25	2	134	124
Timaru Rd	12:00_	193	9	4.66	14	7.25	152	47	6	395	335
High St.	02:00	106	5	4.72	25	23.6	62	7	1	199	240
Gorge Rd		110	6	5.45	12	10.9	32	9	0	189	
Parsonage		69	2	2.9	15	21.7	41	8	1	113	128
Timaru Rd	3:30_	216	10	4.63	15	6.94	157	49	2	451	381
High St.	05:30	130	18	13.8	44	33.8	62	8	11	264	279
Gorge Rd		97	13	13.4	22	22.7	24	11	0	163	
Parsonage		84	9	10.7	4	4.76	39	12	0	169	156
Totals		1443	125	0.09	226	0.16					

Table A2: Summary Information from Home Interview Survey

Internal Zone	H/H per Zone	Interviews /Zone	Expansion Factors	Under-Reporting	H/H Trip Rate
1	67	3	16.66	%	
2	206	6	25.64	4.5	2.82
3	362	13	21.28	16.8	2.82
4	296	14	17.54	13.2	2.82
5	153	6	19.23	19.3	2.82
6	211	18	8.47	13.7	2.82
7	25	1	25		

Zones 1 and 7 (table A.2) could not be realistically assessed from the measured household trip rate because the activities in those zones are retail and commercial, and industrial respectively. However, the fit for the other zones was acceptable bearing in mind that the under-reporting rate included heavy and light goods trips and internal trips made by vehicles driven by persons not resident in Waimate, and therefore not subject to survey. Our measure of heavy vehicle trips for the roads on which number plate surveys were made was 9%. It would be expected that light goods vehicle trips would be of at least the same order, but both these values would be likely to be higher than those for roads which were included in the model but not specifically surveyed.

Assignment of Estimated Trips to a Road Network Model

A matrix of private purpose trips estimated from factoring the Home Interview surveys, was scaled from number plate survey data to include commercial vehicle trips, and was assigned to a model road network. That model shown in Figure 4 subdivides the urban area into 7 zones and includes the more heavily trafficked roads within Waimate comprising 76 links and 20 nodal points or intersections. External traffic enters and leaves the modelled area via 5 rural road connections.

The assignment of trips is by minimum time path determined by the following algorithm.

$$Y_i = \text{Minimum}\ (C_{ij} + y_j) \quad \text{for all } i = r, \ \text{where } Y_r = 0$$

$$C_{ij} = \begin{cases} \text{link \& delay time if arc ij is in network} \\ 8 \text{ if i and j are not in network} \\ 0 \text{ if } i = j \end{cases}$$

Forty two interzonal minimum paths were identified and relevant interzonal trips attributed. Little if any intersection delay is associated with vehicle interaction; most of the delay is attributable to intersection controls such as STOPs and GIVE WAYs.

While the Home Interview Survey established the appropriate household trip rate on which to model, the number which responded satisfactorily to this survey meant it was difficult to establish a robust trip end distribution without using information obtained in the number plate survey. The proportion of flows measured at the outer traffic counters when compared with the 24-hour counts was 46.5%.

This implies that 46.5% of Waimate traffic flows in the 6 busiest hours of the day and that matched pairs obtained from the number plate survey, from which interzonal flows were inferred, could be divided by 0.465 to give an estimate of the amount of travel between zones.

For example, generation in Zone 1 was determined simply by comparing differences between entries to Zone 1 at Queen Street (east) High Street and Gorge Road, and departures from High Street and Queen Street (east and west ends). Turning movements at Mill Road, and Queen Street at the western end, together with the traffic counts obtained from Transit New Zealand determined the daily trips out of Zone 2 and approximately 70% of trips in and out of Zone 3.

Similarly, trip generation in Zone 4 could be reasonably determined by the of number plate survey in Parsonage Road at two separate locations, firstly at the inner end near the Zone 4/ Zone 6 boundary, and at a later time at the outer end near the study area boundary. The difference in generation between the two sites, when corrected for the time of day and compared with the number of matches of vehicle registration plates obtained in number plate surveys in Parsonage Road and Queen Street east, together with the automatic traffic counts from Parsonage Road, indicates the number of the trips generated in Zone 4.

Generation in Zone 5 could be inferred from information gained from the number plate counts within the zone but near the Parsonage Road boundary. While the registration numbers were being recorded, turning movements in and out of the connecting streets, Regent Street and Oxford Street were also being made.

