Attachment 2

Appendix D

Emission Inventory Methodology
Agricultural Irrigation Pumps - Diesel

(Updated August 2006)

EMISSION INVENTORY SOURCE CATEGORY
Fuel Combustion / Food and Agricultural Processing

EMISSION INVENTORY CODES (CES CODES) AND DESCRIPTION
052-042-1200-0000 Agricultural Irrigation I.C. Engines – Diesel/Distillate

INTRODUCTION

Diesel-fueled agricultural irrigation pump engines are a significant source of emissions in California, especially during the April through October growing season. The Air Resources Board (ARB) estimates that in 2005, diesel-powered agricultural irrigation pump engines were the 8th largest source of nitrogen oxides and the 21st largest source of fine particulate matter in the San Joaquin Valley. For the Sacramento Valley, irrigation pump engines are the 10th largest source of nitrogen oxides and the 22nd largest source of fine particulate matter.

Irrigation pumps are used to pump water from either wells or supply canals to the field. They are also used for a number of other purposes, such as discharging water from tailwater pits, ponds, lakes, etc. Booster pumps are used to increase the water pressure for water that has already been removed from the source by another pump.

Pump engines can be either stationary or portable. A stationary pump engine is fixed in place; a portable pump engine is one that is mounted on a mobile piece of equipment or on skids and is moved from place to place depending on the need. Both well pumps and booster pump engines can be either portable or stationary.

METHODS AND SOURCES

Emissions from the irrigation pump engines are estimated by multiplying the number of pump engines by their horsepower rating, load factor, annual operating hours, and emission factor.

The basic equation for calculating the emission of agricultural irrigation pump engines is:

$$E_y = \Sigma\, Pop * EF * Hrs * HP * \%Load$$

where

E = *pollutant specific emissions (tons per year of NOx, HC, CO_2, and diesel PM)*
y = *inventory year*
Pop = *population of diesel agricultural irrigation pump engines*
EF = *emission factor (units of g/bhp-hr)*
Hrs = *average annual use in hours*
HP = *average brake horsepower of engine*
%Load = *average engine load factor*

Population

The 2003 US Department of Agriculture Farm and Ranch Irrigation Survey (FRIS) (reference 1) stated that there are 83,216 electric or fuel-powered irrigation pumps in California, of which 12,535 (or approximately 14.1 percent) are powered with diesel engines. Assuming that well and booster pump engines are powered by the various fuels at the same relative amounts as the general pump engine population, 8,721 of the 12,535 diesel engine pumps are well pumps and the remaining 3,814 pumps are booster pumps, performing such tasks as discharging water from tailwater pits.

For inventory purposes, it is necessary to allocate pump engine populations among the various counties, air basins, and districts of California. This is normally done by one of two methods: the bottom-up method uses databases of individual pump locations to determine where in the state pumps are located; and the top-down method takes a statewide total and uses a surrogate (such as the amount of irrigated acres in a given area) to estimate the pump population in that area. The bottom-up method is usually preferred, but requires extensive databases that are often not available. The top-down method is less specific, but is a more straightforward calculation.

Because of the limited amount of data on individual pump locations, this methodology uses a hybrid approach and uses both bottom-up and top-down methods to allocate pumps (and therefore pump engines) statewide. To the extent possible, district data was used to allocate the number of stationary and portable pump engines to specific areas of the state. Where district data was not available or lacking in specificity, top-down estimates were made of pump engine locations.

Bottom-Up Inventories Used

A database of well and lift pump engines in the Sacramento Ozone Non Attainment area (reference 2) shows 1,032 pump engines in that area; Sacramento Metropolitan AQMD staff estimate an additional 132 pump engines (both stationary and portable) that were not surveyed. The Sacramento Non-Attainment area includes all of Sacramento, Solano, Yolo, and Yuba Counties, and portions of Placer and Sutter Counties. In total, it is estimated that there are 1,164 diesel irrigation pump engines in the Sacramento Non-attainment area. The 132 additional pump engines estimated by Sacramento Metro AQMD staff were assigned to counties within the non-attainment area using the top-down methods described below.

The South Coast AQMD surveyed farm operators in their district in January 2005 and again in 2006 to determine the number and size of irrigation pump engines. Results of these surveys demonstrated that that there are 12 portable and 6 stationary diesel pump engines in the South Coast Air Basin (reference 3). For the purposes of this inventory, the portable engines were assumed to be booster pump engines and the stationary pump engines were assumed to be on well pumps. Because the survey did not include information on the specific county engines were located in, they were attributed to the counties in the South Coast Air Basin by top-down methods as described below.

