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INVENTORY OF NON-ENERGY SOURCES OF GREENHOUSE GAS EMISSIONS IN HAWAII

PHASE I

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Introduction

International concern for global climate change has stimulated a wide range of data gathering and analysis efforts worldwide. The recognition that certain atmospheric gases, many of which are anthropogenic in origin, have the capacity to absorb infrared radiation--and thus trap heat in the atmosphere--has focused research efforts on these so-called "greenhouse" gases. In order for a country to assess its contribution to such global warming, it must first develop an emissions inventory of greenhouse gas sources and sinks. In the United States, the U.S. Environmental Protection Agency (EPA) has recently published such an inventory (U.S. EPA, 1994) and has been funding the efforts of each state to develop their own inventories of sources of greenhouse gas emissions (U.S. EPA, 1995, hereafter titled the *State Phase I Workbook*). It is this latter document which serves as the basis for the present report by providing the bulk of its overall methodology.

Basic Methodology

This report constitutes one of two distinct sections of the greenhouse gas emissions inventory for the State of Hawaii, an inventory which covers both energy and non-energy sources. The inventory of energy sources is the responsibility of the Hawaii State Department of Business, Economic Development and Tourism (DBEDT). The inventory of non-energy sources, which this report summarizes, was contracted to the Hawaii State Department of Health (DOH), which then subcontracted the work to the University of Hawaii Environmental Center. The Environmental Center was asked to collect data on the following non-energy sources:

- Landfills
- Domesticated animals:
  - Cattle
  - Swine
  - Chickens
  - Sheep
- Fertilizer use on:
  - Pineapple
  - Sugarcane
  - Macadamia nut trees
  - Coffee trees
  - Golf courses
- Agricultural crop waste burning:
  - Sugarcane
  - Pineapple
- Sewage management

- Changes to forested lands, including deforestation and tree plantings
- Commercial composting companies
- Volcanic emissions

Subsequent communication with state personnel (who received guidance from the EPA) recommended eliminating volcanic emissions from this report (Alber, 1996); a discussion of these emissions may be published in a separate paper at a later date.

In order to accomplish this inventory, the Environmental Center's tasks included the following:

- *Spreadsheet Calculations* -- Determine which models to use to calculate emissions in accordance with those listed in the *Phase I State Workbook*; determine what input data is necessary to calculate emissions; develop spreadsheet models in Microsoft Excel™ for ease of emissions calculations.

- *Data Gathering* -- Identify and refer to literature sources and personnel contacts to obtain relevant data; input data into emissions models.

- *Results and Data Evaluation* -- Calculate emissions; develop plots to display trends; sum the annual anthropogenic greenhouse gas emissions from all non-energy sources, especially for the years 1990 and 1994; discuss any deviations from the EPA models and any gaps where data are missing; and recommend future actions which would facilitate monitoring and evaluation of greenhouse gas emissions in Hawaii.

The following sections of this report document the Environmental Center's efforts and the detailed methodologies followed to calculate non-energy greenhouse gas emissions for the State of Hawaii. The descriptions are categorized according to these sections of the *Phase I State Workbook*:

1. Workbook Section 5: Methane (CH_4) Emissions from Landfills
2. Workbook Section 6: Methane Emissions from Domesticated Animals
3. Workbook Section 7: Methane Emission from Manure Management Systems
4. Workbook Section 9: Emissions from Agricultural Soil Management
5. Workbook Section 10: Carbon Dioxide (CO_2) Emissions from Forest Management and Land-Use Changes
6. Workbook Section 11: Greenhouse Gas Emissions from Burning of Agricultural Crop Wastes
7. Workbook Section 12: Methane Emissions from Municipal Wastewater.

Various data sources were consulted for each section. For example, for those sections dealing with agricultural data (i.e., fertilizer consumption and domesticated animals), publications were readily available and contained the necessary data. For the workbook sections dealing with forest data, wastewater, and landfills, state and county agencies and on-site personnel were contacted since most of the required data could not be located in publications. In cases where data could not be obtained, default values listed in the *Phase I State Workbook* were used. Summaries for each section will describe in greater detail the methodology and sources used to calculate the relevant greenhouse gas emissions.

Detailed Methodology, Results and Discussion

1. Workbook Section 5: Methane Emissions from Landfills

- *Factors influencing the amount of CH_4 produced*

Landfills are the largest single anthropogenic source of methane emissions in the United States (U.S. EPA, 1993). Although the decomposition of organic waste in landfills occurs in an environment which is mainly anaerobic (oxygen-free), this process results in the generation of both CH_4 and CO_2 (Figure 1.1). The two major factors which determine the quantity of gas produced are management practices and physical factors. Management practices include type of waste management system, density of refuse, and refuse particle size; physical factors include waste composition, moisture content, and leachate pH (U.S. EPA, 1995). In general, however, landfill gas contains roughly equal volumes of CH_4 and CO_2 (U.S. EPA, 1993; Emcon Associates, 1980). Unfortunately, *the Phase I State Workbook* provides formulae for estimating only CH_4 emissions from landfills, ignoring their CO_2 emissions altogether. As a result, this section calculates methane emissions for Hawaiian landfills, then assumes equal volumes for these landfills' CO_2 emissions.

- *Data Gathering: Sources and Spreadsheet Calculations*

Three methods were employed to determine methane emissions from Hawaii's landfills. The first (Method 1) involved using formulae developed by the EPA for data-poor states, requiring only two sets of actual data. The first set of numbers required is the annual *de facto* population of the state, which takes into account the resident tourist population at any given time. The only other number required is the *average* per capita municipal solid waste (MSW) generation rate over a period of years. Although this MSW tonnage ideally excludes waste from construction and demolition (C & D) as well as materials destined for recycling, in Hawaii most data sources combine C & D waste with regular MSW (e.g., Namunart, 1996; Steuteville, 1996; State of Hawaii, 1995). As a result, MSW in this section includes these two types of waste but excludes materials headed for recycling.

The second method (Method 2) began with the same data set as Method 1, but augmented it with (a) the *annual* (as opposed to the multiyear mean) weight of MSW produced on Oahu each year since 1985, again excluding materials destined for recycling; (b) the actual number of large landfills in the state per year; (c) a data-based estimate of the percentage of the state's solid waste-in-place (WIP) tonnage which is kept in large landfills; (d) records from the H-POWER Plant--which generates electricity by burning refuse--operating on Oahu since 1991; (e) approximate annual tonnages of waste burned at the Waipahu Incinerator until its closing in 1994; and (f) records from the project underway at the Kapaa Landfill on Oahu since 1990 to burn emitted methane for electric power. (Oahu has also begun a pilot project to turn greenwaste into mulch, which it expects will soon peak at about 6,000 tons mulched per year. However, due to uncertainties regarding emissions from this process, it has been omitted from these calculations.)

The third method (Method 3) was much more data-intensive, requiring an estimate of the amount of WIP at each of the state's landfills *and* the methane generated by each.

It should be apparent that Method 2 is then something of a hybrid between Methods 1 and 3, in that it utilizes EPA equations but applies them to a wider range of Hawaii state data than does Method 1. Method 2 also avoids some of the uncertainties associated with Method 3.

<u>Waste-in-Place (WIP) Calculation</u>

For Method 1, the EPA in its *Phase I State Workbook* has developed a model to estimate statewide WIP when actual statistics are unavailable, a model which uses data compiled from 85 landfills nationwide (U.S. EPA, 1995). This model is fairly realistic in that it accounts for the fact that methane is released from solid waste for up to 30 years, rather than assuming that the total potential methane production is realized shortly after landfilling. The following is the equation suggested by the EPA to determine WIP in data-poor states (U.S. EPA, 1995):

$$WIP = \frac{30 \times P \times WGR \times L \times GCF}{2000} \qquad \text{(Eq. 1.1)}$$

where:

WIP	=	waste in place (tons) over the past 30 years
P	=	*de facto* population for a given year
WGR	=	per capita waste generation rate (default value = 1,712 lbs/capita/yr)
L	=	percent landfilled (default value = 70%)
GCF	=	growth correction factor (81.5%)
2000	=	conversion factor for lbs to tons

For Method 1, the equations listed above require only the population trend over the last several years for the state as a whole, plus the average per capita waste generation over a period of years. The population figures were obtained from the *Hawaii State Data Book*, 1980-1995 Editions. Since population data for 1995 remain unavailable (each *Data Book* edition reports the previous year's data), population figures for 1995 were extrapolated from the 1995 *Data Book* numbers based on average population growth for the previous ten years.

MSW for Methods 1 and 2 excludes all construction and demolition (C & D) waste and all materials destined for recycling (Namunart, 1996). Since the State of Hawaii Office of Solid Waste does not have a record of WIP data covering the last 30 years (McCabe, 1996), MSW generation per year was taken from the Hawaii State Data Book. Unfortunately, the

MSW generation rate in the data book has been recorded only for Oahu. The 12-year mean of this rate is 1,801 lbs/capita/yr between 1983 and 1984. For the purpose of this study, this rate is assumed to be the same for all counties. However, this assumption may underestimate the statewide rate, for three reasons. First, tourists tend to generate more waste per capita than do residents, and tourists make up a larger percentage of the *de facto* population on the neighbor islands than they do on Oahu (Namunart, 1996). Second, the per capita solid waste generation rate on Kauai jumped upward by an unknown amount following hurricane Iniki in 1992, and this increased volume undoubtedly included a portion of non-C & D waste. Third, on Oahu the annual MSW generation rate has increased dramatically between 1983 and 1994 (see Appendix B, p. B4). Considering this rapid increase on Oahu, the average (1,801 lbs/year) used in Method 1 will increase markedly in any future calculations. As a result of this discussion, it should be apparent that the MSW generation rate used in Method 1 should be taken as a minimum value for the state.

Method 2 used the same formula as Method 1, with the following changes. First, starting with the year 1985, WIP calculations incorporate *annual* data on waste generation for the island of Oahu--where the large majority of the state's population resides--as opposed to the 12-year *mea*n which was used in Method 1. Annual records have been maintained by the State of Hawaii Office of Solid Waste since 1989 (Namunart, 1996), and have been extrapolated back to 1985 by personnel at the Honolulu H-POWER Plant (Jones, 1996). For the purposes of this study, in Method 2 these figures were further extrapolated back to 1980 using the formula described above for Method 1. Second, annual MSW tonnages burned at the H-POWER Plant and the Waipahu Incinerator were obtained from personnel at the H-POWER facility (Jones, 1996).

For Method 3, the data in the left half of Table 1.1 were collected and used to determine WIP for each individual landfill. Information was acquired from personnel at these landfills (e.g., Rosetti, 1996) and from solid waste personnel in each county (e.g., Namunart, 1996; Baker, 1996). Although the majority of legal landfills in the state currently operating have estimates for the annual amount of waste presently being landfilled, little or no such data are available for most of the closed landfills, some of which were sufficiently large to have a potentially significant impact on the resulting methane emission calculations. For illegal landfills, no data were collected, for obvious reasons.

A further problem encountered was the lack of any system-wide method for estimating the amount of waste being landfilled at each site, and thus for estimating the amount of WIP at each. For example, some landfills record only the weight of incoming solid waste, and if the density of the landfill is not recorded as well, volume calculation becomes little more than guesswork. Furthermore, when relevant personnel were asked to estimate the density of solid waste in each landfill, the answers varied over more than a degree of magnitude, bringing all answers into doubt. In Table 1.1, the volumes and tonnages which were given by contacted personnel are shown in bold to separate them from those which were calculated from the area and estimated depth of the landfill. In spite of these uncertainties, according to these calculations the total tonnage entering all legal landfills in the state

Table 1.1: Waste in Place and Methane Emissions by Landfill for Hawaii: Data and Estimates for Methods 2 and 3

Landfill Name	Class	Acres	Years of Operation	Municipal Solid Waste (MSW) Landfilled per Year (tons)	30-Year Growth Correction Factor (percent)	Volume of MSW in Place (MSWIP) (yd^3; in bold if quoted)#	Weight of MSWIP (tons; in bold if quoted)*	Percent Non-combustible Waste	Methane-Producing WIP (tons)	Is Landfill Large or Small?	Conversion Factor (tons WIP to tons CH_4/year)	Methane Emissions (tons/year)
Hawaii County												
Hilo Landfill	Nonarid		1970s-Present	**56,314**	67.2		756,860	15%	643,331	S	0.002695	1,734
W. Hawaii & Kailua LFs	Nonarid	20+18	1970s-Present	**62,571**	51.4		643,230	15%	546,745	S	0.002695	1,473
Maui County												
Central Landfill	Arid		1970-Present	**152,833**	58.2	3,226	**2,312,674**	15%	1,965,773	L	EPA Formula	5,648
Hana Landfill	Nonarid		1965-Present	**1,251**	60.3		23,393	15%	19,884	S	0.002695	54
Olowalu & Makani LFs		2 x 15?	Closed in late 1980s		58.2	726,000	435,600	15%	All flared?	S	0.002079	0
Lana'i Landfill	Arid		1975-Present	**2,190**	75.4	86,691**	34,676	15%	29,475	S	0.002079	61
Kalama'ula Landfill	Arid	19	Early '70s-1993			**326,500**	195,900	15%	166,515	S	0.002079	346
New Moloka'i Landfill	Arid	20	1993-Present	**4,693**	89.2	54,750	12,558	15%	10,674	S	0.002079	22
Honolulu County												
Kapa'a LF (6 Parts), Kailua	Nonarid	133	1960s-Present	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Central Site	"	33***	1970-1979		82.1	1,118,040	670,824	15%	570,200	S	0.002695	1,537
Site No. 2	"	34	1982-1997	141,333	82.1	**3,540,000**	**2,122,147**	15%	All burned?	L	EPA Formula	0
Site No. 3	"	16	1979-1982		82.1	**1,000,000**	600,000	15%	510,000	L	EPA Formula	4,247
Two Old Landfills	"	40***	1950s-1970s		82.1	580,800	348,480	15%	296,208	S	0.002695	798
One Old Constr. LF****	"	10***	1950s-1970s		82.1	145,200	145,200	90%	14,520	S	0.002695	39
Kalaheo LF, Kaneohe	Nonarid		1987-1990		82.1	2,183,333	**1,310,000**	15%	1,113,500	L	EPA Formula	5,456
Waimanalo Gulch Landfill	Nonarid		1989-Present	300,000	82.1	**3,500,000**	2,100,000	15%	1,785,000	L	EPA Formula	6,800
Kawailoa LF, Waialua	Nonarid	28***	1960s-1986		82.1	1,355,200	813,120	15%	691,152	S	0.002695	1,863
Wai'anae Landfill	Arid	10	1971-1984		74.5	484,000	**1,400,000**	15%	1,190,000	L	EPA Formula	4,692
Nanakuli Constr. LF****	Arid?		1990-Present	200,000	82.1	**900,000**	900,000	90%	90,000	S	0.002079	187
Kauai County												
Phase I Landfill	Nonarid		1953-1995	62,571	69.0	**763,886*** **	458,332	20%	244,502	S	0.002695	659
Phase II (Kekaha) Landfill	Nonarid		1993-Present	65,700	69.0	**496,668*** **	298,001	20%	158,971	S	0.002695	428
Halehaka Landfill	Nonarid		Closed		69.0	363,000	217,800	15%	All flared?	S	0.002695	0
Total Landfill	Regular Plus C & D MSW (tons/yr):			**986,887**		MSWIP Total (tons):	**15,798,795**		**10,046,451**		CH_4 Emissions (tons/yr):	**36,045**
Waipahu Incinerator	*(Arid)*	*xxx*	*1967-1994*	*187,714*	*0*	*187,714*	*5,068,286*	*xxx*	*5,063,286*	*(L)*		*9,464*
H-Power Plant	*(Arid)*	*xxx*	*1991-Present*	*600,000*	*0*	*600,000*	*3,625,398*	*xxx*	*3,625,398*	*(L)*		*7,693*
Recycling (Oahu)			*1980-Present*	*332,000*	*0*	*332,000*	*2,475,000*	*xxx*	*2,475,000*	*(L)*		*6,276*
Total Avoided Landfill	*Waste Kept Out of Landfills (tons/yr):*			***1,119,714***				*Total Avoided MSW (tons):*	***11,163,684***		*Avoided CH_4 (tons/yr):*	***23,433***

% of WIP in Large Landfills:	58.5%

*except where noted, sites are compacted; assumes 0.6 tons per cubic yard

**not compacted; assumes 0.4 tons per cubic yard

***Kauai landfills are not compacted, but include C & D refuse from Hurricane Iniki; thus, 0.5 tons per cubic yard are assumed

****construction landfills assume 1 ton per cubic yard

#volumes are estimates based on 4840 yd^2/acre. If depths are unknown, landfills are assumed 3 yds deep if operating < 10 yrs, 7 yds deep if operating 10-15 yrs, and 10 yds deep if operating >15 yrs

EPA formula for large landfill emissions = (419,000 + CCF * methane-producing WIP) * 0.0077; CCF = climate correction factor = 0.16 for arid areas and 0.26 for nonarid areas (about 1 million tons per year; see Table 1.1) is essentially equivalent to the total annual tonnage which the state claims is actually being landfilled (Steuteville, 1996; Harder, 1996; Namunart, 1996).

<u>WIP in Large vs. Small Landfills</u>

The Hawaii State Office of Solid Waste also has no record of the proportion of large vs. small landfills, and thus no record of the proportion of MSW contained in these two groups (McCabe, 1996). Although Hawaii permitting regulations have been revised to require documentation of waste entering each landfill, this legislation was only passed in 1993 (State of Hawaii, 1993); thus, accurate records for individual landfills date back only three years from the time of this writing. As a result, EPA default calculations became necessary for Method 1.