From differences between number plate observations made at the two separate sites in High Street, at the study area boundary and near the Zone 1/ Zone 6 boundary, the generation for Zone 6 was deduced. Zone 7 generation was determined principally from partial observations made in High Street, south of William Street, and at the Gorge Road/Queen Street/William Street intersection.

Once the trip matrix was established, the zone to zone traffic for particular zone pairs was assigned to the already determined shortest interzonal time path. The matrix of interzonal trips is shown in Table A.3 and the minimum distance paths are given in Table A.4.

To obtain the Vehicle Kilometres travelled in the modelled network a matrix of interzonal travel is calculated by multiplying the value in each cell, ij, in the distance matrix by the value in the corresponding cell, ij, in the trip matrix. The new matrix gives interzonal travel for all zone pairs. Row totals from this matrix give the total vehicle kilometres travelled from each zone. By summing down the row totals to the total amount of travel in the network is obtained. This total for Waimate is 14,349 vehicle kilometres per day. This estimate however has been obtained for a midwinter's week day to coincide with the peak incidence of pollution from solid fuel burners. It is expected that summer time traffic flows in the town could be as much 15% higher.

Despite lack of congestion in the road network and the low generation rates Waimate traffic speeds are low. Modelled speeds are about 20km/h and because of short trip lengths and trip duration a majority of trips are made from cool or cold starts.

The emission factors stated in Table A.6 above are further modified to take account of the incidence of heavy vehicles, implying larger capacity motors, moving around in the road network and also the effects of differences in emissions of vehicles powered by diesel engines. These modifiers are given in Table A.7.