Top-Down Inventories Used

Top-down methods were used to allocate pump engine populations to all remaining areas of the state. Surrogates to allocate well pump engines and booster pump engine populations were developed using 2000 U.S. Geological Survey (USGS) data on the amount of ground and surface water withdrawals (reference 4). Ground water withdrawals were used to allocate well pump engine populations. USGS data on the amount of surface water withdrawals for agriculture was used to allocate booster pump engines by county. Because some surface water irrigation is done by gravity and thus does not require any pumping of any kind (for example, in rice fields), the amount of surface water withdrawals was multiplied by the ratio of sprinkler and drip irrigation acreage to total acreage irrigated by sprinkler, drip, and surface irrigation to estimate the potential gravity irrigation for a given county. Data on irrigation acreage by type was obtained from USGS (reference 4). Although surface irrigation can be accomplished by either gravity or pumping, no comprehensive regional data was available to estimate the proportion of surface irrigation that is pumped.

For counties split between air basins or non-attainment areas, GIS data on irrigated acreage developed by the California Department of Water Resources (reference 5) was used to estimate the proportions of pump engines in the split portions of a county.

All 18 estimated pump engines in the South Coast Air Basin and the 132 additional engines in the Sacramento Non-Attainment Area were allocated to counties within the respective regions using the surrogates described above.

Estimation of the split of stationary and portable pump engines by county was done based upon a methodology developed by Booz-Allen & Hamilton for the OFFROAD model (reference 6). This methodology was based upon interviews with engine manufacturers (DDC, Caterpillar, Cummins, and Deutz) and equipment manufacturers (Stewart & Stevenson and Valley Diesel) which suggested that the majority of generator, pump, and compressor engines greater than 100 horsepower were stationary. Table D-1 defines the percentages of portable and stationary engines by horsepower that were developed as a result of this work.

Table D-1 – Portable vs. Stationary Engine Distribution

Horsepower Rating	Percent Portable	Percent Stationary
0-25	100%	0%
26-50	90	10
51-120	70	30
121-175	20	80
176-250	15	85
251-500	10	90
501-750	10	90
>750	10	90

Table D-2 (on Page D-5) summarizes the resulting pump engines population used for the emissions estimates.

Table D-2 – Estimated 2003 Diesel Agricultural Irrigation Pump Engine Population

District	Portable	Stationary	Total
Amador County APCD	5	12	17
Antelope Valley APCD	2	17	19
Bay Area AQMD	49	98	147
Butte County AQMD	183	304	487
Calaveras County AQMD	1	3	4
Colusa County APCD	98	228	327
El Dorado County APCD	4	7	11
Feather River AQMD	214	315	529
Glenn County APCD	109	177	286
Great Basin Unified APCD	46	102	148
Imperial County APCD	46	69	115
Kern County APCD	4	11	15
Lake County AQMD	7	21	28
Lassen County APCD	48	121	169
Mariposa County APCD	0	1	1
Mendocino County AQMD	8	16	24
Modoc County APCD	35	72	107
Mojave Desert AQMD	0	2	2
Monterey Bay Unified APCD	161	513	674
North Coast Unified APCD	20	45	64
Northern Sierra AQMD	19	31	50
Northern Sonoma County APCD	7	12	20
Placer County APCD	27	34	61
Sacramento Metropolitan AQMD	35	65	101
San Diego County APCD	74	104	178
San Joaquin Valley Unified APCD	2092	4965	7057
San Luis Obispo County APCD	32	92	124
Santa Barbara County APCD	75	165	241
Shasta County AQMD	33	81	114
Siskiyou County APCD	87	161	248
South Coast AQMD	12	6	18
Tehama County APCD	60	135	195
Tuolumne County APCD	1	2	3
Ventura County APCD	44	100	145
Yolo/Solano AQMD	238	570	808
Statewide	**3879**	**8656**	**12535**

Horsepower Distribution

Where available, district data was used to define pump engine horsepower. Information on horsepower ratings of 1,032 engines from the Sacramento Non-Attainment Area and South Coast AQMD was used to allocate pump engines for these areas. Also, Carl Moyer Program data for approximately 1,300 pump engines replaced between 1997 and 2003 was used to estimate emissions for engines in the Sacramento, San Joaquin, and Monterey Unified local air district jurisdictions.

To estimate the horsepower of pump engine populations across the state where no specific information was available, the minimum horsepower required to move water for irrigation was calculated. Where engine specific horsepower was available, comparisons were made between actual engine horsepower data and the estimated horsepower to ensure that the estimated horsepower profiles were reasonable estimates.