In Method 1, the calculated ratio of WIP in large vs. small landfills in the state--and the amount of methane generated by each--utilized the WIP from Equation 1.1 According to this method, the amount of methane generated per unit of waste is significantly greater in landfills containing more than 1.1 million tons of WIP than in those with less WIP. This method also required determination of the overall climate of the state (i.e., arid vs. nonarid) for large landfills, yet not for small landfills. Thus, two separate equations were used for calculation of emissions from large vs. small landfills in Method 1 (U.S. EPA, 1995):

$$M_L = N \times [419{,}000 + (CF_1 \times WIP_L/N)] \times CF_2 \qquad \text{(Eq. 1.2)}$$

where:

M_L	=	methane from large landfills (tons/yr) ± 15%
N	=	number of large landfills in the state
419,000	=	constant recommended in *Phase I State Workbook* (basis unknown)
CF_1	=	conversion factor for tons of waste to ft^3/day methane = 0.26 in non-arid areas and 0.16 in arid areas
WIP_L	=	waste in place in all large landfills statewide (tons)
CF_2	=	conversion factor from ft^3/day to tons/yr methane = 0.0077.

Similarly,

$$M_S = WIP_S \times CF_1 \times CF_2 \qquad \text{(Eq. 1.3)}$$

where:

M_S	=	methane from small landfills (tons/yr) ± 20%
WIP_S	=	waste in place in all small landfills statewide (tons)
CF_1	=	conversion factor for tons of waste to ft^3/day methane = 0.35 in non-arid areas and 0.27 in arid areas
CF_2	=	conversion factor for ft^3/day to tons/yr methane = 0.0077.

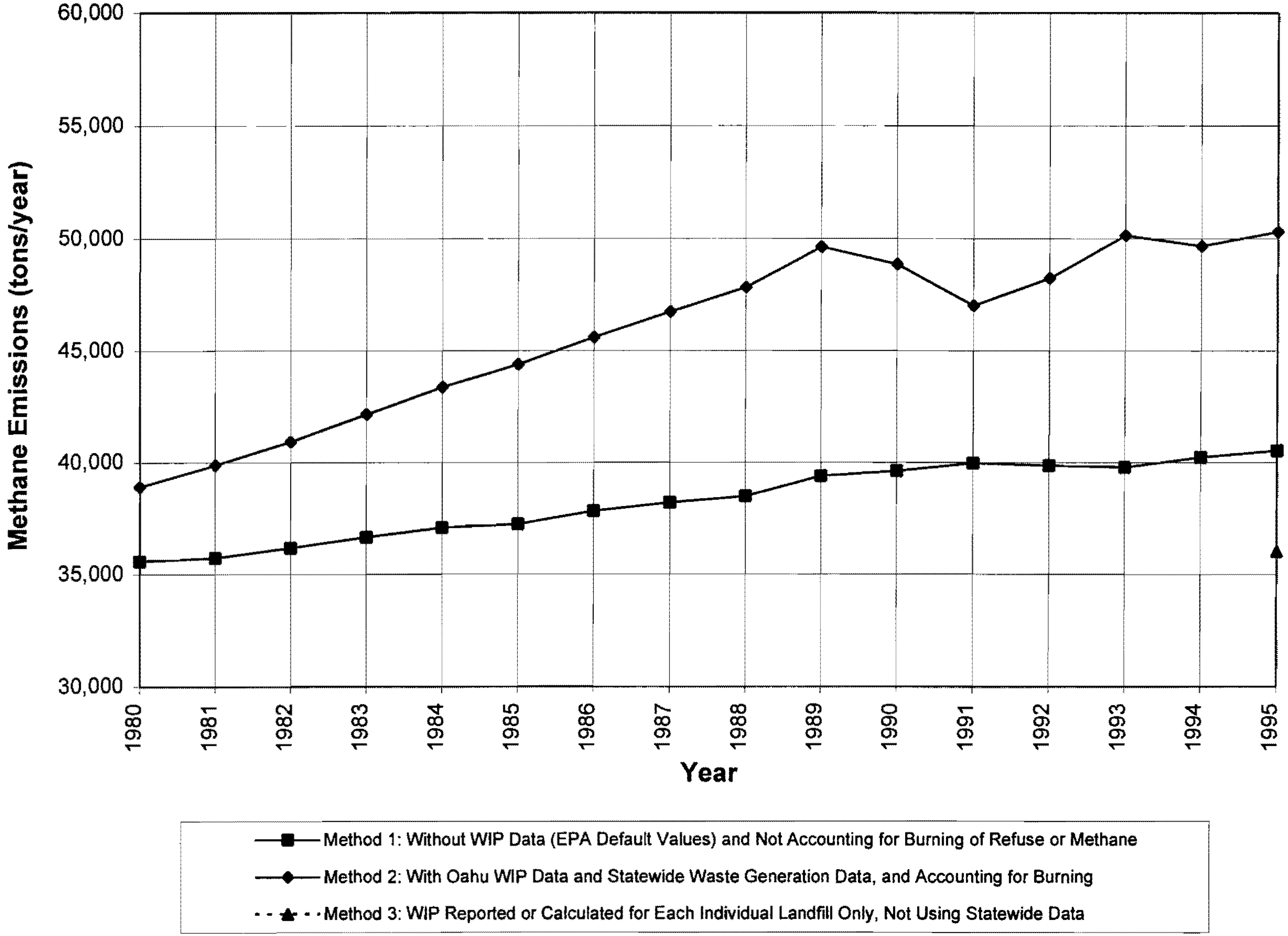
The EPA default value of 0.86 was used as the fraction of WIP in large landfills for Method 1; thus, the value of WIP_L = 0.86 x WIP, and WIP_S = 0.14 x WIP. Using Equation 1.1, it was then determined that a population size of 70,000 people would generate about 1.1 million tons of WIP over a 30-year period; thus, a population of 1.2 million would generate about 19 millions tons of WIP over this same period. Using this calculated ratio and population data from the *Hawaii State Data Book* for Oahu, Maui, and Hawaii Islands, five large landfills were assumed to be present in the state, and this figure was used in Equation 1.2. This figure is corroborated by actual landfill data, as will be seen shortly.

Method 2 makes use of a greater amount of recorded data than does Method 1. This avoids the use of Equations 1.2 and 1.3, which are broad estimates based on national rather than local data. Method 2 uses some of the data in Table 1.1 (as opposed to Method 3, which uses *all* of this data) to determine both the number of landfills in the state and the ratio of large vs. small landfills. These figures were both calculated from data acquired for each legal landfill in operation in Hawaii during the last 30 years. Personnel were contacted at the county level and at some of the individual landfills currently operating (e.g., Jones, 1996; Namunart, 1996; Chock, 1996). Additional data were obtained from Parametrix, Inc. (1995) and Brown and Caldwell Consultants (1993). This information is summarized in the left half of Table 1.1. It should be noted that Table 1.1 breaks Kapaa landfill on Oahu down into its constituent parts (of which all are presently closed, Site 2 having closed in early 1997), and this site is therefore counted as one large and five small landfills. As a result of these calculations, the number of large (>1.1 million tons WIP) landfills in the state is considered to be approximately five (with about 19 small landfills), which is in agreement with the number calculated via the EPA instructions in Method 1. However, the percentage of solid waste that has entered large landfills--rather than small landfills--is then calculated to be only about 59% (Table 1.1), as opposed to the figure of 86% suggested by the *Phase I State Workbook*. This is due to both the unusual number (per capita) and sizes of small landfills in the state.

Method 3, as noted above, used data from each individual landfill to give values for the current WIP volume *at each landfill*. Thus, each landfill must be classified as large vs. small, and also arid vs. nonarid, the latter based on data in Giambelluca et al. (1986). Equations 1.2 and 1.3 were then used to determine methane emission potentials from each landfill, with these changes: WIP_L = WIP for each large landfill, WIP_S = WIP for each small landfill, and N = 1. Since landfills in Hawaii have not--until recently--been required to monitor the amount of solid waste entering each site, annual WIP calculations are impossible at present using Method 3. As a result, the calculations for Method 3 produce only a single data point in Figure 1.2 (following page).

In spite of these efforts to base calculations on actual data, the WIP totals in Table 1.1 may still be underestimates as a result of two assumptions. First, for those landfills which lack any data on either WIP or waste entering the site annually, WIP volumes have been estimated by multiplying the acreage by the assumed depth of fill, as suggested by Namunart (1996). For those sites in operation ten years or less, it is assumed that depth

Figure 1.2: Methane Emissions from Hawaii Landfills (1980-1995)



equals about ten feet, or one 'lift'; for those sites in operation between ten and 15 years, depth is assumed to be about 20 feet or two lifts; and for those landfills in operation over 15 years, depth is assumed to be about 30 feet or three lifts (Table 1.1). Yet these calculations probably result in values below the true values in some cases. For example, although the depth of Kalaheo Landfill in Waimanalo is estimated in Table 1.1 to be about 21 feet deep, in places it is reported to reach up to 150 feet in depth (Namunart, 1996). Second, landfills are divided in Table 1.1 into those which compact their refuse prior to landfilling and those which do not. For the former, Namunart (1996) suggests a density of 0.6 tons per yd^3, vs. 0.4 tons per yd^3 for the latter. However, Namunart (1996) also points out that landfill material settles over time as it degrades and is subject to overlying pressure, thus increasing its density (which may account for some of the discrepancies in landfill densities noted earlier).

In spite of these uncertainties, the resulting total of ~987,000 tons of regular plus C & D MSW being landfilled per year in Table 1.1 agrees with the ~1 million tons per year reported for the state by Steuteville (1996), as well as the ~680,000 tons entering Oahu's landfills per year according to Naumunart (1996). These figures are collected together in Table 1.2.

Table 1.2. Mean Annual Municipal Solid Waste Generated in Hawaii in the 1990s, According to Various Sources (tons)

Type	Namunart (1996)	Jones (1996)	Hawaii State Data Book (1995)	Steuteville (1996)	This Report, Table 1.1
Oahu					
Waste Generated w/o C&D or Recycling	988,000	1,005,000	986,000		
Total Waste Generated	1,620,000				
Construction & Demolition Waste	300,000				200,000
To Recycling	332,000				
To H-POWER Plant	610,000	610,000			
Non-C&D Waste Landfilled	378,000	395,000			441,000
Total Waste Landfilled	678,000				641,000
All Islands					
Total Waste Generated				2,000,000	
Construction & Demolition Waste					200,000
To Recycling				400,000	
To H-POWER Plant				600,000	
Non-C&D Waste Landfilled					787,000
Total Waste Landfilled				1,000,000	987,000

The agreement across Table 1.2 may then be taken as vindication of the techniques employed in Methods 2 and 3. The data, both official and calculated, indicate that calculations recommended in the *Phase I State Workbook* significantly underestimate the volume of generated waste and WIP in Hawaii. For example, the official *de facto* per capita generation rate on Oahu in 1994--even after subtracting C & D waste and recycling--was 2,187 lbs per year (State of Hawaii, 1995), well outside the range of 1,460 to 1,825 lbs per year suggested by the EPA for data-poor states (U.S. EPA, 1995). The rate on the neighbor islands would be even higher since Oahu's portion of the state's population has varied from about 78% in 1980 to about 71.5% in 1994 (State of Hawaii, 1995), yet during this period it contributed on average only about 69% of the state's waste.

Ultimately, the WIP--and thus methane generation--results from all three of the methods discussed in this section are likely to further underestimate the true WIP values due to the presence in each county of a number of illegal landfills (of which around 100 are thought to exist on the Big Island alone), for which little or not data are available.

Other Adjustments Regarding Emitted Methane

Three additional computations were necessary in this analysis. First, in Methods 2 and 3, the operation of the Kapaa landfill methane-burning plant was taken into account. In Method 2, this was accomplished by first noting the annual wattage produced by this facility, then multiplying this by the conversion factor of 0.25 kilowatts per metric ton of MSW, as recommended in the *Phase I State Workbook*. This annual tonnage of burned methane was then subtracted from the annual methane emitted to the atmosphere from the state's landfills, as shown in Table 1.3 and Appendix B, p. B3. In Method 3, this was accomplished by assuming that Kapaa Site 2 produces no methane (Table 1.1). Also in Method 3, the fact that methane is currently being flared at the Olowalu and Makani Landfills on Maui and from the Haleakala Landfill on Kauai (all closed) was taken into account in the same way (Table 1.1). During flaring, approximately 98% of emitted CH_4 is converted to CO_2 (U.S. EPA, 1992). Thus, for those landfills which flare their methane, the tonnage of methane was subtracted from the CH_4 total, converted to CO_2 tonnage, and added to the CO_2 totals shown in Table 1.4 and the tables in Section 8 of this report. The rationale and equation for this CH_4-to-CO_2 conversion will be presented below.

Second, in all three methods, adjustment was made for the oxidation of methane within the soil layer overlying the landfilled material. As per instructions in the *Phase I State Workbook*, it was assumed that 10% of the generated methane is oxidized by this soil layer. The results of this calculation are shown in Tables 1.1 and 1.2, as well as in Appendix B, p. B3.

Third, in Method 3, the landfills of the state were divided into those accepting mainly MSW and those accepting primarily C & D waste. This C & D waste is far less combustible than regular MSW, and thus produces far smaller amounts of greenhouse gases. For the purposes of this report, it was assumed that the solid waste in C & D landfills is only about 10% combustible material (Table 1.1). This helps place the methane emissions from Method 3 under the same constraints as those from Methods 1 and 2, which assume little or no construction waste in state MSW landfills (U.S. EPA, 1995). However, it appears likely that this correction is insufficient to account for all of the C & D waste in Hawaii. This caveat comes from several sources: First, on Oahu alone the C & D tonnage going into landfills in Table 1.1 is about 200,000 tons/year; yet Namunart (1996) claims that around 300,000 tons of (nonrecyclable) C & D waste are generated on Oahu annually, a significant discrepancy. Second, Parametrix, Inc. (1995) states that only about 85.7% of the MSW contained in the Kapaa Landfill is combustible material, a figure corroborated by Namunart (1996). Third, the annual recycling survey printed in *BioCycle* Magazine (e.g., Steuteville, 1996) reports that the two million tons of MSW plus recycling materials generated in Hawaii each year since 1993 includes an undetermined portion of C & D waste. As a result of these considerations, in Table 1.1 the waste in most of Hawaii's regular MSW landfills is estimated to be 85% combustible material. However, the two landfills active on Kauai in the 1990s have been allotted only 80% combustible waste in order to account for the large influx of demolition material following Hurricane Iniki in 1992.

Calculation of Emitted Carbon Dioxide

The volume of gas emitted from an average landfill tends to stabilize at about 50% CH_4 and 50% CO_2 after a period of a few months (Figure 1.1). Although the EPA acknowledges this (US EPA, 1993), the *Phase I State Workbook* omits CO_2 from its calculations on the grounds that for most states, this CO_2 is derived from biomass sources (e.g., crops and forests) which will then reabsorb these emissions. In Hawaii, however, crop wastes are generally not landfilled, and paper products come exclusively from outside the state. Thus, although the *State Phase I Workbook* omits these CO_2 emissions, they are included here.

An equal volume of two gases under identical conditions will differ in weight according to the relative molecular weights of the two gases; thus, since the weight of methane emitted from landfills in Hawaii has been calculated above, to a first order the weight of an equivalent volume of CO_2 can be estimated according to the following formula:

$$W_{CO2} = W_{CH4} \times CF$$

where:

W_{CO2}	=	weight of emitted CO_2 in tons
W_{CH4}	=	weight of emitted CH_4 in tons
CF	=	difference in molecular weights = 44/16.

This is demonstrated in Table 1.4, and the resulting total is included in Figure 1.3 and the tables in Section 8. On the other hand, CO_2 emissions due to the flaring of methane are ignored in this report since these emissions can only be estimated using Method 3, while the numbers in Figure 1.3, Table 1.4 and in Section 8 were acquired using Method 2.

CO_2 is also generated, along with CO, by (a) conversion of CH_4 when methane is burned for power at Kapaa Site No. 2, (b) refuse incineration at the Honolulu H-POWER Plant, and (c) refuse incineration at the Waipahu Incinerator prior to mid-1994 (Jones, 1996). Since the Kapaa and H-POWER plants are energy sources, it is assumed that they will be considered in the documentation of energy sources for greenhouse gases currently being undertaken by DBEDT. The Waipahu Incinerator, on the other hand, is appropriately considered here since it was never used to generate electricity. The tonnage of refuse burned at the Waipahu Incinerator per year is shown in Table B2 and Appendix B. Until 1989, this totaled around 150,000 tons per year. Since about 50% of wood consists of carbon (see Section 5 below), the carbon content of MSW burned at this facility would be somewhat less than 50%. If one assumes that (1) 30% of the weight of this refuse consists of carbon, (2) only about 1% of this carbon is retained as ash, and (3) half of this emitted carbon is converted to CO_2 and half to CO, the necessary equations are as follows:

$$W_{CO2} = \frac{(W_{MSW} \times \%C) - \%A}{2} \times CF_1 \qquad \text{(Eq. 1.5)}$$

where:

W_{CO2}	=	weight of emitted CO_2 in tons
W_{MSW}	=	weight of municipal solid waste entering incinerator, in tons
%C	=	percent of MSW consisting of carbon, expressed as a fraction
%A	=	percent of carbon left behind as ash
2	=	conversion factor accounting for half of emitted gas volume consisting of CO_2
CF_1	=	difference in molecular weights between CO_2 and C = 44/12;

$$W_{CO} = \frac{(W_{MSW} \times \%C) - \%A}{2} \times CF_2 \qquad \text{(Eq. 1.6)}$$

where:

W_{CO}	=	weight of emitted CO in tons
W_{MSW}	=	weight of municipal solid waste entering incinerator, in tons
%C	=	percent of MSW consisting of carbon, expressed as a fraction
%A	=	percent of carbon left behind as ash
2	=	conversion factor accounting for half of emitted gas volume consisting of CO
CF_2	=	difference in molecular weights between CO and C = 28/12;

It follows that the incinerator probably produced somewhere around 85,000 tons of CO_2 and 55,000 tons of CO annually until 1989. Between 1990 and 1993, the incinerator would then have produced about half of this amount per year, until it ceased operations in mid-1994. These tonnages are shown in Table 1.4, and are included in Figure 1.3 and in Section 8.