Waimate Road Network Model

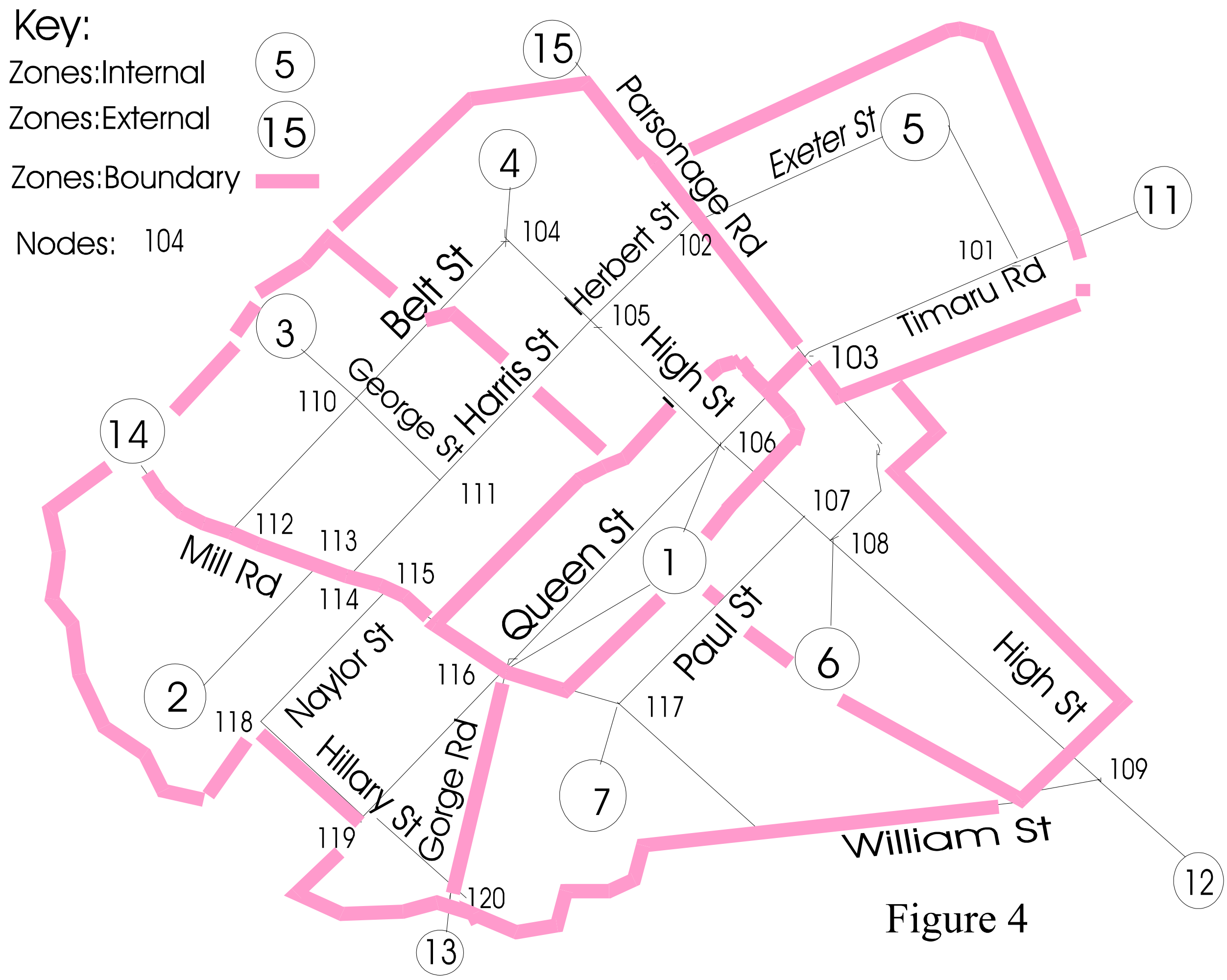


Figure 4

Table A.3: Matrix of 24 hour Interzonal Trips (All Purposes)

TRIP MATRIX													
Zone	1	2	3	4	5	6	7	11	12	13	14	15	Totals
1	0	264	528	431	196	270	56	538	332	325	30	127	3097
2	264	0	66	25	23	72	35	36	19	26	12	30	608
3	528	66	0	114	59	37	55	99	119	40	29	80	1226
4	431	25	114	0	49	37	55	92	25	44	24	65	961
5	196	23	59	49	0	39	40	27	33	27	6	35	534
6	270	72	37	37	39	0	59	61	36	29	5	21	666
7	56	35	55	55	40	59	0	45	170	80	12	14	621
11	538	36	99	92	27	61	45	0	37	62	4	21	1022
12	332	19	119	25	33	36	170	37	0	15	3	12	801
13	325	26	40	44	27	29	80	62	15	0	2	16	666
14	30	12	29	24	6	5	12	4	3	2	0	3	130
15	127	30	80	65	35	21	14	21	12	16	3	0	424

Table A.4: Matrix of Interzonal Distances (including zone connectors)

Minimum Time path Distance Matrix												
Zone	1	2	3	4	5	6	7	11	12	13	14	15
1	0	1.02	1.03	1.27	1.15	0.8	0.77	1.59	1.69	1.2	1.03	1.5
2	1	0	1.05	1.58	1.7	1.65	0.94	1.76	0.99	1.3	0.76	1.7
3	1	1.05	0	0.83	1.57	1.53	0.94	1.28	1.64	1.4	0.73	1.92
4	1.3	1.27	0.83	0	1.26	1.52	0.94	1.63	1.19	1.4	1.26	1.38
5	1.1	1.15	1.7	1.26	0	1.39	1.97	0.8	1.34	2.3	1.7	0.85
6	0.8	0.8	1.65	1.53	1.39	0	1.16	1.39	1.39	1.8	1.65	1.3
7	0.8	0.77	0.94	0.94	1.97	1.16	0	1.88	1.71	1.4	0.94	1.78
11	1.6	1.59	1.76	1.28	0.8	1.39	1.88	0	1.74	2.7	2.44	2.09
12	1.7	1.69	0.99	1.64	1.34	1.39	1.71	1.74	0	2.7	2.21	1.78
13	1.2	1.19	1.31	1.41	2.3	1.82	1.36	2.7	2.68	0	1.36	2.3
14	1	1.03	0.76	0.73	1.7	1.65	0.94	2.44	2.21	1.4	0	1.62
15	1.5	1.5	1.7	1.92	0.85	1.3	1.78	2.09	1.78	2.3	1.62	0

Table A5: Matrix of Interzonal Vehicle Kilometres Travelled

Interzonal Vehicle Kilometres Travelled													
Zone	1	2	3	4	5	6	7	11	12	13	14	15	Totals
1	0	268	545	548	225	216	43.1	858	559	388	31	190	3871
2	268	0	69	39.4	39.1	119	32.8	63.3	18.8	34	9.13	51	743.6
3	545	69	0	94.6	92.5	56.5	51.5	127	195	56	21.2	153	1462
4	548	31.8	94.6	0	61.9	56.3	51.5	150	29.8	60	30.2	89.9	1204
5	225	26.4	100	61.9	0	54.4	78.9	21.6	44.4	62	10.2	29.8	714.3
6	216	57.6	61	56.5	54.4	0	68.3	85	49.9	53	8.27	27.2	736.8
7	43	27	51.5	51.5	78.9	68.3	0	84.6	291	109	11.2	24.9	841.4
11	858	57.4	174	118	21.6	85	84.6	0	64.5	167	9.77	43.9	1683
12	559	32	117	41	44.4	49.9	291	64.5	0	40	6.62	21.4	1268
13	388	31	52.4	61.8	62	52.8	109	167	40.2	0	2.72	36.8	1003
14	31	12.4	22.1	17.5	10.2	8.27	11.2	9.77	6.62	2.7	0	4.86	136.6
15	190	44.9	136	125	29.8	27.2	24.9	43.9	21.4	37	4.86	0	684.4