Three equations define the brake horsepower required to pump a given amount of water:

Equation 1:

$$TDH = SH + FH + VH + PH$$

Where:
TDH = Total Dynamic Head (feet)
SH = Total Static Head (feet) (total vertical distance pump must lift water)
FH = Friction Head (feet) (pressure head loss due to friction in pipes)
VH = Velocity Head (feet) (energy imparted to water to get it in motion; usually negligible)
PH = Pressure Head (feet) (pressure required to operate the irrigation system)
(1 foot of pressure = 2.31 pounds per square inch)

Equation 2:

$$WHP = Q * TDH / 3960$$

Where:
WHP = Water Horse Power
Q = Flow Rate in gallons per minute
TDH = Total Dynamic Head (feet; from equation 1))

Equation 3:

$$BHP = WHP / (PE * DE * LF * DRE)$$

Where:
BHP = Brake Horsepower
WHP = Water Horsepower (from equation 2)
PE = Pump Efficiency (percent)
DE = Drive Efficiency (percent)
LF = Load Factor
DRE = Relative Efficiency of Diesel Engines compared to Electric Motors

Well Pumps

The total static head for well pumps is the depth to water for a well plus the drawdown (the lowering of the water table as a result of the pumped water). The average depth to water was obtained from USGS for over 10,000 wells in California (reference 7). A drawdown of 50 feet was assumed for wells with water depths of less than 500 feet; a drawdown of 100 feet was assumed for deeper wells. The depth of pump drawdowns can vary from well to well based on location and quality of the well. In general the drawdown of a well should be negligible. However, in practice the distance can change because of seasonal rain fall or pumping at a rate that exceed the ability of the well to refresh itself. Therefore, the maximum drawdown is the distance between the initial water level and the top of the pump bowls formed by the water pumping. To compensate for this change in static head a minimum distance between the water level and the pump bowl is assumed to range from 50 to 100 feet depending on the depth of the well.

Well locations were determined with GIS software, and only wells located within irrigated agricultural fields (as defined in the Department of Water Resources land use data set found in reference 5) were used to determine horsepower. Because the USGS well database contains information on specific wells at specific locations, these data were used to determine horsepower profiles specific to each county, air basin, and district.

Because pumps are purchased to accomplish a wide variety of tasks, a pressure head of 75 pounds per square inch (psi) was assumed as an upper bound of typical operating pressures. This pressure would be typical of that found in a booster pump that lifts the water an additional 10 feet once the water has reached the surface and pressurizes a sprinkler system such as rainmakers.

Table D-3 lists the parameters used to calculate horsepower profiles for well pump engines. Data on flow rates and the static head of booster pumps were obtained from the 2003 FRIS (reference 1). Friction head was estimated at 2.54 feet, based on data contained in publication by the National Resources Conservation Service (reference 8), which represents the friction imparted by a flow rate of 900 gallons per minute through 100 feet of steel 8-inch diameter pipe. This value was selected as a mid-range estimate of friction loss. Friction head varies with the length of irrigation pipe, flow rate, and the diameter of pipe and can range between near zero to well over 20 feet for high flow rates and lengthy pipes.

Table D-3 – Parameters Used to Calculate Horsepower of Irrigation Pump Engines

Parameter	**Well Pump**	**Booster Pumps**		
		Tailwater Pump	**Pond/Lake Discharge**	**Relift**
Static Head	Average Depth to Water	11	20	19
Friction Head (feet)	2.54	2.54	2.54	2.54
Pressure Head (psi)	75	75	75	75
Flow Rate (gpm)	802	450-4937	450-4376	450-5277
Pump Efficiency	86%	80%	80%	80%
Drive Efficiency	85%	95%	95%	95%

The pump efficiency can vary between 70 and 90 percent depending on the type, size, and number of stages. A pump efficiency of 86 percent was assumed for these calculations. The drive efficiency is the efficiency of the drive between the engine and the pump itself; it varies between 70 percent and 100 percent depending on the method used to connect the motor and the pump. For these calculations, a drive efficiency of 85 percent was used. The relative efficiency of diesel engines compared to electric motors is about 75 percent; that is, an electric motor needs to be only 75 percent as powerful as a diesel engine to perform the same amount of work.