- *Results and Data Evaluation*

The results of Method 1 are displayed graphically for methane in Figure 1.2 as the "Without WIP Data" line. According to this line, methane emissions rose fairly steadily from less than 36,000 tons CH_4/yr in 1980 to less than 41,000 tons CH_4/yr in 1995. Inclusion of MSW incineration (via H-POWER) and methane burning would suppress this rise somewhat, and possibly cause a net decline in annual methane emissions from landfills since 1990.

Table 3.1. 1990 Methane Emissions Due to Animal Manure Management Practices in Hawaii

Animal Type	Population	CH_4 (cu. ft)	CH_4 (lbs.)	CH_4 (tons)
Dairy Cattle	19,174	157,094,431.0	6,488,000	3,244
Beef Cattle	185,826	12,300,242.1	508,000	254
All Cattle	205,000	169,394,673.1	6,996,000	3,498
Swine	36,000	53,317,191.3	2,202,000	1,101
Sheep	27,000	677,966.1	28,000	14
Chickens	974,000	67,796,610.2	2,800,000	1,400
Total	**1,037,000**	**460,581,113.8**	**19,022,000**	**6,013**

Table 3.2. 1994 Methane Emissions Due to Animal Manure Management Practices in Hawaii

Animal Type	Population	CH_4 (cu. ft.)	CH_4 (lbs.)	CH_4 (tons)
Dairy Cattle	16,112	137,481,840.2	5,678,000	2,839
Beef Cattle	141,000	12,203,389.8	504,000	252
All Cattle	157,112	149,685,230.0	6,182,000	3,091
Swine	35,000	52,203,389.8	2,156,000	1,078
Sheep	23,000	581,113.8	24,000	12
Chickens	823,000	57,288,135.6	2,366,000	1,183
Total	**881,000**	**409,443,099.3**	**16,910,000**	**5,364**

4. Workbook Section 9: Emissions from Agricultural Soil Management

Greenhouse gas emissions can result from various agricultural soil management practices. Emissions of nitrous oxide (N_2O), for example, which occur naturally in soils, can be increased by the application of nitrogen-bearing synthetic and organic fertilizers. Soils are both sources and sinks for CO_2 and carbon monoxide (CO), sources of N_2O, and sinks for CH_4. Fluxes of such gases can be affected by tillage practices, irrigation, and the non-use (fallowing) of fields. The *Phase I State Workbook* endeavors to quantify emissions based on fertilizer use only, since much uncertainty remains about the other management practices and the direction (i.e., source or sink) and magnitude of their effects.

Fertilizer usage data that were necessary to determine emissions were obtained from the *Fertilizer Summary* (1986-1992), published annually by the Tennessee Valley Authority (TVA) National Fertilizer and Environment Research Center. State Department of Agriculture personnel had stated that the TVA publication was an accurate data source, since it is the only agency currently monitoring fertilizer usage for Hawaii. All emissions calculations were performed in accordance with models developed by the EPA as listed in the *Phase I State Workbook.* The following equation was used to calculate emissions:

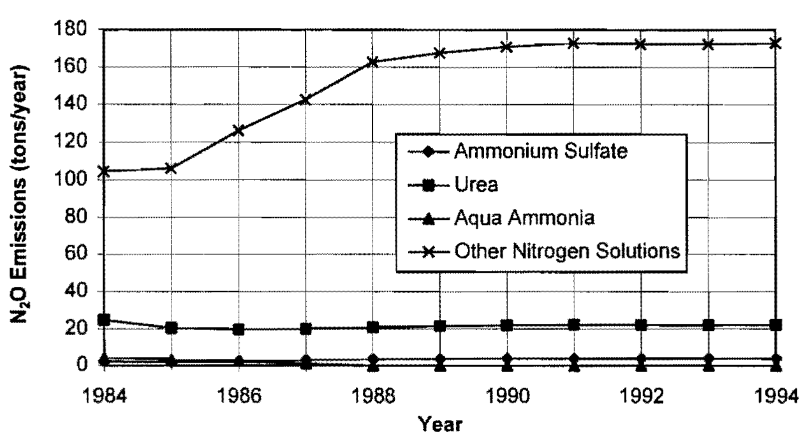
$$E_f = F_f \times N\% \times CF_1 \times CF_2 \quad \text{(Eq. 4.1)}$$

where:

E_f	=	annual N_2O emissions from fertilizer "f"
F_f	=	annual usage of fertilizer "f" (T/yr)
N%	=	percent of nitrogen in fertilizer "f"
CF_1	=	conversion factor for nitrogen (T/yr) to N_2O as N (T/yr) = 0.0117
CF_2	=	conversion factor for N_2O as N to N_2O (T/yr) = 44/28 = 1.57.

The *Fertilizer Summary* (Tennessee Valley Authority, 1986-1992) contained all necessary information to calculate emissions; however, this publication was discontinued as of 1992. Calculations were performed for the years 1983-92, to take into account the three-year averaging requirement. Since data were not available for years beyond 1992, estimations were made and data extrapolated to include the years 1993 and 1994. Figure 4.1 displays the resulting emissions by fertilizer type:

Figure 4.1. Nitrous Oxide Emissions from Agricultural Soil Management (1984 - 1994)



From Figure 4.1, it can be seen that 'other nitrogen solutions' make the largest contribution to N_2O emissions. Use of these 'other' fertilizers increased from 1984-94, thus causing overall fertilizer emissions to rise every year. Use of fertilizers containing ammonium sulfate, aqua ammonia, and urea has remained steady for the past ten years, resulting in a fairly constant quantity of N_2O emissions form these sources. Emissions from these fertilizers are also only 1/5 to 1/8 that of fertilizers with other nitrogen solutions. Because the TVA has discontinued its fertilizer inventory, there is currently no other mechanism in place to monitor fertilizer consumption for Hawaii. Without a regulatory requirement for reporting such information, individual suppliers or users are reluctant to reveal sales or usage data. As a result, future inventory efforts may be problematic. Fortunately, the quantities of fertilizers involved and their respective N_2O emissions are orders of magnitude below other greenhouse gas sources such as landfills and domesticated animals.

Data for 1990 and 1994 are summarized in Tables 4.1 and 4.2, respectively.

Table 4.1. 1990 N_2O Emission from Fertilizer applications in Hawaii

Fertilizer Type	Fertilizer Applied (tons)	N_2O Emitted (tons)
Ammonium Sulfate	965	3.7
Urea	2,638	22.3
Aqua Ammonia	0	0
Other: Nitrogen Solutions	19,392	174.7
Total:	**22,995**	**200.7**

Table 4.2. 1994 N_2O Emission from Fertilizer Applications in Hawaii

Fertilizer Type	Fertilizer Applied (tons)	N_2O Emitted (tons)
Ammonium Sulfate	956	3.7
Urea	2,612	22.1
Aqua Amonia	0	0
Other: Nitrogen Solutions	19,199	173
Total:	**22,767**	**198.7**

5. Workbook Section 10: Carbon Dioxide Emissions from Forest Management and Land-Use Change

Human activities involving forest management and land-use changes affect the net flux of carbon by altering the amount of carbon stored in the biomass and soils of forest ecosystems. For example, intensified forest management can cause an increased growth rate among forest vegetation, which increases biomass density and thus carbon uptake. Similarly, increased carbon uptake and storage in biomass and soils can result when cropland is abandoned, allowing natural regeneration of forest vegetation. Such activities as these pose concerns because they involve a number of greenhouse gases, including CO_2, CH_4, and N_2O; however, CO_2 is the gas of primary concern and is the focus of workbook Section 10.

Workbook Section 10 provided the models to determine the magnitude and trends of CO_2 fluxes from forest management practices. The methodology employed was based on the assumption that CO_2 flux to and from the atmosphere is equal to changes in the carbon stocks of existing biomass and soils. Three categories of activity were evaluated:

- Changes in forests and other biomass stocks (logging, planting, restocking, urban forestry, agroforestry, and fuelwood extraction)
- Forest and grassland conversion (permanent forest clearing, conversion of grasslands to cultivated lands, shifting cultivation, urban development, suburban development, and parking lots)

- Abandonment of managed lands (abandonment of managed pastureland, cropland, etc.).

The formula for determining carbon emissions from or uptake by forest management practices is as follows:

$$CO_2 \text{ Flux} = A_i \times GR_i \times C\% \times BH_i \times CF$$

where:

A_i = area of accumulating biomass for forest of type "i", in acres
GR_i = annual growth rate of tree type "i", in tons of dry matter per acre per year
$C\%$ = percent of biomass consisting of carbon (essentially the same for all Hawaiian tree types), expressed as a fraction
BH_i = biomass of forest type "i" harvested per year
CF = conversion factor for C to CO_2 = 44/12.

Although this section was detailed in the models developed by the EPA, data inventory proved to be difficult. For example, published data could not be found on changes in forests. Since the data available were minimal and insufficient, calculations were not made; however, discussions with forestry personnel did result in some information. The State Division of Forestry and Wildlife (DFW) reported that there are currently 1.99 million acres of forest, of which 97.7% is native forest. The remaining 2.3%, comprising 46,000 acres of managed forests, is planted with eucalyptus, other hardwoods, and pines. The DFW also indicated that no harvesting has been carried out in any forest on state land since the late 1970s and early 1980s. Forestry personnel stated that limited harvesting has been carried out on private lands, but no records were available. For these 46,000 acres of managed forest, the *Phase I State Workbook* (October 1996 update) provides a table listing the average annual increment in biomass per acre per year for a normally-growing forest plantation covered with various types of forest. These data have been incorporated into Table 5.1 below:

Table 5.1. Carbon Dioxide Uptake by Forestry Management in Hawaii

Type of Tree	Total Area with Accumulating Biomass[1] (acres)	Annual Growth Rate[2] (t dm/acre/yr)	Annual Biomass Increment (t dm/yr)	Carbon Fraction of Dry Matter (t C / t dm)	Annual Carbon Uptake Increment (t C/yr)	Annual Biomass Harvested (t dm/yr)	Net Annual Carbon Emissions (+) or Uptake (-) (t C/yr)
Eucalyptus	27,500	6.5	178,750	0.5	89,375	0.0	-327,708.3
Other Hardwoods	12,000	3.0	36,000	0.5	18,000	0.0	-66,000.0
Pines	6,500	1.8	11,700	0.5	5,850	0.0	-21,450.0
Total	**46,000**		**226,450**		**113,225**	**0.0**	**-415,158.3**

1: State of Hawaii Data Book 1993 - 94, Table 1.4
2: EPA State Workbook (Revised 10/96), Table 10-1
dm = dry matter.

As can be seen in this table, use of Equation 5.1 for the 46,000 acres of managed forest on state lands in Hawaii shows a substantial uptake of carbon by forests in these managed plantations. Indeed, this uptake is sufficient to more than offset the total tonnage of all greenhouse gases emitted by all other land use practices described in this report. However, as will be discussed in the summary below, mere tonnages are misleading and, in spite of this large negative figure, Hawaii's anthropogenic non-energy greenhouse gas emissions still have a significant positive climate warming capability.

Since annual data for forest management are unavailable, 1990 and 1994 summary tables cannot be provided here, and the total tonnage from Table 5.1 is presented as both the 1990 and the 1994 tonnages in Tables 8.1 and 8.2 below. Although the 1994 value should be somewhat higher than the 1990 value, the actual difference between these two years remains unknown.

Detailed data as required in the *Phase I State Workbook* could not be found on forest and grassland conversion from state or private sources. The most likely conversion to have occurred in Hawaii over the past 20 years would be from agricultural lands to urban; however, no published statistics could be found. While little or no conversion of forest land was found to have occurred, some of Hawaii's former sugar cane lands have been converted to other crops such as macadamia nut and coffee trees.

Data on abandoned lands, also required by the *Phase I State Workbook*, could not be found. In recent years, several large sugar plantations have closed in Hawaii and left thousands of acres of former sugarcane fields lying fallow, converted to other crops, or rezoned for urban uses (residential, resort, commercial, or industrial). Although this loss of cane fields is expected to continue as economics forces the closure of other sugar growing and processing operations in Hawaii, it is not expected that those lands which have been "abandoned" will remain so for long enough to develop significant tree growth. However, at the present time, nearly 60,000 acres have been temporarily abandoned across four islands (Hawaii, Maui, Oahu and Kauai). In recognition of this state of affairs, the current carbon uptake by these have been calculated according to the following formula from the *Phase I State Workbook*:

$$CO_2 \text{ Flux} = A \times GR \times US \times C\% \times CF \quad \text{(Eq. 5.2)}$$

where:

A = 20-year (or less) total area of land abandoned and regrowing, in acres
GR = annual rate of aboveground biomass growth, in tons of dry matter per acre per year
US = annual rate of carbon uptake by soils, in tons per acre per year
C% = percent of biomass consisting of carbon (essentially the same for all Hawaiian tree types), expressed as a fraction
CF = conversion factor for C to CO_2 = 44/12.

Since no values are available in the *Phase I State Workbook* (October 1996 update) for carbon uptake by tropical or semitropical soils, the value of US for temperate soils, 0.58, is used in Equation 5.2. The resulting calculation is presented in Table 5.2:

Table 5.2. Carbon Uptake by Abandoned Lands in Hawaii

Climate Type	20 yr total area (abandoned and regrowing)[1] (acres)	Annual Rate of Aboveground Biomass Growth[2] (t dm/acre/yr)	Annual Above-ground Biomass Growth (tons dm)	Carbon Fraction of Above-ground Biomass (t C/t dm)	Annual Carbon Uptake in Aboveground Biomass, < 20 years (tons C/yr)	Annual Uptake of Carbon in Soils (t C/acre/yr)	Total Annual Carbon Uptake in Soils ≤ 20 yrs (tons C/yr)	Total Carbon Dioxide Emission (+) or Uptake (-) ($t CO_2/yr$)
Moist	59,500	3.6	214,200	0.5	107,100	0.58	34,510	**-519,237**

1: State of Hawaii Data Book 1993 - 1994, Table 1.5
2: EPA State Workbook (Revised 10/96), Table 10-5
dm = dry matter.

The current trend of abandonment of agricultural lands in Hawaii induces a carbon uptake similar to that of forest management practices discussed above. This trend will likely taper off in the future, however, as these lands are brought into new types of cultivation or are developed for other uses. However, current plans to convert much of this acreage to crops of macadamia, coffee, eucalyptus and other trees should dampen this decline. Unfortunately, the lack of annual data reporting for this sector in Hawaii negates the possibility of producing tables for 1990 and 1994 emissions from abandoned agricultural lands. As a result, the total reported here is used for both the 1990 and the 1994 values in Tables 8.1 and 8.2. Similarly, since annual data is also lacking for emissions from managed forests, the total from that calculation is used for both the 1990 and the 1994 values in Tables 8.1 and 8.2.

Due to the scarcity of data found for emission variables in this section, it was only possible to perform calculations for forest management practices on state land, and it was impossible to report any trends due to the lack of annual data for any of these land uses. Although there are many uncertainties that surround emissions from forest and land-use changes, considering the massive carbon uptake capability of Hawaii's forests, shrublands and abandoned agricultural fields, state personnel should develop a mechanism by which forest and agricultural activity can be monitored in order to determine how these changes affect greenhouse gas emissions.

6. Workbook Section 11: Greenhouse Gas Emissions from Burning of Agricultural Crop Waste

Post-harvest burning of agricultural fields is practiced in some parts of the U.S. to clear remaining straw and stubble and to prepare the fields for the next cycle of planting. In Hawaii, although burning of sugarcane and pineapple crops has been practiced for over a century, this practice has decreased quite sharply over the past several years as these two crops are phased out of the state economy due to overseas competition (e.g., Tam, 1996). The remaining sugarcane growers continue to burn their crops prior to harvest, a practice which is intended to reduce the mass of material which must be transported to sugar mills. Although field burning continues to be practiced in Hawaii, for sugarcane it differs from the method employed in the mainland U.S., in that in Hawaii crop burning is not practiced annually but rather on a two-year cycle for any given field.

Burning of crop matter is included here since it results in the release of several greenhouse gases including CO_2, CO, CH_4, and various nitrogen oxides (NOx). The practice, however, is not considered a net source of CO_2 because the released CO_2 is normally reabsorbed by crop regrowth during the next growing season.

To determine the emissions of the above greenhouse gases, the following steps were carried out:

- Collect data on sugarcane and pineapple crop annual production
- Convert provided or obtained data into pounds of biomass produced to determine emissions
- As per the models listed in the *Phase I State Workbook*, determine the annual greenhouse gas emissions for each crop
- Plot results and evaluate for any trends.

Statewide sugarcane production data were obtained from the Hawaiian Sugar Planters' Association for the period 1980-1994. Unfortunately, although pineapple crop waste has been burned in Hawaii for several years, data on this crop could not be obtained: while records have been maintained for this crop by the Clean Air Branch of the State Department of Health, all records for years prior to 1993 were recently discarded (Tam, 1996). Thus, calculations for pineapple crop waste were not performed. In addition, the *Phase I State Workbook* does not contain any emissions factors for pineapple, factors which were necessary parameters for any emissions equations.