Table A.6: Emission Factors by Speed and Emission Type

Speed	CO_2	CO	NOx	SOx	VOC	PM_{10}
km/h	g/km	g/km	g/km	g/km	g/km	g/km
20	212.0	25.87	1.97	.39	3.09	7.97

Table A. 7: Weighted Proportions of Vehicles by Size and Motive Power

Vehicle Size	Prop. Petrol	Prop. Diesel	Total
Pass. Car	.7255	.0245	.75
Light Goods	.1169	.0431	.16
Heavy Goods	.0287	.0613	.09
Total	.8711	.1289	1.0

The proportion of vehicles by vehicle class travelling within each of the four time periods is based on the proportion of total traffic travelling in each of the time periods, modified by the observed splits in vehicle class by time of day. These modifying factors are given in Table A.8.

Table A.8 Proportions of Vehicles by Vehicle Class and Time of Day

Time of Day	6-10am	10am-4pm	4-10pm	10pm-6am	Total
Pass. Car	13.2	38.70	24.18	2.16	78.24
LightGoods	3.37	5.08	5.24	0.32	14.01
HeavyGoods	2.37	2.11	3.08	0.19	7.75

Summary Tables have been produced showing the amounts of emissions by emission types in tonnes per day for both time of day, Table A.9, and by vehicle type Table A.10.

The first of these tables which gives time of day emissions by emission type is calculated for each emission type by multiplying total vehicle kilometres by proportion of vehicles moving during that period of the day and by the appropriate emission factor. The emission factor is found by multiplying the stated emission factor (by type of emission) by the proportion of vehicles of that motive power moving in that period relative to the total number of vehicles

Table A.9: Motor Vehicle Emissions (tonnes) by Emission Type and Time of Day

Waimate Road Network Motor Vehicle Emissions based on Modelled Traffic Flows											
Emissions	CO2		CO		NOx		SOx		VOCs		PM10
Period	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Diesel
6am-10am	0.5	0.074	0.068	0.002	0.004	0.001	4E-04	6E-04	0.008	6E-04	3E-04
10am-4pm	1.22	0.18	0.165	0.005	0.01	0.003	0.001	0.002	0.019	0.001	7E-04
4pm-10pm	0.86	0.127	0.117	0.003	0.007	0.002	7E-04	0.001	0.013	1E-03	5E-04
10pm-6am	0.07	0.01	0.01	3E-04	6E-04	2E-04	6E-05	9E-05	0.001	8E-05	4E-05
Totals	2.65	0.392	0.361	0.011	0.022	0.006	0.002	0.003	0.041	0.003	0.001
Total Ems.		3.042		0.371		0.028		0.006		0.044	

The second of these tables which gives emissions by vehicle class and emission type is calculated for each emission type by multiplying total vehicle kilometres by the proportion of vehicles in that vehicle class and by the appropriate emission factor.
The emission factor is found by multiplying the stated emission factor (by type of emission) by the proportion of vehicles of that class relative to the total number of vehicles.

Table A.10: Motor Vehicle Emissions (tonnes) by Emission Type & Vehicle Class

Waimate Road Network Motor Vehicle Emissions based on Modelled Traffic Flows											
Emissions	CO2		CO		NOx		SOx		VOCs		PM10
Veh. Type	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Diesel
Pass. Car	2.21	0.075	0.3	0.002	0.018	0.001	0.002	6E-04	0.034	6E-04	3E-04
Light Gds	0.36	0.131	0.048	0.004	0.003	0.002	3E-04	0.001	0.006	0.001	5E-04
Heavy Gds	0.09	0.186	0.012	0.005	7E-04	0.003	7E-05	0.002	0.001	0.001	7E-04
Totals	2.65	0.392	0.361	0.011	0.022	0.006	0.002	0.003	0.041	0.003	0.001