Table D-4 lists the average estimated horsepower and the range of horsepower used to calculate emissions. This data was used only when districts did not provide specific data. The bottom-up data for the Sacramento Non-Attainment Area has an average horsepower of 147 hp for well pump engines, which compares favorably with the 149 hp/157 hp estimates for engines in the Yolo/Solano AQMD and the Sacramento Metro AQMD local air districts. The average horsepower of the engines replaced under the Carl Moyer Program for the San Joaquin Valley is 197 hp, which is very close to the 196 hp estimate in Table D-4 for the San Joaquin Unified APCD. In 1996, Sonoma Technology (reference 9) surveyed San Joaquin Valley farmers on their irrigation pumps and showed an average horsepower of 161 hp for diesel engines. However, this average was based on only 35 responses out of 368 qualified respondents.

Table D-4 – Estimated Horsepower of Diesel Well Pump Engines[1]

District	Average	Minimum	Maximum
Bay Area AQMD	148	104	248
Butte County AQMD	129	102	157
Colusa County APCD	141	116	189
Feather River AQMD	144	99	190
Glenn County APCD	132	103	162
Imperial County APCD	114	98	205
Monterey Bay Unified APCD	149	112	187
Sacramento Metropolitan AQMD	157	98	203
San Diego County APCD	130	56	305
San Joaquin Valley Unified APCD	196	76	705
San Luis Obispo County APCD	162	100	346
Santa Barbara County APCD	151	63	446
South Coast AQMD	180	100	363
Ventura County APCD	181	98	401
Yolo/Solano AQMD	149	103	211
Statewide Average	**184**	**56**	**705**

1. Statewide average assigned to areas without data

Booster Pumps

Data to calculate booster pump engine horsepower profiles is summarized in Table D-3. All parameters except for the pressure head and friction head are average values obtained from Tables 19 and 20 of the 2003 Farm and Ranch Irrigation Survey. Table D-5 summarizes the horsepower profiles of the three types of booster pump engines.

Table D-5 – Estimated Horsepower of Diesel Booster Pump Engines

Type	Percent of Type	Calculated HP
Tailwater	46%	51
Tailwater	23%	85
Tailwater	18%	141
Tailwater	3%	197
Tailwater	6%	282
Tailwater	3%	556
Tailwater	**Average**	**111**
Pond/Lake	10%	40
Pond/Lake	19%	66
Pond/Lake	9%	111
Pond/Lake	12%	155
Pond/Lake	37%	221
Pond/Lake	12%	387
Pond/Lake	**Average**	**176**
Relift	21%	53
Relift	19%	88
Relift	17%	147
Relift	16%	205
Relift	21%	294
Relift	4%	620
Relift	**Average**	**177**

Activity

The average annual usage of diesel irrigation pump engines is assumed to be 1,000 hours. Data on electrical use for Pacific Gas and Electric small and large agricultural electric rate payers indicates that average pumping hours may have ranged from 187 to 4,569 for year 2003 (PG&E, 2004). The 2003 Farm and Ranch Irrigation Survey indicates that the average hours of operation of well pump engines was 1,016 hours. Finally, analysis of irrigation pump engines replaced under the Carl Moyer Program shows that the average pump usage is about 1,000 hours.

Age Distribution

The average useful life of an irrigation pump engine is about 20 years; that is, half of the engines that were purchased 20 years ago will still be in operation. Engines

replaced under the Carl Moyer Program were as old as 61 years but averaged 18 years of age. The American Society of Agricultural Engineers has estimated the average agricultural engine is used 20,000 hours (ASAE, 2005). At an average annual usage of 1,000 hours, 20 years is a reasonable estimate of useful life.
The actual age of irrigation pump engines was available for 1,032 engines in the Sacramento Non-Attainment area and the 1,300 pump engines replaced through the Carl Moyer Program from 1997 through 2003. For all other pump engines, an age distribution was calculated using the methodology used in the ARB OFFROAD model. Table D-6 shows the base year age distribution. The OFFROAD age distribution methodology takes into account an "S"-shaped scrappage curve and historic diesel engine populations reported in the Farm and Ranch Irrigation Surveys for the years 1984, 1988, 1994, 1998, and 2003. For all other years within the complete 40 year time span, the average yearly growth between the years 1984 and 2003 was assumed. (Note: for future years, different growth rates are assumed and will be discussed in the "Growth" section).