The following equations were used to determine greenhouse gas emissions for sugarcane:

$$DM = CP \times R{:}C \times RB\% \times DM\% \times B\% \qquad \text{(Eq. 6.1)}$$

where:

DM	=	dry matter burned (lbs)
CP	=	crop production (lbs)
R:C	=	residue/crop ratio = 0.8
RB%	=	percent of residue burned, expressed as a fraction = 0.1 (EPA default value)
DM%	=	percent of residue consisting of dry matter, expressed as a fraction = 0.90 (EPA default value)
B%	=	"fraction burned," a variable which is not explained (and which may be superfluous; see below) = 0.93 (EPA default value);

$$TCO = DM \times C\% \times C_{OX}\% \qquad \text{(Eq. 6.2)}$$

where:

TCO = total carbon oxidized (lbs CO_2 as C)
DM = dry matter burned (lbs)
C% = percent of dry matter consisting of carbon, expressed as a fraction = 0.4695
C_{OX}% = percent of carbon oxidized, expressed as a fraction = 0.88;

$$TNR = TCO \times N:C \qquad \text{(Eq. 6.3)}$$

where:

TNR = total nitrogen released (lbs N)
TCO = total carbon oxidized (lbs CO_2 as C)
N:C = nitrogen:carbon ratio = 0.0064;

$$CG = TCO \times CFC / 2000 \qquad \text{(Eq. 6.4)}$$

where:

CG = carbon gas (CO or CH_4) emissions (tons)
TCO = total carbon oxidized (lbs CO_2 as C)
CFC = conversion factors for carbon gases: CO = 0.06; CH_4 = 0.003;

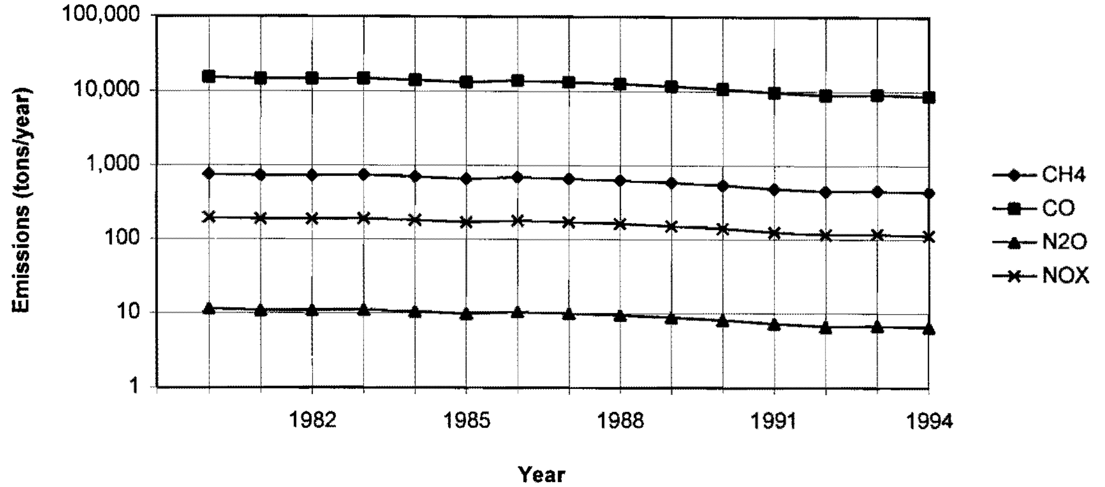
$$NG = TNR \times CFN / 2000 \qquad \text{(Eq. 6.5)}$$

where:

NG = nitrogen gas (N_2O or NOx) emissions (tons)
TNR = total nitrogen released (lbs N)
CFN = conversion factor for nitrogen gases: N_2O = 0.007; NOx = 0.121.

Some of the variables in Equations 6.1 - 6.5 have questionable merit, especially those in Equation 6.1. For example, the term "fraction burned" is never explained in the workbook, and seems superfluous since a fraction for "residue burned" is already included. Furthermore, the EPA has provided default values for sugarcane (but not pineapple) in the workbook--values which may not be applicable to Hawaii. In particular, the suggestion that only 10% of sugarcane "residue" is burned seems to be far too low. However, since the State of Hawaii does not keep records on these variables, the EPA default values must be used. Using Equations 6.1 - 6.5, greenhouse gas emissions were calculated for sugarcane crop burning. Figure 6.1 displays the results:

Figure 6.1. Emissions from Agricultural Field Burning in Hawaii (1980 - 1994)



The logarithmic scale in Figure 6.1 gives a clear picture of the relative emission tonnages for the four gases of concern in this section. From this figure, one can see that CO is the primary greenhouse gas being emitted. This predominance is not surprising, since CO emission is typically a result of oxygen starvation during fires, which is common in field burning of carbonaceous matter on this scale. Figure 6.1 also shows a slight downward trend in emissions over the survey years. This trend will continue--and will likely accelerate for the next few years--as economics continues to cause sugarcane plantations to cease operations in Hawaii.

The values in Figure 6.1 may underestimate the actual emissions. Some reasoning for this assertion has already been explained above, but this does not exhaust the arguments. For example, in 1972 the State of Hawaii estimated that agricultural field burning produced 57,200 tons of carbon monoxide and 1,140 tons of nitrogen oxides per year (quoted in American Lung Association of Hawaii, 1974). Furthermore, Daniels (1979) found through field experiments that previous small-scale measurements of CO emissions from both sugarcane and pineapple waste burning had grossly underestimated CO emissions per ton of biomass. Daniels concluded that sugarcane produced a surprising 5,000 lbs/ton of CO per ton of biomass, vs. 70.6 lbs/ton as measured in previous burn tower experiments. This discrepancy was attributed by Daniels to accumulation of dried leaves and other material on the ground surface, which restricted airflow near the ground (Daniels, 1979). Thus, the numbers in Figure 6.1 and in Table 6.1 below should perhaps be considered minimum values for emissions of the various greenhouse gases.

Data for 1990 and 1994 are displayed in Table 6.1:

Table 6.1. 1990 and 1994 Greenhouse Gas Emissions from Agricultural Field (Sugarcane) Burning

Year	Total Crop Production (T/yr)	Dry Matter (tons)	Total Carbon Oxidized (tons)	Total Nitrogen Released (tons)	CH4 Emitted (tons)	CO Emitted (tons)	N2O Emitted (tons)	Nox Emitted (tons)	Total Greenhouse Gases Emitted (tons)
1990	6,540,925	437,980	180,956	1,158	543	10,857	8.1	140	11,548
1994	5,268,859	352,803	145,764	933	437	8,746	6.5	113	9,303

Although emissions were successfully calculated for sugarcane, at least from the standpoint of the *Phase I State Workbook*, it may benefit the state to develop a more rigorous method for determining the contribution of greenhouse gas emissions from pineapple crop residue. This would result in a more accurate analysis of greenhouse gas contributions from agricultural crop burning. State personnel may also want to develop Hawaii-specific emissions factors instead of using those listed in the *Phase I State Workbook*, as discussed above. As pointed out both here and in the workbook, the models developed by the EPA are crude and possess a fairly large degree of uncertainty. Research may be needed to determine specific emission ratios based on type of biomass and burn conditions. Also ignored in the EPA model is the effect of previous burns on soil carbon content, which may influence emissions from current or future burns.

7. Workbook Section 12: Methane Emissions from Municipal Wastewater

Wastewater treatment is another process that can contribute to methane generation and emissions. Wastewater can be treated aerobically and/or anaerobically and can degrade, untreated, via either mechanism (U.S. EPA, 1995). Methane is generated under anaerobic conditions as the organic matter is degraded. Important in determining the level of methane generation is the organic loading or biochemical oxygen demand (BOD), which is a measure of the oxygen required by microorganisms to degrade the organic matter in the wastestream. Therefore, a wastestream with a high BOD will generate more methane than one with a lower BOD.

To determine the methane emissions from municipal wastewater, the following items were necessary (U.S. EPA, 1995):

- Pounds of BOD_5 per capita (BOD_5 refers to 5-day BOD test)
- State population
- Fraction of wastewater treated anaerobically.

State population data were obtained from the *Hawaii State Data Book* for the period 1980-1994. Unfortunately, although the counties keep track of both the volume of wastewater being produced annually and the volume being treated, the *Phase I State Workbook* provides no way to incorporate those figures into methane emissions. To determine BOD_5 and other wastewater characteristics for Hawaii, State Department of Health (DOH) officials were contacted. Exact data on fraction of wastewater treated anaerobically could not be obtained: many Oahu residents are not connected to a wastewater treatment plant

(WWTP) and have instead a cesspool or septic tank, which can be a source of methane generation. Accurate records on cesspools and septic tanks were unavailable, thus the default value listed in the *Phase I State Workbook* was used. DOH personnel did, however, provide an average value for BOD_5.

The following equation was used to determine methane emissions from municipal wastewater treatment in accordance with models developed by the EPA and recommended in the *Phase I State Workbook*:

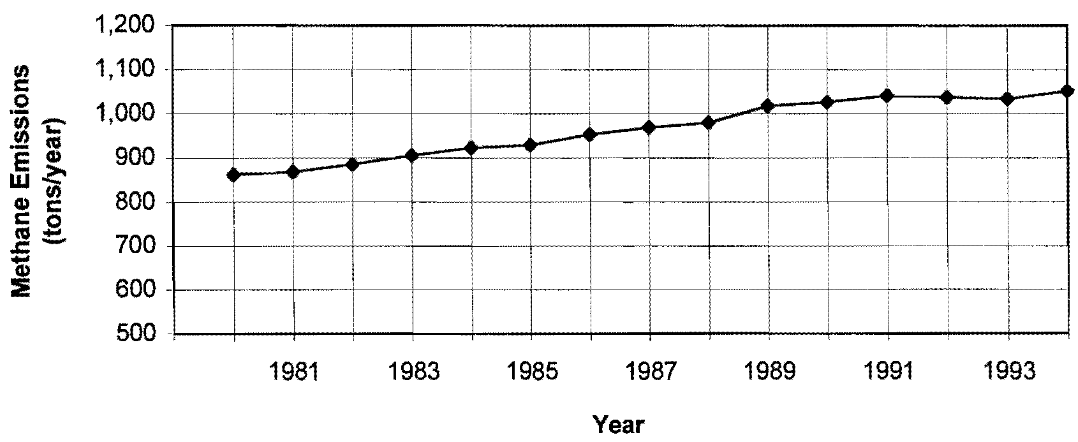
$$E_y = (P \times B \times 365 \times EF \times A\%)/ 2000 - MR \qquad \text{(Eq. 7.1)}$$

where:

E_y	=	methane emissions for year "y" (tons)
B	=	BOD_5 generation rate (0.1356 lbs/capita/day)
P	=	*de facto* population
365	=	conversion factor (days/year)
EF	=	emissions factor (lbs CH_4 / lb BOD_5) = 0.22
A%	=	percentage of wastewater treated anaerobically, expressed as a fraction
2000	=	conversion factor (lbs/ton)
MR	=	methane recovered (tons)

Using Equation 7.1, methane emissions were calculated for wastewater in Hawaii. Figure 7.1 displays the results:

Figure 7.1. Methane Emissions from Municipal Wastewater Treatment (1980 - 1994)



From Figure 7.1, one can see that methane emissions from wastewater treatment have increased fairly steadily over the last 14 years. This is expected, since such emissions are directly proportional to population. As the population in Hawaii has increased, emissions have increased in tandem, and would be expected to grow further as population rises. The data for 1990 and 1994 are extracted and presented in Table 7.1 below:

Table 7.1. Methane Emissions From Municipal Wastewater Treatment in Hawaii

Year	State *De Facto* Population	BOD_5 Generation Rate (lbs/capita/ day)	Fraction of Total Wastewater Treated Anaerobically	Methane Emission Factor (lbs/CH_4/ lb BOD_5)	Methane Recovered (tons CH_4)	Total Methane Emissions (tons CH_4)
1990	1,257,000	0.1356	0.15	0.22	0	1,027
1994	1,287,600	0.1356	0.15	0.22	0	1,052

It should be fairly easy to continue monitoring emissions due to wastewater treatment. It is recommended, in addition, that state personnel try to develop a mechanism to accurately include contributions from septic tanks and cesspools and determine accurate percentages for BOD_5 generation and fraction of wastewater treated anaerobically. Since the effect of these factors on the trend seen here is uncertain, such data would provide a better picture of methane emissions from wastewater treatment. These data would also aid any future state decisions about development of additional wastewater treatment systems and/or upgrading of existing facilities.

Summary and Conclusions

Non-energy greenhouse gas *emissions* estimated in this report are summarized graphically in Figures 8.1 and 8.1a on the following pages. These figures omit CO_2 uptake by forest management and agricultural land abandonment for the moment, since the massive uptake of CO_2 by these two practices overwhelms the emissions by other practices. This omission from Figures 8.1 and 8.1a allows one to discern the trend in anthropogenic *emissions*, as opposed to *sources*, over the last decade. Forest management practices and agricultural land abandonment will be reincorporated into the discussion below in order to view the net effect of sources *and* sinks together.

Since 1989, the annual total *emissions* appear to have declined sharply from approximately 360,000 to approximately 240,000 tons--a change of about 33%, due largely to burning of refuse at the H-POWER facility and to burning and flaring of methane at landfills. Landfills are the predominant non-energy sources, with emissions in the hundreds of thousands of tons per year--an entire order of magnitude greater than those from domesticated animals and agricultural field burning, whose emissions never reach above 20,000 tons per year. Emissions from landfills, domesticated animals and agricultural field burning remain in a state of decline, while those from such sources as wastewater and agricultural soil management appear to be increasing. In the future, it is expected that methane emissions from the predominant source, landfills, will continue to decline due to continued burning of solid waste for H-POWER, as well as methane recovery and flaring

Figure 8.1. Non-Energy Greenhouse Gas Emissions in Hawaii (1983 - 1994), Excluding Forestry Management and Land-Use Changes

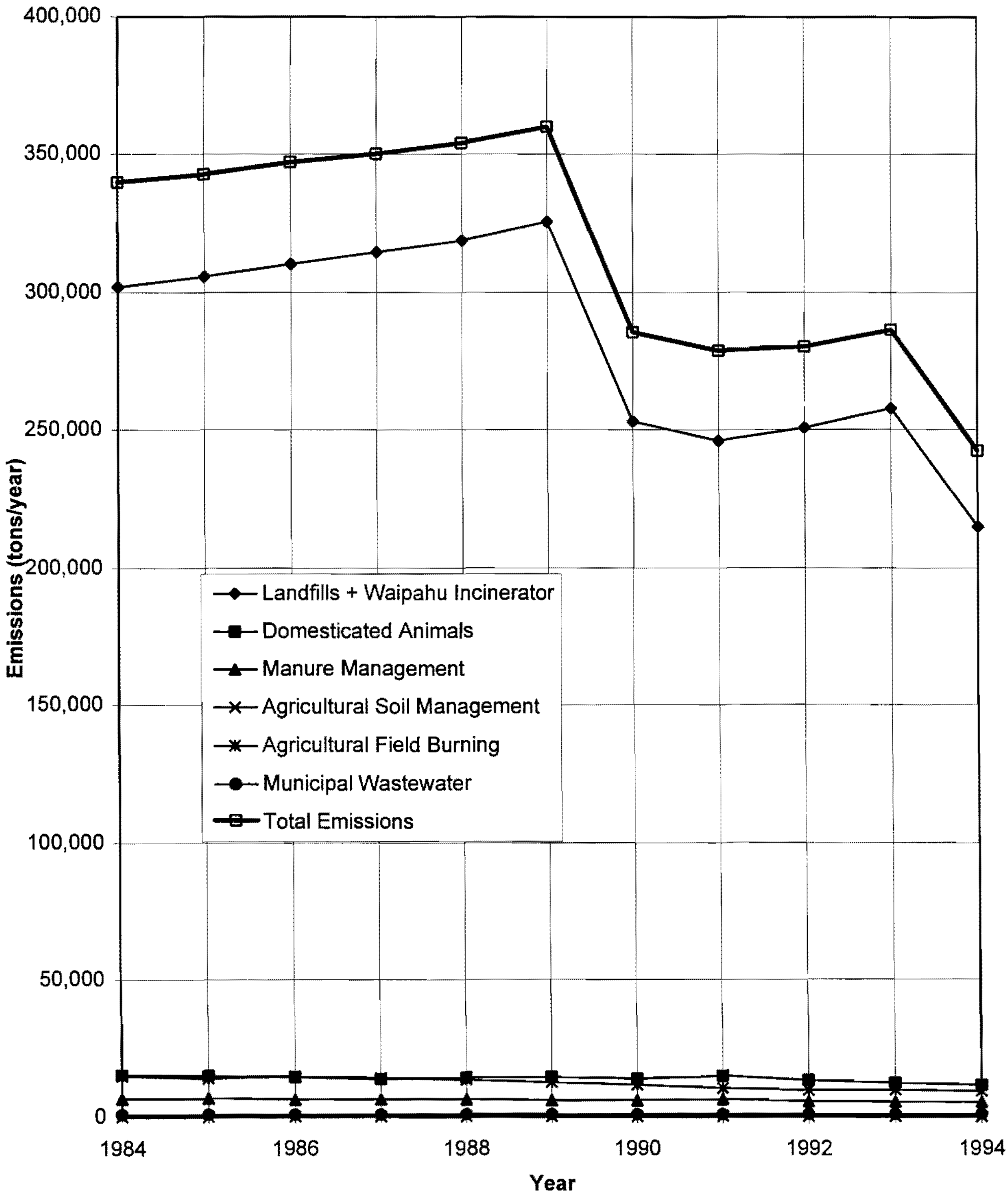
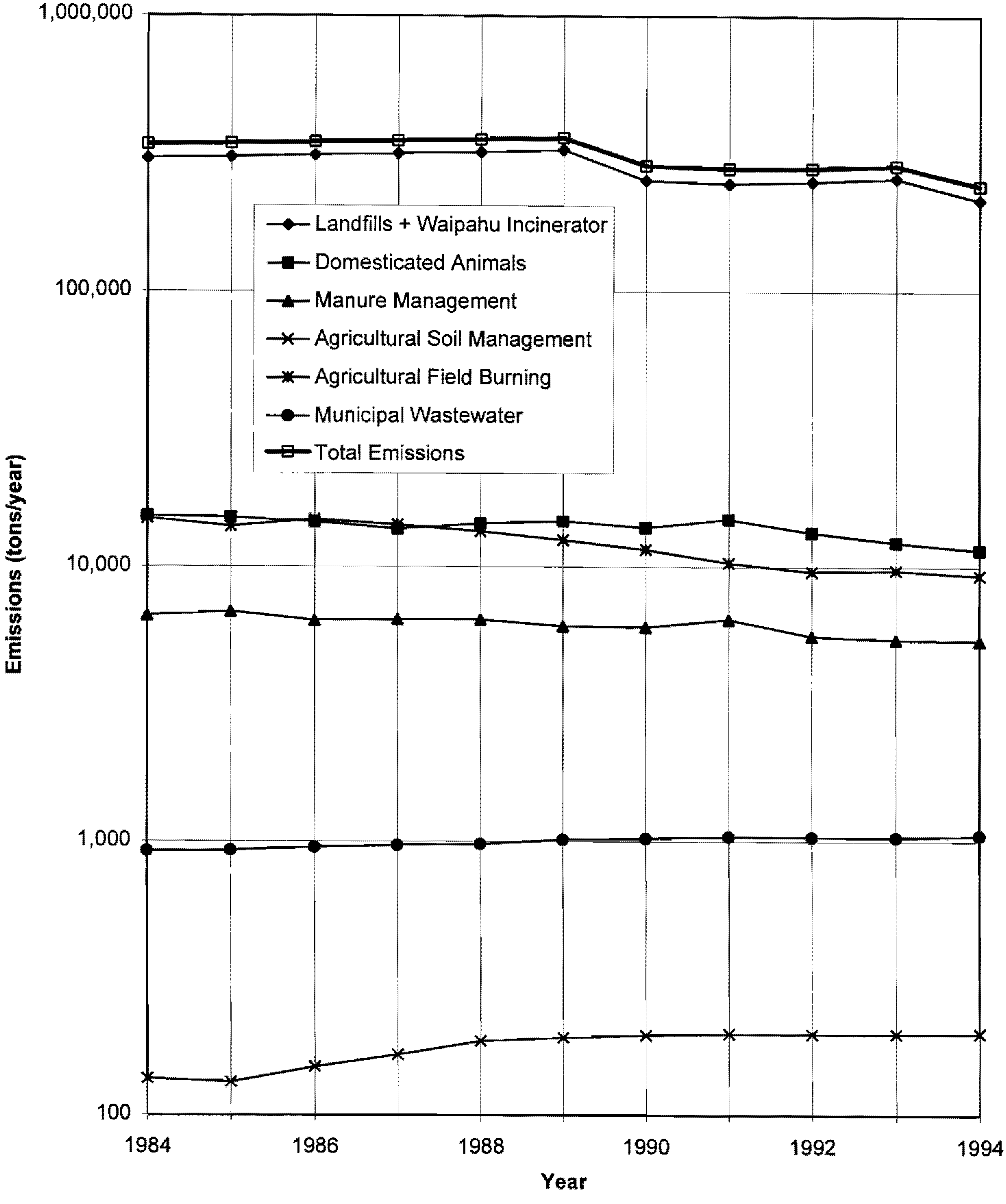


Figure 8.1a. Non-Energy Greenhouse Gas Emissions in Hawaii (1983 - 1994), Excluding Forestry Management and Land-Use Changes



from existing landfills. Emissions from field burning are expected to decline further in the future as sugar plantations cease operations, eventually either reaching a plateau due to economic stability in the sugar and pineapple industries or approximating zero with complete shutdown of these industries in Hawaii. It must be kept in mind, however, that this net decrease, predominantly the result of landfill practices, is in large part an artifact of the particular bookkeeping processes necessitated by the division of this project between energy and non-energy reports. Most of the emission sources which appear to have been eliminated are actually still there; they are just in another report.

Now we are in a position to consider all of the non-energy data together. When carbon *uptake* by forest management practices and abandoned agricultural lands is added to the 1990 and 1994 total *emissions* in Figures 8.1 and 8.1a, the total tonnage of greenhouse gases for all human practices in Hawaii is suddenly in the neighborhood of *negative* 630,000 tons per year--a *net uptake* of greenhouse gases by growing plants. The total data for 1990 and 1994 are summarized in Tables 8.1 and 8.2, respectively.

Table 8.1. 1990 Anthropogenic Non-Energy Greenhouse Gas Emissions in Hawaii

Land Use	CH_4 Emitted (tons CH_4)	CO Emitted (tons CO)	CO_2 Emissions (+) or Uptake (-) (tons CO_2)	N_2O Emitted (tons N_2O)	NO_X Emitted (tons NO_X)	Total Greenhouse Gas Emissions (t)
Landfills + Incinerators	48,860	27,101	176,953			252,914
Domestic Animals	13,804					13,804
Manure Management	2,515					6,013
Sugarcane Burning	543	10,857		8	140	11,548
Fertilizer				201		201
Changes in Biomass			-415,160			-415,160
Abandoned Lands			-455,970			-455,970
Wastewater	1,027					1,027
Total	66,749	37,958	-694,177	209	140	-585,623

Table 8.2. 1994 Anthropogenic Non-Energy Greenhouse Gas Emissions in Hawaii

Land Use	CH_4 Emitted (tons CH_4)	CO Emitted (tons CO)	CO_2 Emissions (+) or Uptake(-) (tons CO_2)	N_2O Emitted (tons N_2O)	NO_X Emitted (tons NO_X)	Total Greenhouse Gas Emissions (t)
Landfills + Incinerators	49,670	11,138	154,094			214,902
Domestic Animals	11,496					11,496
Manure Management	2,273					5,364
Sugarcane Burning	437	8,746		7	113	9,303
Fertilizer				199		199
Changes in Biomass			-415,160			-415,160
Abandoned Lands			-455,970			-455,970
Wastewater	1,052					1,052
Total	64,928	19,884	-717,036	205	113	-628,815

Taking into account the increase in biomass growing on abandoned agricultural lands between 1990 and 1994, the difference between these two years for total uptake is probably greater than the difference shown here; however, lack of annual data precludes any quantification of this change, as discussed in Section 5. This net uptake is also probably an overestimate of the actual value, for reasons explained in Sections 1 and 6 above. Nevertheless, it is obvious that agricultural practices overwhelm all other non-energy practices, leading to a significant net uptake of greenhouse gases in Hawaii at the present time.

But we are not finished yet; one more crucial consideration must be made. Although the net greenhouse gas emissions appear from Tables 8.1 and 8.2 to be negative--and would probably still be negative even with the corrections suggested in Sections 1 and 6--we must still take into account the relative radiative forcing (i.e., warming) capacities of the various greenhouse gases, as summarized for 1994 in Table 8.3:

Table 8.3. 1994 Anthropogenic Nonenergy Greenhouse Gas Emissions in Hawaii and Their Relative Warming Potentials

	Methane (CH_4)	Carbon Monoxide (CO)	CO_2 Emissions (+) or Uptake (-)	N_2O	NO_X	Total Emissions
Emissions (tons)	68,019	19,884	-717,036	205	113	-628,815
Radiative Forcing Index (EPA, 1995)	22	2.3	1	270	270	
Warming Potential (EPA, 1995)	1,496,418	45,733	-717,036	55,404	30,510	911,029
Radiative Forcing Index (Reilly, 1992)	58	2.3	1	206	206	
Warming Potential (Reilly, 1992)	3,945,102	45,733	-717,036	42,271	23,278	3,339,348

Different greenhouse gases have different radiative forcing indices (RFIs); in other words, different gases have different potentials for causing climate warming. Of all greenhouse gases, CO_2 has the smallest warming potential per ton; thus, the relative RFI scale is normalized with the potential of CO_2 counting as 1. According to the EPA, the warming potential of CO is then 2.3 times greater than that of CO_2 per ton, CH_4 is 22 times greater than CO_2, and N_2O is 205 times greater. Although these numbers are also those agreed upon by the Intergovernmental Panel on Climate Change (IPCC, 1992), they may be underestimates. For example, Reilly (1992) claims that the RFI of CH_4 is 58, while that of N_2O is 206. Regardless of who is right, the RFIs from all authors still place the net anthropogenic flux in Hawaii *back on the positive side of zero*. Using the EPA values, the total warming potential of Hawaii's greenhouse gas emissions in 1994 was a positive 911,000, while according to Reilly (1992) this potential was a *positive 3.34 million*, or the equivalent of 3.34 million tons of CO_2 emitted to the atmosphere (Table 8.3).

To place some perspective on the magnitude of Hawaii's non-energy greenhouse gas emissions, one can compare them with the national figures from a recent EPA report (U.S. EPA, 1994). Total methane emissions in 1990 were estimated at 27 million metric tons for the U.S. as a whole, of which Hawaii's non-energy sources contributed approximately 0.25%. Similarly in the case of NO_X, Hawaii's 140 tons from non-energy sources in 1990 amounted to just 0.04% of the estimated national total of 400,000 metric tons. Based on the magnitude of the emissions reported here and on the fact that several major sources are already or are projected to decline, one could conclude that greenhouse gas emissions from non-energy sources in Hawaii are of minor significance. However, this must be considered in the context of the rather substantial per capita use of oil in this isolated state, as will be addressed in the section of this study dealing with energy sources of greenhouse gas emissions.

It is hoped that the information reported will find a variety of uses. In particular, these results will be of use to environmental managers in Hawaii and elsewhere as the United States strives to meet its goals for greenhouse gas reduction over the next several years. For example, data on landfills and manure management systems may be used to help determine what types of waste management systems need to be constructed for future uses in the state. Decisions such as these would likely contribute to a reduction in greenhouse gas emissions for the state, and would add an incremental reduction to the emissions of the nation as a whole.

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Appendix A: Contact List for Hawaii Non-Energy Greenhouse Gas Inventory

Name & Organization	Source Categories
City & County of Honolulu Department of Refuse Collection and Disposal *Ms. Wilma Namunart* Chief Engineer (808) 527-5378	landfills
Department of Wastewater Management *Mr. Ross Tanimoto* (808) 527-6754	municipal wastewater
Hawaii Forest Industry Association *Mr. Michael Robinson* Former Director (808) 934-0502	forest management and land-use change
Hawaiian Sugar Planters Association *Ms. Stephanie Whalen* (808) 486-5310	burning of agricultural crop waste (sugarcane)
Honolulu Resource Recovery Venture (H-POWER) *Mr. Colin Jones* Information Coordinator (808) 692-1359	landfills
Nanakuli Landfill *Mr. Vernon Chock* Information Manager (808) 593-9191	landfill
State Department of Agriculture Statistics Service Branch *Mr. Donald Martin* (808) 586-9588	domesticated animals manure management agricultural soil management
State Department of Health Clean Air Branch *Mr. Robert Tam* (808) 586-4200	burning of agricultural crop waste (pineapple)

Solid and Hazardous Waste Branch *Mr. John Harder* Coordinator, Solid Waste Division (808) 586-4240	landfills
Solid and Hazardous Waste Branch *Ms. Carrie McCabe* (808) 586-4243	landfills
State Department of Land & Natural Resources Division of Forestry and Wildlife *Mr. Wayne Ching* (808) 587-0166	forest management and land-use changes
Division of Land Management *Mr. Sam Lemmo* (808) 587-0435	forest management and land-use changes
Division of Land Management *Mr. Al Jodar* (808) 587-0446	forest management and land-use changes
Waimanalo Gulch Landfill *Mr. Ray Rosetti* Technical Engineer (808) 668-2985	landfill

LANDFILLS

Workbook 5: Methane Emissions from Landfills in Hawaii

Includes Burning of MSW and Methane (for Methods 2 and 3)

Required Data:	Units	EPA Value	Actual Value
time period:	years	30	
per capita waste generation rate, or WGR (default):	lb/cap/yr	1801	1801
percent landfilled, or L (default; see sheet 2 for calculations):	%	70.0%	
growth rate:	%	1.44	
growth correction factor, or GCF (interpolated; see sheet 2):	%	81.7%	
fraction of WIP in large vs. small landfills:	%	86.0%	69.4%
No. of large landfills in the state:	each	5	5
Methane recovery or flaring:	T/yr	0	see Table 1.1
Energy generated from burning at 100% efficiency[2]:	kW/metric T	0.25	
Thermal efficiency of methane combustion (estimated)[3]:	%	25.0%	

Waste in place calculation:

WIP (Table B1) = 30 x P x WGR x L x GCF/2000[1]

where: WIP = waste in place (tons)

30 = 30 years

P = state de facto population

WGR = waste generation rate (lb/capita/yr)

L = percent waste landfilled

GCF = population growth correction factor

2000 = lb/T conversion factor

WIP (Table B2) uses *Oahu* WIP value for 1980, then adds total municipal solid waste (MSW) collected on Oahu per year. From 1990, amount diverted to H-POWER is also included.[3] Thus, WIP here is *only for Oahu*.

Small Landfill Emissions:

M_S = CF x WIP x 0.0077[1]

where: M_S = methane emissions (T/yr) from small landfills.

CF = conversion factor for tons of waste to ft^3/day

(0.27 for arid climate; 0.35 for non-arid)[1]

WIP = waste in place (tons)

0.0077 = conversion factor from ft^3/day to T/yr[1]

Large Landfill Emissions:

M_L = N x (419,000 + (CF x W_{avg}))[1]

where: M_L = methane emissions (T/yr) from large landfills.

N = number of large landfills

CF = conversion factor for tons of waste to ft^3/day

(0.16 for arid climate; 0.26 for non-arid)[1]

W_{avg} = average waste per large landfill (.86WIP/N)[1]

0.0077 = conversion factor from ft^3/day to T/yr[1]

References:

1. *State of Hawaii Data Book*, 1993-1994, Tables 1.4 and 5.29
2. U.S. Energy Information Administration, 1995. *Emissions of Greenhouse Gases in the United States, 1987-1994*. U.S. Department of Energy, Washington, D.C., p. 37.
3. Colin Jones, Honolulu H-POWER Plant, personal communication, 11/96.

LANDFILLS

Table B1: Landfill Methane Emissions for Hawaii, Method 1: Using Only State Population Data; Excludes Burning of Refuse and Methane

Year	State *De Facto* Population	Waste in Place (WIP) (tons)	Waste in Small Landfills (tons)	Waste in Large Landfills (tons)	Small Landfills Methane (M_S) (tons/year)	Large Landfills Methane (M_L) (tons/year)	All Landfills Methane (tons/year)	Adjusted for Methane Oxidation (tons/year)
1980	1,055,400	16,298,003	2,281,720	14,016,282	6,149	36,626	42,775	**38,498**
1981	1,062,600	16,409,189	2,297,286	14,111,902	6,191	36,744	42,935	**38,641**
1982	1,084,600	16,748,924	2,344,849	14,404,074	6,319	37,104	43,423	**39,081**
1983	1,109,200	17,128,809	2,398,033	14,730,776	6,463	37,506	43,969	**39,572**
1984	1,130,500	17,457,734	2,444,083	15,013,651	6,587	37,855	44,441	**39,997**
1985	1,137,800	17,570,464	2,459,865	15,110,599	6,629	37,974	44,603	**40,143**
1986	1,167,500	18,029,106	2,524,075	15,505,031	6,802	38,460	45,262	**40,736**
1987	1,186,500	18,322,513	2,565,152	15,757,361	6,913	38,771	45,684	**41,116**
1988	1,200,400	18,537,164	2,595,203	15,941,961	6,994	38,998	45,992	**41,393**
1989	1,245,600	19,235,164	2,692,923	16,542,241	7,257	39,738	46,995	**42,296**
1990	1,257,000	19,411,209	2,717,569	16,693,639	7,324	39,924	47,248	**42,523**
1991	1,274,800	19,686,085	2,756,052	16,930,033	7,428	40,216	47,643	**42,879**
1992	1,269,400	19,602,696	2,744,377	16,858,318	7,396	40,127	47,523	**42,771**
1993	1,265,100	19,536,293	2,735,081	16,801,212	7,371	40,057	47,428	**42,685**
1994	1,287,600	19,883,749	2,783,725	17,100,024	7,502	40,425	47,927	**43,134**
1995 (est.)	1,306,141	20,122,354	2,817,130	17,305,224	7,592	40,678	48,270	**43,443**

LANDFILLS

Table B2: Landfill Methane Emissions for Hawaii, Method 2: Accounting for Burning of Refuse and Methane, and Including 1985-1995 WIP Records from Oahu

Year	Oahu De Facto Population (July 1)	De Facto Population of Neighbor Islands	Calculated WIP on *Neighbor Is.* (tons)	WIP on *Oahu* If No Burning (tons)*	Amount Used for H-POWER (tons)	Amount to Waipahu Incinerator (tons)†	Oahu Waste In Place (WIP) (tons)■	Statewide WIP in Small Landfills (tons)	Statewide WIP in Large Landfills (tons)	Methane from Small Landfills (M_s) (T/yr)	Methane from Large Landfills (M_L) (T/yr)	CH_4 from All Oahu Landfills (tons/yr)	Adjusted for CH_4 Oxidation (tons/yr)	Methane Recovery (kilowatts of energy)**	Adjusted for CH_4 Recovery (tons/yr)
1980	823,400	232,000	3,582,466	12,714,665	0	156,429	12,558,236	4,939,055	11,201,647	13,311	29,932	43,243	38,918	0	38,918
1981*	824,700	237,900	3,673,571	13,414,665	0	156,429	13,101,808	5,133,266	11,642,113	13,834	30,475	44,309	39,878	0	39,878
1982*	837,600	247,000	3,814,091	14,124,665	0	156,429	13,655,379	5,345,658	12,123,812	14,407	31,068	45,475	40,927	0	40,927
1983*	846,300	262,900	4,059,613	14,844,665	0	156,429	14,218,950	5,593,240	12,685,323	15,074	31,760	46,834	42,150	0	42,150
1984*	852,300	278,200	4,295,870	15,574,665	0	156,429	14,792,522	5,841,048	13,247,344	15,742	32,452	48,194	43,374	0	43,374
1985	854,800	283,000	4,369,990	16,324,665	0	156,429	15,386,093	6,045,362	13,710,722	16,292	33,023	49,315	44,384	0	44,384
1986	871,000	296,500	4,578,453	17,074,665	0	156,429	15,979,665	6,290,784	14,267,334	16,954	33,709	50,663	45,596	0	45,596
1987	881,000	305,500	4,717,428	17,849,665	0	156,429	16,598,236	6,522,593	14,793,071	17,578	34,357	51,935	46,741	0	46,741
1988	888,200	312,200	4,820,887	18,627,665	0	156,429	17,219,808	6,744,452	15,296,242	18,176	34,976	53,153	47,837	0	47,837
1989	905,900	339,700	5,245,533	19,552,665	0	156,429	17,988,379	7,109,577	16,124,335	19,160	35,997	55,157	49,641	0	49,841
1990	912,100	344,900	5,325,829	20,507,665	0	78,214	18,865,165	7,402,444	16,788,550	19,950	36,815	56,765	51,088	8,912	48,860
1991	916,500	358,300	5,532,748	21,557,665	583,000	78,214	19,253,950	7,584,730	17,201,968	20,441	37,324	57,765	51,989	19,893	47,015
1992	911,700	357,700	5,523,483	22,584,543	614,000	78,214	19,588,614	7,684,302	17,427,795	20,709	37,603	58,312	52,481	16,984	48,235
1993	909,100	356,000	5,497,232	23,608,034	591,000	78,214	19,942,891	7,784,677	17,655,445	20,980	37,883	58,863	52,976	11,313	50,148
1994	920,500	367,100	5,668,634	24,610,174	589,000	32,143	20,323,888	7,953,712	18,038,810	21,435	36,355	59,791	53,812	16,566	49,870
1995***	933,755	372,386	5,750,259	25,583,428	633,000	0	20,684,142	8,082,807	18,331,594	21,783	38,716	60,499	54,449	16,566	50,308

*WIP values for Oahu are interpolated between 1980 (as calculated via EPA methods) and 1985 (when county records begin). Excludes construction/demolition waste and recycled materials.

†Annual incinerator tonnage calculated assuming 600 T/day, 5 days/week until 1990, then 300 T/day to mid-1994.

**Methane recovered at Kapa'a Landfill, Waimanalo, Oahu.

***Projected population data.

■Calculated by subtracting the sum of all tonnages burned in previous years (i.e., tonnages which did not go into landfills)

LANDFILLS

Table B3: Oahu Waste Generation Rate, Minus Construction & Demolition Waste and Recycled Material

Year	Oahu MSW/Yr (tons)[1]	Oahu *De Facto* Population	MSW Generation Rate (lb/capita/yr)	Percent Increase per Year	EPA Default Range, Upper Limit	Oahu MSW Rate / EPA Upper Limit	EPA Default Range, Mean	Oahu MSW Rate / EPA Mean
1983	626,835	846,300	**1,481**	xxx	1825	**0.81**	1,637.5	**0.90**
1984	611,386	852,300	**1,435**	**-3.2%**	1825	**0.79**	1,637.5	**0.88**
1985	615,574	854,800	**1,440**	**0.4%**	1825	**0.79**	1,637.5	**0.88**
1986	681,874	871,000	**1,566**	**8.7%**	1825	**0.86**	1,637.5	**0.96**
1987	678,392	881,000	**1,540**	**-1.6%**	1825	**0.84**	1,637.5	**0.94**
1988	739,820	888,200	**1,666**	**8.2%**	1825	**0.91**	1,637.5	**1.02**
1989	778,673	905,900	**1,719**	**3.2%**	1825	**0.94**	1,637.5	**1.05**
1990	825,058	912,100	**1,809**	**5.2%**	1825	**0.99**	1,637.5	**1.10**
1991	1,015,842	916,500	**2,217**	**22.5%**	1825	**1.21**	1,637.5	**1.35**
1992	1,049,647	911,700	**2,303**	**3.9%**	1825	**1.26**	1,637.5	**1.41**
1993	1,023,113	909,100	**2,251**	**-2.2%**	1825	**1.23**	1,637.5	**1.37**
1994	1,017,367	930,500	**2,187**	**-2.8%**	1825	**1.20**	1,637.5	**1.34**
Mean	**743,352**	**821,492**	**1,801**	**3.8%**		**0.99**		**1.10**

Reference:

1. *Hawaii State Data Book 1995,* Hawaii Department of Business Economic Development and Tourism, Tables 1-7 and 5-24.

LANDFILLS

Workbook 5: Calculations for Methane Emissions from Landfills

Table B4: Required Population Data Used in the Emissions Equations on Pages B1-B3.

Year	State *De Facto* Population	Percent Change per Year	State Resident Population	Oahu *De Facto* Population	*De Facto* / Resident Ratio	Data Source	Growth Rate (Percent)	Growth Correction Factor (GCF) (%)
1980	1,055,400		968,900	823,400	1.089	EPA Wkbk, Table 5-1	1.0%	86.5%
1981	1,062,600	0.68	980,100	824,700	1.084			
1982	1,084,600	2.07	997,500	837,600	1.087			
1983	1,109,200	2.27	1,018,400	846,300	1.089	Hawaii, calculated	**1.4%**	**81.7%**
1984	1,130,500	1.92	1,035,700	852,300	1.092			
1985	1,137,800	0.65	1,049,900	854,800	1.084			
1986	1,167,500	2.61	1,063,600	871,000	1.098	EPA Wkbk, Table 5-1	2.0%	75.4%
1987	1,186,500	1.63	1,082,000	881,000	1.097			
1988	1,200,400	1.17	1,098,200	888,200	1.093			
1989	1,245,600	3.77	1,108,229	905,900	1.126			
1990	1,257,000	0.92	1,112,900	912,100	1.129			
1991	1,274,800	1.42	1,134,900	916,500	1.124			
1992	1,269,400	-0.42	1,155,700	911,700	1.101			
1993	1,265,100	-0.34	1,171,600	909,100	1.080			
1994	1,287,600	1.78	1,187,528	920,500	1.084			
1995 (Est.)	1,306,141	1.44	1,204,629	933,755	1.084			
	Mean:	**1.44**			**1.10**			

Reference:

1. *Hawaii State Data Book 1995,* Hawaii Department of Business Economic Development and Tourism, Table 1-4.

LANDFILLS

Table B5: Landfill + Incinerator Emissions of CH_4, CO_2 and CO

Year	CH_4	CO_2	CO
1980	38,918	192,201	54,203
1981	39,878	194,839	54,203
1982	40,927	197,725	54,203
1983	42,150	201,089	54,203
1984	43,374	204,455	54,203
1985	44,384	207,231	54,203
1986	45,596	210,565	54,203
1987	46,741	213,714	54,203
1988	47,837	216,728	54,203
1989	49,641	221,689	54,203
1990	48,860	176,953	27,101
1991	47,015	171,880	27,101
1992	48,235	175,233	27,101
1993	50,148	180,495	27,101
1994	49,670	154,094	11,138
1995	50,308	138,346	0

DOMESTICATED ANIMALS

Workbook 6: Methane Emissions from Domesticated Animals

Swine

Required Data:	Units	Value
animal type:	type	**pigs**
animal population:*	head	variable
identify geographic region:	region	"west"
methane emission factor:	lbs/head/yr	3.3

* includes both boars and sows

Formula:

M = P x EF x CF
where: M = methane emissions (T/yr)
P = population of pigs (head)
EF = methane emission factor (lb/head/yr)
CF = convert lbs to tons (1/2000)

Resulting emissions

Year	No. of Pigs	Methane (T/yr)
1980	57,000	94
1981	55,000	91
1982	49,000	81
1983	48,000	79
1984	47,000	78
1985	55,000	91
1986	50,000	83
1987	47,000	78
1988	43,000	71
1989	39,000	64
1990	36,000	59
1991	34,000	56
1992	35,000	58
1993	33,000	54
1994	35,000	58

References:

1. *Statistics of Hawaiian Agriculture*, Hawaii Department of Agriculture, annual publications, 1987 - 1995.

DOMESTICATED ANIMALS

Workbook 6: Methane Emissions from Domesticated Animals

Sheep

Required Data:	Units	Value
animal type:	type	**sheep**
animal population:*	head	variable
identify geographic region:	region	"west"
methane emission factor:	lbs/head/yr	17.6

* includes all sheep and lambs

Formula:

M = P x EF x CF
where: M = methane emissions (T/yr)
P = population of sheep (head)
EF = methane emission factor (lb/head/yr)
CF = convert lbs to tons (1/2000)

References:

1. *Statistics of Hawaiian Agriculture*, Hawaii Department of Agriculture, annual publications, 1987 - 1995.

Resulting emissions

Year	No. of Sheep	Methane (T/yr)
1987	21,908	193
1988	n/a	n/a
1989	24,000	211
1990	27,000	238
1991	29,000	255
1992	21,000	185
1993	21,000	185
1994	23,000	202
1995	22,000	194

n/a - not available

DOMESTICATED ANIMALS

Workbook 6: Methane Emissions from Domesticated Animals

Cattle

Required Data:	Units	Value
animal type:	type	**cattle**
animal subtype:	subtype	variable
animal subtype population:	head	variable
identify geographic region:	region	"west"
methane emission factor for animal subtype::	lbs/head/yr	variable

Formulas:

$$M_a = P_a \times EF_a \times CF$$

where: M_a = methane emissions (T/yr) for animal subtype "a"
P_a = population of animal subtype "a"
EF_a = methane emission factor for subtype "a" (lb/head/yr)
CF = conversion factor for lbs to tons (1/2000)

$$M_{1-x} = M_{a1} + M_{a2} \ldots M_{ax}$$

where : M_{1-x} = total methane emissions for animal subtypes 1 thru x (see Table 2.1 or Page B11)
M_{a1} = annual methane emissions for animal subtype 1
M_{a2} = annual methane emissions for animal subtype 2
M_{ax} = annual methane emissions for animal subtype x

DOMESTICATED ANIMALS

Cattle Methane Emissions	Emission Factor (lbs CH_4/head/yr)	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Dairy Cattle													
Mature Cows[1]	262.5	12,000	12,000	11,000	12,000	12,000	12,000	11,000	11,000	10,000	11,000	11,000	11,000
Methane Emissions (T/yr)		1,575	1,575	1,444	1,575	1,575	1,575	1,444	1,444	1,313	1,444	1,444	1,444
Replacements 0-12 months[2]	134.6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Methane Emissions (T/yr)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Replacements 12-24 months[3]	45.5	18,000	19,000	20,000	17,000	19,000	18,000	6,000	9,000	5,000	4,000	4,000	4,000
Methane Emissions (T/yr)		410	432	455	387	432	410	137	205	114	91	91	91
Heifers 500 lbs and over[4]	45.5	2,323	2,400	2,391	2,550	2,562	2,323	2,174	2,418	1,724	1,483	1,112	837
Methane Emissions (T/yr)		53	55	54	58	58	53	49	55	39	34	25	19
Beef Cattle													
Mature Cows[5]	152	81000	83000	81000	68000	77000	81000	75,000	80,000	77,000	78,000	78,000	81,000
Methane Emissions (T/yr)		6,156	6,308	6,156	5,168	5,852	6,156	5,700	6,080	5,852	5,928	5,928	6,156
Replacements 0-12 months[2]	49.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Methane Emissions (T/yr)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Replacements 12-24 months[6]	142.7	20,000	16,000	14,000	20,000	15,000	14,000	16,000	18,000	15,000	12,000	11,000	16,000
Methane Emissions (T/yr)		1,427	1,142	999	1,427	1,070	999	1,142	1,284	1,070	856	785	1,142
Bulls[7]	220	7,000	6,000	6,000	5,000	5,000	5,000	5,000	6,000	5,000	5,000	5,000	5,000
Methane Emissions (T/yr)		770	660	660	550	550	550	550	660	550	550	550	550
Yearlings[8]	104.7	26,000	23,000	20,000	23,000	22,000	21,000	26,000	28,000	20,000	12,000	8,000	7,000
Methane Emissions (T/yr)		1,361	1,204	1,047	1,204	1,152	1,099	1,361	1,466	1,047	628	419	366
Weanlings[9]	51.7	55,000	56,000	52,000	45,000	48,000	57,000	49,000	42,000	53,000	44,000	39,000	44,000
Methane Emissions (T/yr)		1,422	1,448	1,344	1,163	1,241	1,473	1,267	1,086	1,370	1,137	1,008	1,137
Heifers 500 lbs and over[10]	142.7	15,677	16,600	17,609	14,450	16,438	15,677	14,826	17,582	13,276	10,517	7,888	6,163
Methane Emissions (T/yr)		1,119	1,184	1,256	1,031	1,173	1,119	1,058	1,255	947	750	563	440
Other Heifers 500 lbs and over[11]	94.1	18,000	19,000	20,000	17,000	19,000	18,000	17,000	20,000	15,000	12,000	9,000	7,000
		847	894	941	800	894	847	800	941	706	565	423	329
Total Methane (T/yr):		**15,177**	**14,939**	**14,395**	**13,401**	**14,035**	**14,319**	**13,545**	**14,513**	**13,046**	**12,021**	**11,274**	**11,712**

DOMESTICATED ANIMALS

Notes to Page B10:

1. Corresponds to "Milk cows that have calved" in Reference 1.
2. No state data were available for this EPA category.
3. Corresponds to "Heifers 500 pounds and over; Milk cow replacements" in Reference 1.
4. Non-EPA category set equivalent to "Replacements 12-24 months"; computed by multiplying ratio of Mature Milk Cows/{Total Mature Milk + Beef Cows} times "Other Heifers" in Reference 1.
5. Corresponds to "Beef cows that have calved" in Reference 1.
6. Corresponds to "Heifers 500 pounds and over; Beef cow replacements" in Reference 1.
7. "Bulls 500 lbs and over" in Reference 1.
8. "Steers 500 lbs and over" in Reference 1.
9. "Steers, heifers, and bulls under 500 lbs." in Reference 1.
10. Non-EPA category set equivalent to "Replacements 12-24 months"; computed by multiplying ratio of Mature Beef Cows/{Total Mature Milk + Beef Cows} times "Other Heifers" in Reference 1.
11. Non-EPA category from Reference 1; prorated between milk and beef cows and computed as "replacements".

References:

1. Statistics of Hawaiian Agriculture, Hawaii Department of Agriculture, annual publications, 1987 - 1995.

DOMESTICATED ANIMALS

Workbook 6: Methane Emissions from Domesticated Animals in Hawaii

Total Emissions per Animal Type

Year	Cattle	Swine	Sheep	Total	Cattle %
1980	n/a	94	n/a	n/a	n/a
1981	n/a	91	n/a	n/a	n/a
1982	n/a	81	n/a	n/a	n/a
1983	n/a	79	n/a	n/a	n/a
1984	15,177	78	n/a	15,254	n/a
1985	14,939	91	n/a	15,030	n/a
1986	14,395	83	n/a	14,477	n/a
1987	13,401	78	193	13,671	98.0%
1988	14,035	71	202	14,308	98.1%
1989	14,319	64	211	14,594	98.1%
1990	13,545	59	238	13,842	97.9%
1991	14,513	56	255	14,824	97.9%
1992	13,046	58	185	13,288	98.2%
1993	12,021	54	185	12,261	98.0%
1994	11,274	58	202	11,534	97.7%
1995	11,712	n/a	194	11,906	98.4%

n/a = data not available

References:

1. *Statistics of Hawaiian Agriculture*, Hawaii Department of Agriculture, annual publications, 1987-1995.

MANURE MANAGEMENT

Workbook 7: Methane Emissions from Manure Management Systems

Swine

Required Data:	**Units**	**Value**
animal type	type	**swine**
animal subtype:	subtype	**breeders**
animal type population:	head	variable
manure management system usage		
anaerobic lagoon:	%	32
dry lot:	%	7
pit storage <1 month:	%	17
pit storage >1 month:	%	36
other:	%	8
typical animal mass:	lbs/head	399
lbs volatile solids (VS) / lb animal mass	lbs VS/lb	3.1
max methane producing capacity factor	ft^3 CH_4/lb VS	5.77
methane conversion factors		
anaerobic lagoon:[1]	%	90
dry lot:[2]	%	2.4
pit storage <1 month:[3]	%	19.3
pit storage >1 month:[4]	%	38.6
other:[5]	%	10
methane density	lb CH_4/ft^3	0.0413
conversion factor	lb/T	2000

Notes:

1. Workbook, Table 7-12, Other Systems
2. Workbook, Table 7-12, Florida
3. Workbook, Table 7-12, Other Systems
4. Workbook, Table 7-12, Other Systems
   assumed 50% of liquid/slurry (Florida)
5. Workbook, Table 7-12, Other Systems
   assumed litter/deep pit stacks

Required Data:	**Units**	**Value**
animal type	type	**swine**
animal subtype:	subtype	**market**
animal type population:	head	variable
typical animal mass:	lbs/head	101
lbs volatile solids (VS) / lb animal mass	lbs VS/lb	3.1
max methane producing capacity factor	ft^3 CH_4/lb VS	7.53

References:

1. *Statistics of Hawaiian Agriculture*, Hawaii Department of Agriculture, annual publications, 1987 - 1994.

MANURE MANAGEMENT

Methane Emissions from Breeder Swine Manure Management in Hawaii

Year	Breeder Population (head)	Anaerobic Lagoon (T/yr)	Dry Lot (T/yr)	Pit Storage <1 month (T/yr)	Pit Storage >1 month (T/yr)	Other (T/yr)	Total (T/yr)
1983	7,000	297	1.7	33.8	143.4	8.3	**484**
1984	7,000	297	1.7	33.8	143.4	8.3	**484**
1985	9,000	382	2.2	43.5	184.3	10.6	**623**
1986	8,000	340	2.0	38.7	163.8	9.4	**553**
1987	7,000	297	1.7	33.8	143.4	8.3	**484**
1988	7,000	297	1.7	33.8	143.4	8.3	**484**
1989	6,000	255	1.5	29.0	122.9	7.1	**415**
1990	6,000	255	1.5	29.0	122.9	7.1	**415**
1991	6,000	255	1.5	29.0	122.9	7.1	**415**
1992	6,000	255	1.5	29.0	122.9	7.1	**415**
1993	6,000	255	1.5	29.0	122.9	7.1	**415**
1994	6,000	255	1.5	29.0	122.9	7.1	**415**

Methane Emissions from Market Swine Manure Management in Hawaii

Year	Market Population (head)	Anaerobic Lagoon (T/yr)	Dry Lot (T/yr)	Pit Storage <1 month (T/yr)	Pit Storage >1 month (T/yr)	Other (T/yr)	Total (T/yr)
1983	41,000	575	3.4	65.5	277.4	16.0	**937**
1984	40,000	561	3.3	63.9	270.6	15.6	**914**
1985	46,000	645	3.8	73.5	311.2	17.9	**1,051**
1986	42,000	589	3.4	67.1	284.1	16.4	**960**
1987	40,000	561	3.3	63.9	270.6	15.6	**914**
1988	36,000	505	2.9	57.5	243.6	14.0	**823**
1989	33,000	463	2.7	52.7	223.3	12.9	**754**
1990	30,000	421	2.5	47.9	203.0	11.7	**686**
1991	28,000	393	2.3	44.7	189.4	10.9	**640**
1992	29,000	407	2.4	46.3	196.2	11.3	**663**
1993	27,000	379	2.2	43.1	182.7	10.5	**617**
1994	29,000	407	2.4	46.3	196.2	11.3	**663**

Total Annual Methane Emissions from Swine Manure Management in Hawaii

Year	Total Swine Population (head)	Anaerobic Lagoon (T/yr)	Dry Lot (T/yr)	Pit Storage <1 month (T/yr)	Pit Storage >1 month (T/yr)	Other (T/yr)	Total (T/yr)
1983	48,000	872	5	99	421	24	**1,421**
1984	47,000	858	5	98	414	24	**1,399**
1985	55,000	1,027	6	117	496	29	**1,674**
1986	50,000	928	5	106	448	26	**1,513**
1987	47,000	858	5	98	414	24	**1,399**
1988	43,000	802	5	91	387	22	**1,307**
1989	39,000	717	4	82	346	20	**1,169**
1990	36,000	675	4	77	326	19	**1,101**
1991	34,000	647	4	74	312	18	**1,055**
1992	35,000	661	4	75	319	18	**1,078**
1993	33,000	633	4	72	306	18	**1,032**
1994	35,000	661	4	75	319	18	**1,078**

MANURE MANAGEMENT

Workbook 7: Methane Emissions from Manure Management Systems

Sheep

Required Data:	**Units**	**Value**
animal type	type	**sheep**
animal subtype:	subtype	**non-feedlot**
animal type population:	head	variable
manure management system usage		
pasture:[1]	%	92
other:[1]	%	8
typical animal mass:	lbs/head	154
lbs volatile solids (VS) / lb animal mass	lbs VS/lb	3.36
max methane producing capacity factor[2]	ft^3 CH_4/lb VS	3.04
methane conversion factors		
pasture, range & paddocks:[3]	%	1.5
other:[4]	%	2.4
methane density	lb CH_4/ft^3	0.0413
conversion factor	lb/T	2000

Notes:

1. Workbook Table 7-8, assume goats.
2. Workbook Table 7-11, not in feedlots
3. Workbook Table 7-12, Florida
4. Workbook Table 7-12, Florida, drylot

Required Data:	**Units**	**Value**
animal type	type	**sheep**
animal subtype:	subtype	**feedlot**
animal type population:	head	variable
typical animal mass:	lbs/head	154
lbs volatile solids (VS) / lb animal mass	lbs VS/lb	3.36
max methane producing capacity factor	ft^3 CH_4/lb VS	5.77

References:

1. *Statistics of Hawaiian Agriculture*, Hawaii Department of Agriculture, annual publications, 1987 - 1994.

MANURE MANAGEMENT

Methane Emissions from Non-Feedlot Sheep in Hawaii

Year	Sheep Population (head)	Volatile Solids (VS) Produced (lb/yr)	Methane Emissions from Pasture Sheep (t CH_4/yr)	Methane Emissions from Other Sheep (t CH_4/yr)	Total Methane Emissions from Sheep (t CH_4/yr)
1983	n/a	n/a	n/a	n/a	**n/a**
1984	n/a	n/a	n/a	n/a	**n/a**
1985	n/a	n/a	n/a	n/a	**n/a**
1986	n/a	n/a	n/a	n/a	**n/a**
1987	21,908	11,336,076	10	1.4	**11**
1988*	22,954	11,877,318	10	1.4	**12**
1989	24,000	12,418,560	11	1.5	**12**
1990	27,000	13,970,880	12	1.7	**14**
1991	29,000	15,005,760	13	1.8	**15**
1992	21,000	10,866,240	9	1.3	**11**
1993	21,000	10,866,240	9	1.3	**11**
1994	23,000	11,901,120	10	1.4	**12**
1995	22,000	11,383,680	10	1.4	**11**

* Missing data; interpolated
n/a = not available
No data are available for feedlot sheep

MANURE MANAGEMENT

Workbook 7: Methane Emissions from Manure Management Systems in Hawaii

Chickens: Layers

Required Data:	Units	Value
animal type	type	chicken
animal subtype:	subtype	layer
animal subtype population:	head	variable
manure management system		
anaerobic lagoon:	%	80
deep pit	%	10
other:	%	10
typical animal mass:	lbs/head	3.5
volatile solids (VS) per lb animal mass	lbs VS/lb	4.4
max methane producing capacity factor	ft^3 CH_4/lb VS	5.45
methane conversion factors		
anaerobic lagoon:[1]	%	90
deep pit:[2]	%	19.3
other:[3]	%	90
methane density	lb CH_4/ft^3	0.0413
conversion factor	lb/T	2000

Notes:

1. Workbook, Table 7-12, Other Systems
2. Workbook, Table 7-12, Other Systems assumed 50% of liquid/slurry (Florida)
3. Workbook, Table D7-4, assumed "Other" to be "Litter"

References:

1. *Statistics of Hawaiian Agriculture*, Hawaii Department of Agriculture, annual publications, 1987 - 1994.

Methane Emissions by Poultry Manure Management Systems

Year	Population (head)	Lagoon (T/yr)	Deep Pit (T/yr)	Other (T/yr)	Total (T/yr)
1983	855,000	1,067	29	133	**1,229**
1984	939,000	1,172	31	146	**1,350**
1985	983,000	1,227	33	153	**1,413**
1986	987,000	1,232	33	154	**1,419**
1987	975,000	1,217	33	152	**1,401**
1988	1,016,000	1,268	34	158	**1,460**
1989	989,000	1,234	33	154	**1,421**
1990	974,000	1,215	33	152	**1,400**
1991	966,000	1,205	32	151	**1,388**
1992	960,000	1,198	32	150	**1,380**
1993	861,000	1,074	29	134	**1,238**
1994	823,000	1,027	28	128	**1,183**

MANURE MANAGEMENT

Workbook 7: Methane Emissions from Manure Management Systems

Dairy Cattle

Required Data:	Units	Value
animal type	type	**dairy cattle**
animal subtype:	subtype	**cows**[1]
animal subtype population:	head	variable
manure management system usage		
anaerobic lagoon:	%	31
liquid slurry:	%	57
daily spread:	%	6
other:	%	6
typical animal mass:	lbs/head	1345
lbs volatile solids (VS) per lb animal mass	lbs VS/lb	3.65
max methane producing capacity factor	ft^3 CH_4/lb VS	3.84
methane conversion factors[2]		
anaerobic lagoon:	%	90
liquid slurry:	%	38.6
daily spread:	%	0.6
other (estimate):	%	10
methane density	lb CH_4/ft^3	0.0413
conversion factor	lb/T	2000

Methane Emissions from Cow Manure Management in Hawaii

Year	Population (head)	Anaerobic Lagoon (T/yr)	Liquid Slurry (T/yr)	Daily Spread (T/yr)	Other (T/yr)	Total Emissions (T/yr)
1983	n/a	n/a	n/a	n/a	n/a	**n/a**
1984	12,000	1,303	1027.8	1.7	28.0	**2,361**
1985	12,000	1,303	1027.8	1.7	28.0	**2,361**
1986	11,000	1,195	942.2	1.5	25.7	**2,164**
1987	12,000	1,303	1027.8	1.7	28.0	**2,361**
1988	12,000	1,303	1027.8	1.7	28.0	**2,361**
1989	12,000	1,303	1027.8	1.7	28.0	**2,361**
1990	11,000	1,195	942.2	1.5	25.7	**2,164**
1991	11,000	1,195	942.2	1.5	25.7	**2,164**
1992	10,000	1,086	856.5	1.4	23.4	**1,967**
1993	11,000	1,195	942.2	1.5	25.7	**2,164**
1994	11,000	1,195	942.2	1.5	25.7	**2,164**
1995	11,000	1,195	942.2	1.5	25.7	**2,164**

n/a = data not available

MANURE MANAGEMENT

Dairy Cattle (cont'd)

Dairy Heifers

Required Data:	Units	Value
animal type	type	**dairy cattle**
animal subtype:	subtype	**heifers**[3]
animal type population:	head	variable
typical animal mass:	lbs/head	903
lbs volatile solids (VS) per lb animal mass	lbs VS/lb	3.65
max. methane producing capacity factor	ft^3 CH_4/lb VS	3.84

Methane Emissions from Heifer Manure Management in Hawaii

Year	Population (head)	Anaerobic Lagoon (T/yr)	Liquid Slurry (T/yr)	Daily Spread (T/yr)	Other (T/yr)	Total Emissions (T/yr)
1983	n/a	n/a	n/a	n/a	n/a	**n/a**
1984	7,000	510	402.5	0.7	11.0	**925**
1985	6,000	438	345.0	0.6	9.4	**793**
1986	5,000	365	287.5	0.5	7.8	**660**
1987	5,000	365	287.5	0.5	7.8	**660**
1988	5,000	365	287.5	0.5	7.8	**660**
1989	4,000	292	230.0	0.4	6.3	**528**
1990	6,000	438	345.0	0.6	9.4	**793**
1991	9,000	656	517.5	0.8	14.1	**1,189**
1992	5,000	365	287.5	0.5	7.8	**660**
1993	4,000	292	230.0	0.4	6.3	**528**
1994	4,000	292	230.0	0.4	6.3	**528**
1995	4,000	292	230.0	0.4	6.3	**528**

n/a = data not available

All Other Heifers

Required Data:	Units	Value
animal type	type	**dairy cattle**
animal subtype:	subtype	**heifers**[4]
animal type population:	head	variable

All Other Heifers >500 lbs (head)	Year	Prorated Population (head)	Anaerobic Lagoon (T/yr)	Liquid Slurry (T/yr)	Daily Spread (T/yr)	Other (T/yr)	Total Emissions (T/yr)
n/a	1983	n/a	n/a	n/a	n/a	n/a	**n/a**
18,000	1984	2,323	169	133.6	0.2	3.6	**307**
19,000	1985	2,400	175	138.0	0.2	3.8	**317**
20,000	1986	2,391	174	137.5	0.2	3.7	**316**
17,000	1987	2,550	186	146.6	0.2	4.0	**337**
19,000	1988	2,562	187	147.3	0.2	4.0	**338**
18,000	1989	2,323	169	133.6	0.2	3.6	**307**
17,000	1990	2,174	159	125.0	0.2	3.4	**287**
20,000	1991	2,418	176	139.0	0.2	3.8	**319**
15,000	1992	1,724	126	99.1	0.2	2.7	**228**
12,000	1993	1,483	108	85.3	0.1	2.3	**196**
9,000	1994	1,112	81	64.0	0.1	1.7	**147**
7,000	1995	837	61	48.1	0.1	1.3	**111**

n/a = data not available

Notes:

1. Corresponds to "Milk cows that have calved" in Reference 1.
2. Workbook, Table 7-12, Florida
3. Corresponds to "Heifers 500 pounds and over; Milk cow replacements" in Reference 1.
4. Computed by multiplying ratio of Mature Milk Cows/(Total Mature Milk+ Beef Cows) times "Other Heifers" in Reference 1.

References:

1. *Statistics of Hawaiian Agriculture*, Hawaii Department of Agriculture, annual publications, 1987 - 1995.

MANURE MANAGEMENT

Methane Emissions from All Dairy Cattle Manure Management

Year	Dairy Cow Population (head)	Anaerobic Lagoon (T/yr)	Liquid Slurry (T/yr)	Daily Spread (T/yr)	Other (T/yr)	Total Emissions (T/yr)
1983	n/a	n/a	n/a	n/a	n/a	**n/a**
1984	21,323	1,983	1,564	3	43	**3,592**
1985	20,400	1,916	1,511	2	41	**3,470**
1986	18,391	1,734	1,367	2	37	**3,140**
1987	19,550	1,854	1,462	2	40	**3,358**
1988	19,562	1,855	1,463	2	40	**3,360**
1989	18,323	1,764	1,391	2	38	**3,196**
1990	19,174	1,791	1,412	2	39	**3,244**
1991	22,418	2,027	1,599	3	44	**3,672**
1992	16,724	1,576	1,243	2	34	**2,856**
1993	16,483	1,595	1,257	2	34	**2,888**
1994	16,112	1,567	1,236	2	34	**2,839**
1995	15,837	1,547	1,220	2	33	**2,803**

n/a = data not available

MANURE MANAGEMENT

Workbook 7: Methane Emissions from Manure Management Systems

Beef Cattle

Methane Emissions from Beef Cows

Required Data:	Units	Value
animal type	type	**beef cattle**
animal subtype:	subtype	**cows**[1]
animal subtype population:	head	variable
manure management system usage		
pasture:	%	90
drylot:	%	10
n/a	%	0
n/a	%	0
other:	%	0
typical animal mass:	lbs/head	1102
volatile solids (VS) per lb animal mass	lb VS/lb	2.6
max methane producing capacity factor		
Pasture:	ft^3 CH_4/lb VS	2.72
Feedlot:	ft^3 CH_4/lb VS	5.29
methane conversion factors		
pasture:[2]	%	1.5
dry lot:[2]	%	2.4
n/a	%	0
n/a	%	0
other:	%	0
methane density	lb CH_4/ft^3	0.0413
conversion factor	lb/T	2000

Methane Emissions from Beef Cow Manure Management

Year	Population Population (head)	Pasture Emissions (T/yr)	Dry Lot Emissions (T/yr)	Other Emissions (T/yr)	Total Emissions (T/yr)
1983	n/a	n/a	n/a	n/a	**n/a**
1984	81,000	176	60.8	0.0	**237**
1985	83,000	180	62.3	0.0	**243**
1986	81,000	176	60.8	0.0	**237**
1987	68,000	148	51.1	0.0	**199**
1988	77,000	167	57.8	0.0	**225**
1989	81,000	176	60.8	0.0	**237**
1990	75,000	163	56.3	0.0	**219**
1991	80,000	174	60.1	0.0	**234**
1992	77,000	167	57.8	0.0	**225**
1993	78,000	169	58.6	0.0	**228**
1994	78,000	169	58.6	0.0	**228**
1995	81,000	176	60.8	0.0	**237**

n/a = data not available

Methane Emissions from Beef Heifers

Required Data:		Units	Value
animal type		type	**beef cattle**
animal subtype:		subtype	**heifers**[3]
animal type population:		head	variable
typical animal mass:	pasture:	lbs/head	794
	feedlot:		915

For notes see p. B24

Methane Emissions from Beef Heifer Manure Management

Year	Population Population (head)	Pasture Emissions (T/yr)	Dry Lot Emissions (T/yr)	Other Emissions (T/yr)	Total Emissions (T/yr)
1983	n/a	n/a	n/a	n/a	**n/a**
1984	20,000	31	12.5	0.0	**44**
1985	16,000	25	10.0	0.0	**35**
1986	14,000	22	8.7	0.0	**31**
1987	20,000	31	12.5	0.0	**44**
1988	15,000	23	9.4	0.0	**33**
1989	14,000	22	8.7	0.0	**31**
1990	16,000	25	10.0	0.0	**35**
1991	18,000	28	11.2	0.0	**39**
1992	15,000	23	9.4	0.0	**33**
1993	12,000	19	7.5	0.0	**26**
1994	11,000	17	6.9	0.0	**24**
1995	16,000	25	10.0	0.0	**35**

n/a = data not available

MANURE MANAGEMENT

Beef Cattle (cont'd)

Methane Emissions from Other Heifers

Required Data:		Units	Value
animal type		type	**beef cattle**
animal subtype:		subtype	**heifers**[4]
animal type population:		head	variable
typical animal mass:	pasture:	lbs/head	794
	feedlot:		915

For notes see p. B24

Methane Emissions from Other Heifer Manure Management

All Other Heifers >500 lbs	Year	Prorated Population (head)	Pasture Emissions (T/yr)	Dry Lot Emissions (T/yr)	Other Emissions (T/yr)	Total Emissions (T/yr)
	1983	n/a	n/a	n/a	n/a	**n/a**
18,000	1984	15,677	28	11.2	0.0	**39**
19,000	1985	16,600	30	11.9	0.0	**42**
20,000	1986	17,609	31	12.5	0.0	**44**
17,000	1987	14,450	27	10.6	0.0	**37**
19,000	1988	16,438	30	11.9	0.0	**42**
18,000	1989	15,677	28	11.2	0.0	**39**
17,000	1990	14,826	27	10.6	0.0	**37**
20,000	1991	17,582	31	12.5	0.0	**44**
15,000	1992	13,276	23	9.4	0.0	**33**
12,000	1993	10,517	19	7.5	0.0	**26**
9,000	1994	7,888	14	5.6	0.0	**20**
7,000	1995	6,163	11	4.4	0.0	**15**

n/a = data not available

Methane Emissions from Beef Steers

Required Data:		Units	Value
animal type		type	**beef cattle**
animal subtype:		subtype	**steers**[5]
animal type population:		head	variable
typical animal mass:	pasture:	lbs/head	794
	feedlot:		915

For notes see p. B24

Methane Emissions from Beef Steer Manure Management

Year	Population (head)	Pasture Emissions (T/yr)	Dry Lot Emissions (T/yr)	Other Emissions (T/yr)	Total Emissions (T/yr)
1983	0	0	0.0	0.0	**0**
1984	26,000	41	16.2	0.0	**57**
1985	23,000	36	14.3	0.0	**50**
1986	20,000	31	12.5	0.0	**44**
1987	23,000	36	14.3	0.0	**50**
1988	22,000	34	13.7	0.0	**48**
1989	21,000	33	13.1	0.0	**46**
1990	26,000	41	16.2	0.0	**57**
1991	28,000	44	17.5	0.0	**61**
1992	20,000	31	12.5	0.0	**44**
1993	12,000	19	7.5	0.0	**26**
1994	8,000	13	5.0	0.0	**18**
1995	7,000	11	4.4	0.0	**15**

n/a = data not available

MANURE MANAGEMENT

Beef Cattle (cont'd)

Methane Emissions from Beef Bulls

Required Data:	Units	Value
animal type	type	**beef cattle**
animal subtype:	subtype	**bulls**[6]
animal type population:	head	variable
typical animal mass:	lbs/head	1587

For notes see p. B24

Methane Emissions from Beef Bull Manure Management

Year	Population (head)	Pasture Emissions (T/yr)	Dry Lot Emissions (T/yr)	Other Emissions (T/yr)	Total Emissions (T/yr)
1983	n/a	n/a	n/a	n/a	**n/a**
1984	7,000	22	7.6	0.0	**29**
1985	6,000	19	6.5	0.0	**25**
1986	6,000	19	6.5	0.0	**25**
1987	5,000	16	5.4	0.0	**21**
1988	5,000	16	5.4	0.0	**21**
1989	5,000	16	5.4	0.0	**21**
1990	5,000	16	5.4	0.0	**21**
1991	6,000	19	6.5	0.0	**25**
1992	5,000	16	5.4	0.0	**21**
1993	5,000	16	5.4	0.0	**21**
1994	5,000	16	5.4	0.0	**21**
1995	5,000	16	5.4	0.0	**21**

n/a = data not available

Methane Emissions from Beef Calves

Required Data:	Units	Value
animal type	type	**beef cattle**
animal subtype:	subtype	**calves**[7]
animal type population:	head	variable
typical animal mass:	lbs/head	397

For notes see p. B24

Methane Emissions from Beef Calf Manure Management

Year	Population (head)	Pasture Emissions (T/yr)	Dry Lot Emissions (T/yr)	Other Emissions (T/yr)	Total Emissions (T/yr)
1983	n/a	n/a	n/a	n/a	**n/a**
1984	55,000	43	14.9	0.0	**58**
1985	56,000	44	15.2	0.0	**59**
1986	52,000	41	14.1	0.0	**55**
1987	45,000	35	12.2	0.0	**47**
1988	48,000	38	13.0	0.0	**51**
1989	57,000	45	15.4	0.0	**60**
1990	49,000	38	13.3	0.0	**52**
1991	43,000	34	11.6	0.0	**45**
1992	53,000	41	14.3	0.0	**56**
1993	44,000	34	11.9	0.0	**46**
1994	39,000	31	10.6	0.0	**41**
1995	44,000	34	11.9	0.0	**46**

n/a = data not available

MANURE MANAGEMENT

Beef Cattle (cont'd)

Notes:

1. Corresponds to "Beef cows that have calved" in Reference 1.
2. Workbook, Table 7-12, Florida
3. Corresponds to "Heifers 500 pounds and over; Beef cow replacements" in Reference 1.
4. Computed by multiplying ratio of Mature Beef Cows/(Total Mature Milk+ Beef Cows) times "Other Heifers > 500 lbs" in Reference 1.
5. Corresponds to "Steers 500 lbs and over" in Reference 1.
6. Corresponds to "Bulls 500 lbs and over" in Reference 1.
7. Corresponds to "Steers, heifers, and bulls under 500 lbs" in Reference 1.

References:

1. *Statistics of Hawaiian Agriculture*, Hawaii Department of Agriculture, annual publications, 1987 - 1995.

Total Methane Emissions from Beef Cattle Manure Management

Year	Population Population (head)	Pasture Emissions (T/yr)	Dry Lot Emissions (T/yr)	Other Emissions (T/yr)	Total Emissions (T/yr)
1983	n/a	n/a	n/a	n/a	n/a
1984	204,677	341	123	0	281
1985	200,600	334	120	0	278
1986	190,609	320	115	0	267
1987	175,450	293	106	0	243
1988	183,438	308	111	0	258
1989	193,677	319	115	0	267
1990	185,826	309	112	0	254
1991	192,582	330	119	0	273
1992	183,276	303	109	0	258
1993	161,517	276	98	0	254
1994	148,888	259	92	0	252
1995	159,163	273	97	0	272

n/a = data not available

MANURE MANAGEMENT

Total Methane Emissions from Manure Management in Hawaii, by Animal Type (tons/yr)

Year	Swine	Sheep	Poultry	Dairy Cattle	Beef Cattle	Total Emissions
1983	1,421	*n/a*	1,229	*n/a*	*n/a*	**2,650**
1984	1,399	*n/a*	1,350	103	281	**3,132**
1985	1,674	*n/a*	1,413	99	278	**3,464**
1986	1,513	*n/a*	1,419	89	267	**3,288**
1987	1,399	11	1,401	95	243	**3,149**
1988	1,307	12	1,460	95	258	**3,132**
1989	1,169	12	1,421	91	267	**2,961**
1990	1,101	14	1,400	93	254	**2,862**
1991	1,055	15	1,388	105	273	**2,837**
1992	1,078	11	1,380	83	258	**2,809**
1993	1,032	11	1,238	85	254	**2,619**
1994	1,078	12	1,183	85	252	**2,609**
1995	*n/a*	11	*n/a*	85	272	**368**

n/a = data not available

AGRICULTURAL SOIL MANAGEMENT

Workbook 9: Emissions from Agricultural Soil Management

Required Data:	Units	Value
annual fertilizer consumption by type (3-year average)	T/yr	variable
OR total tons of nitrogen consumed over 3-year period	T/yr	variable
nitrogen content:		
ammonium sulfate	%	21
ammonium nitrate	%	33.5
sodium nitrate	%	16
urea	%	46
anhydrous ammonia	%	82
aqua ammonia	%	25
other nitrogen solutions	%	49
conversion factor (tons N_20 as N per ton N applied)	T N_20-N/T N	0.0117
conversion factor (N_20 as N to N_20) 44/28 =		1.57

Formula:

$$E_f = F_f \times N\% \times CF_1 \times CF_2$$

where: E_f = annual N_2O emissions of fertilizer "f"

F_f = annual tons of fertilizer "f" applied

N% = percent of nitrogen in fertilizer "f"

CF_1 = convert tons N applied to tons N_2O as N = 0.0117

CF_2 = convert tons N_2O as N to tons N_2O = 1.57

References:

1. *Fertilizer Summary*, Tennessee Valley Authority annual publications, 1986 - 1992

AGRICULTURAL SOIL MANAGEMENT

Workbook 9: Emissions from Agricultural Soil Management

Fertilizer	Nitrogen Applied (T/yr)										----------Estimated----------		
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Ammonium Sulfate	776	482	463	426	884	902	911	965	956	946	956	956	956
Ammonium Nitrate	0	1	1	0	0	0	0	0	0	0	0	0	0
Sodium Nitrate	3	2	0	0	0	0	0	0	0	0	0	0	0
Urea	3685	2723	2353	2165	2416	2464	2489	2638	2612	2586	2612	2612	2612
Anhydrous Ammonia	0	16	0	0	0	0	0	0	0	0	0	0	0
Aqua Ammonia	1401	623	757	696	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Other - Nitrogen Solutions	11086	11128	12624	11614	17758	18113	18294	19392	19198	19006	19199	19199	19199

n/a = data not available

Fertilizer	N_2O Emissions (T/yr)										----------Estimated----------		
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Ammonium Sulfate	3.0	1.9	1.8	1.6	3.4	3.5	3.5	3.7	3.7	3.7	3.7	3.7	3.7
Urea	31.2	23.0	19.9	18.3	20.4	20.8	21.1	22.3	22.1	21.9	22.1	22.1	22.1
Aqua Ammonia	6.4	2.9	3.5	3.2	0	0	0	0	0	0	0	0	0
Other - Nitrogen Solutions	99.9	100.3	113.7	104.6	160.0	163.2	164.8	174.7	173.0	171.2	173.0	173.0	173.0
Total:	140.5	128.0	138.9	127.8	183.8	187.5	189.4	200.7	198.7	196.8	198.7	198.7	198.7
3-year averages:	-	135.8	131.6	150.2	166.4	186.9	192.5	196.3	198.7	198.1	198.1	198.7	-

Fertilizer	N_2O Emissions: 3-Year Averages (T/yr)										
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Ammonium Sulfate	2.2	1.8	2.3	2.8	3.5	3.6	3.6	3.7	3.7	3.7	3.7
Urea	24.7	20.4	19.5	19.9	20.8	21.4	21.8	22.1	22.0	22.0	22.1
Aqua Ammonia	4.3	3.2	2.2	1.1	0	0	0	0	0	0	0
Other Nitrogen Solutions	104.6	106.2	126.1	142.6	162.7	167.6	170.8	173.0	172.4	172.4	173.0
Total	135.8	131.6	150.2	166.4	186.9	192.5	196.3	198.7	198.1	198.1	198.7

FOREST MANAGEMENT AND LAND USE CHANGES

Workbook 10: Greenhouse Gas Emissions from Forest Management & Land-Use Changes

Biomass Change from Forestry Management

Required Data:	Units	Value
tree type	type	variable
area of managed forest[1]	acres	variable
annual growth rate[2]	tons dm/yr	variable
carbon fraction of dry matter	tons C/tons dm	0.5
annual biomass harvested	tons dm/yr	0

Notes:

1: State of Hawaii Data Book 1993 - 94, Table 1.4
2: EPA State Workbook (Revised 10/96), Table 10-1.
dm = dry matter

FOREST MANAGEMENT AND LAND-USE CHANGES

Workbook 10: Carbon Dioxide Emissions from Forest Management and Land-use Changes

Biomass Change from Abandoned Agricultural Lands

Required Data:	Units	Value
climate type	type	moist
20-year total area of abandoned land[1]	acres	59,500
annual rate of aboveground biomass growth[2]	tons dm/acre/yr	3.6
carbon fraction of aboveground biomass	tons C/tons dm	0.5
annual uptake of carbon by soils	tons C/acre/yr	0.29
conversion factor from C to CO_2	none	44/12

Notes:

1: State of Hawaii Data Book 1993 - 94, Table 1.5

2: EPA State Workbook (Revised 10/96), Table 10-5.

dm = dry matter

BURNING OF AGRICULTURAL CROP WASTE

Workbook 11: Greenhouse Gas Emissions From Burning of Agricultural Crop Wastes

Required Data:	Units	Value
crop type	type	**sugarcane**
annual production	lbs	variable
residue/crop ratio	n/a	0.8
fraction residue burned	n/a	0.1
fraction dry matter	n/a	0.9
"fraction burned"	n/a	0.93
fraction dry matter carbon content	n/a	0.4695
fraction carbon oxidized	n/a	0.88
nitrogen/carbon ratio	n/a	0.0064
CH_4 emissions ratio	n/a	0.003
CO emissions ratio	n/a	0.06
N_2O emissions ratio	n/a	0.007
NO_x emissions ratio	n/a	0.121
conversion from lbs to tons	lbs/ton	2000

BURNING OF AGRICULTURAL CROP WASTE

Workbook 11: Greenhouse Gas Emissions From Burning of Agricultural Crop Wastes

Formulas:

DM = CP x 0.8 x 0.10 x 0.93

where: DM = dry matter burned (lbs/yr)
CP = crop production (lbs)
0.8 = residue/crop ratio
0.10 = residue burned
0.90 = dry matter
0.93 = fraction burned

TCO = DM x 0.4695 x 0.88

where: TCO = total carbon oxidized (lbs CO_2-C)
DM = dry matter burned (lbs/yr)
0.4695 = carbon content
0.88 = fraction oxidized

TNR = TCO x 0.0064

where: TNR = total nitrogen released (lbs N)
TCO = total carbon oxidized (lbs CO_2-C)
0.0064 = nitrogen/carbon ratio

CH_4 = TCO x 0.003 / 2000

where: CH_4 = methane emissions (tons CH_4-C)
TCO = total carbon oxidized (lbs CO_2-C)
0.003 = CH_4 emissions ratio

CO = TCO x 0.06 / 2000

where: CO = carbon monoxide emissions (tons CO-C)
TCO = total carbon oxidized (lbs CO_2-C)
0.003 = CH_4 emissions ratio

N_2O = TNR x 0.007 / 2000

where: N_2O = N_2O emissions (tons N_2O-N)
TNR = total nitrogen released (lbs N)
0.007 = N_2O emissions ratio

NOx = TNR x 0.121 / 2000

where: NOx = NOx emissions (tons NOx-N)
TNR = total nitrogen released (lbs N)
0.121 = NOx emissions ratio

References:

1. *Hawaiian Sugar Manual*, 1995, Hawaiian Sugar Planters Association,

BURNING OF AGRICULTURAL CROP WASTE

Greenhouse Gas Emissions from Sugarcane Burning in Hawaii

Year	Production (T/yr)	Dry Matter (tons)	Total Carbon Oxidized (tons)	Total Nitrogen Released (tons)	CH_4 Emissions (tons)	CO Emissions (tons)	N_2O Emissions (tons)	NOx Emissions (tons)	Total
1980	9,214,136	616,979	254,911	1,631	765	15,295	11.4	197	**16,268**
1981	8,831,477	591,356	244,325	1,564	733	14,659	10.9	189	**15,593**
1982	8,807,998	589,784	243,675	1,560	731	14,620	10.9	189	**15,551**
1983	8,926,358	597,709	246,949	1,580	741	14,817	11.1	191	**15,760**
1984	8,453,721	566,061	233,874	1,497	702	14,032	10.5	181	**14,926**
1985	7,916,459	530,086	219,010	1,402	657	13,141	9.8	170	**13,977**
1986	8,379,463	561,089	231,819	1,484	695	13,909	10.4	180	**14,795**
1987	8,012,899	536,544	221,678	1,419	665	13,301	9.9	172	**14,147**
1988	7,602,414	509,058	210,322	1,346	631	12,619	9.4	163	**13,423**
1989	7,078,479	473,975	195,827	1,253	587	11,750	8.8	152	**12,498**
1990	6,540,925	437,980	180,956	1,158	543	10,857	8.1	140	**11,548**
1991	5,852,868	391,908	161,921	1,036	486	9,715	7.3	125	**10,334**
1992	5,432,286	363,746	150,285	962	451	9,017	6.7	116	**9,591**
1993	5,506,072	368,687	152,327	975	457	9,140	6.8	118	**9,721**
1994	5,268,859	352,803	145,764	933	437	8,746	6.5	113	**9,303**

MUNICIPAL WASTEWATER

Workbook 12: Methane Emissions From Municipal Wastewater In Hawaii

Required Data:	Units	Value	
BOD_5 generation rate	lbs/capita/day	0.1356	(default)
state population	capita	variable	
fraction of total wastewater treated anaerobically	n/a	0.15	(default)
amount of methane (CH_4) recovered	lbs	0	
methane emission factor	lbs CH_4/lb BOD_5	0.22	

Formula:

E = 365 x B x P x 0.15 x 0.22 / 2000

where: E = annual CH_4 emissions (T/yr)

365 = days/yr
B = BOD_5 generation rate (lb/capita/day)
P = de facto population
0.15 = fraction of total wastewater treated anaerobically
0.22 = methane emission factor
2000 = conversion from lbs to tons

Reference:

1. *State of Hawaii Data Book, 1993 - 1995,* Hawaii Department of Business Economic Development and Tourism (DBEDT), Table 1.4

MUNICIPAL WASTEWATER

Workbook 12: Methane Emissions From Municipal Wastewater in Hawaii

Year	*De Facto* Population	Methane Recovered (tons CH_4/yr)	BOD_5 Generation Rate (lbs/capita/ day)	Fraction of Wastewater Treated Anaerobically (lbs/capita/ day)	Methane Emission Factor (lbs CH_4/lb BOD_5)	Methane Emissions (tons CH_4/yr)
1980	1,055,400	0	0.1356	0.15	0.22	**862**
1981	1,062,600	0	0.1356	0.15	0.22	**868**
1982	1,084,600	0	0.1356	0.15	0.22	**886**
1983	1,109,200	0	0.1356	0.15	0.22	**906**
1984	1,130,500	0	0.1356	0.15	0.22	**923**
1985	1,137,800	0	0.1356	0.15	0.22	**929**
1986	1,167,500	0	0.1356	0.15	0.22	**953**
1987	1,186,500	0	0.1356	0.15	0.22	**969**
1988	1,200,400	0	0.1356	0.15	0.22	**980**
1989	1,245,600	0	0.1356	0.15	0.22	**1,017**
1990	1,257,000	0	0.1356	0.15	0.22	**1,027**
1991	1,274,800	0	0.1356	0.15	0.22	**1,041**
1992	1,269,400	0	0.1356	0.15	0.22	**1,037**
1993	1,265,100	0	0.1356	0.15	0.22	**1,033**
1994	1,287,600	0	0.1356	0.15	0.22	**1,052**

TOTALS

Total Greenhouse Gas Emissions for the State of Hawaii, by Source Type (tons/yr); Does Not Include Land-Use Changes

Year	Landfills +Waipahu Incinerator	Domesticated Animals	Manure Management	Agricultural Soil Management	Agricultural Field Burning	Municipal Wastewater	Total Emissions
1984	302,032	15,254	3,132	135.8	15,760	923	**337,237**
1985	305,818	15,030	3,464	131.6	14,926	929	**340,298**
1986	310,364	14,477	3,288	150.2	13,977	953	**343,210**
1987	314,658	13,671	3,149	166.4	14,795	969	**347,408**
1988	318,768	14,308	3,132	186.9	14,147	980	**351,523**
1989	325,533	14,594	2,961	192.5	13,423	1,017	**357,721**
1990	252,914	13,842	2,862	196.3	12,498	1,027	**283,338**
1991	245,996	14,824	2,837	198.7	11,548	1,042	**276,446**
1992	250,569	13,288	2,809	198.1	10,334	1,039	**278,237**
1993	257,744	12,261	2,619	198.1	9,591	1,038	**283,452**
1994	214,902	11,534	2,609	198.7	9,721	1,052	**240,018**

Selected Hawaii Greenhouse Gas Emissions vs. Total U.S. Emissions (tons/yr)

	1990		1993	
State	*Hawaii*	*U.S.*[1]	*Hawaii*	*U.S.*
CH_4 Emissions	270,644	27,000,000	273,663	n/a
% of U.S. Emissions	0.91%		n/a	
N_2O Emissions	166	400,000	196	n/a
% of U.S. Emissions	0.04%		n/a	

Notes:

1. U.S. EPA, 1994. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1993*.
EPA Document No. 230-R-94-014, Office of Policy, Planning and Evaluation, Washington, D.C.