Table D-6 – Base Year Age Distribution of Diesel Irrigation Pump Engines

Age	Model Year	Percent
0	2003	8.3%
1	2002	7.7%
2	2001	7.5%
3	2000	7.2%
4	1999	3.1%
5	1998	3.0%
6	1997	2.8%
7	1996	2.6%
8	1995	4.4%
9	1994	4.3%
10	1993	4.1%
11	1992	3.9%
12	1991	3.7%
13	1990	3.5%
14	1989	4.5%
15	1988	4.3%
16	1987	4.0%
17	1986	3.7%
18	1985	2.5%
19	1984	2.9%
20	1983	2.4%
21	1982	1.5%
22	1981	1.3%
23	1980	1.1%
24	1979	1.0%
25	1978	0.8%
26	1977	0.7%
27	1976	0.6%
28	1975	0.5%
29	1974	0.4%
30	1973	0.4%
31	1972	0.3%
32	1971	0.2%
33	1970	0.2%
34	1969	0.2%
35	1968	0.1%
36	1967	0.1%
37	1966	0.1%
38	1965	0.1%
39	1964	0.1%
40	1963	0.0%

Load Factor

The load factor assumed for agricultural irrigation pump engines was 65 percent. This figure was based on extensive discussions with engine dealers, manufacturers, and irrigation experts.

Emission Factors

Emission factors for CO, hydrocarbons, NOx, PM, and CO_2 were used to estimate emissions. These emission factors are from the OFFROAD model and are based upon source tests of engines. The OFFROAD emission factors are in three parts: the zero hour emission factor; the base emission rate for a new engine; and a deterioration factor, which is dependant on the cumulative number of hours an engine has been in operation. The final emission factor is the zero hour emission factor plus the deterioration factor times the cumulative engine use (in hours). Because engines can only deteriorate a certain amount before they cease to operate, deterioration was capped at the average useful life of the engine, or 20 years (20,000 hours). These emission factors are summarized in Table D-7.

OFFROAD diesel emission factors require adjustment for calculation of TOG: hydrocarbon emissions must be multiplied by a factor of 1.44 to get TOG. OFFROAD emission factors for NOx and PM also need to be corrected for the difference between the fuels the factors were developed with and the fuels actually used in California. These fuel correction factors are specific for the year of emission estimates, the model year of the equipment, and the horsepower of the equipment. For NOx, the fuel correction factor varies between 0.93 and 1; for PM, the fuel correction factor varies between 0.72 and 1.0. For ROG, the fuel correction factor is 0.72 for diesel fuel.

Table D-7 – Diesel Emission Factors

		(g/hp-hr)	(g/hp-hr^{2})	(g/hp-hr)	(g/hp-hr^{2})	(g/hp-hr)	(g/hp-hr^{2})	(g/hp-hr)	(g/hp-hr^{2})
HP	**Year**	**HC**	**HC det**	**CO**	**CO det**	**NOX**	**NOX det**	**PM**	**PM det**
26 - 50	<= 1987	1.84	2.35E-04	5	5.13E-04	7	1.05E-04	0.76	5.89E-05
26 - 50	1988 - 1998	1.8	2.30E-04	5	5.13E-04	6.9	1.04E-04	0.76	5.89E-05
26 - 50	1999 - 2003	1.45	1.85E-04	4.1	4.20E-04	5.55	1.03E-04	0.6	4.65E-05
26 - 50	2004	0.64	9.80E-05	3.27	3.34E-04	5.1	9.33E-05	0.43	3.36E-05
26 - 50	2005	0.37	6.90E-05	3	3.05E-04	4.95	9.67E-05	0.38	2.93E-05
26 - 50	2006 - 2007	0.24	5.45E-05	2.86	2.90E-04	4.88	9.83E-05	0.35	2.72E-05
26 - 50	2008 - 2012	0.1	4.00E-05	2.72	2.76E-04	4.8	1.00E-04	0.16	1.22E-05
26 - 50	2013 - 2020	0.1	4.00E-05	2.72	2.76E-04	2.9	6.04E-05	0.01	1.11E-06
51 - 120	<= 1987	1.44	6.66E-05	4.8	1.27E-04	13	3.01E-04	0.84	6.11E-05
51 - 120	1988 - 1997	0.99	4.58E-05	3.49	9.23E-05	8.75	2.02E-04	0.69	5.02E-05
51 - 120	1998 - 2003	0.99	4.58E-05	3.49	9.23E-05	6.9	1.60E-04	0.69	5.02E-05
51 - 120	2004	0.46	3.33E-05	3.23	8.55E-05	5.64	1.03E-04	0.39	2.85E-05
51 - 120	2005	0.28	2.92E-05	3.14	8.33E-05	5.22	8.40E-05	0.29	2.12E-05
51 - 120	2006 - 2007	0.19	2.71E-05	3.09	8.21E-05	5.01	7.45E-05	0.24	1.76E-05
51 - 120	2008 - 2011	0.1	2.50E-05	3.05	8.10E-05	2.89	3.80E-05	0.2	1.45E-05
51 - 120	2012	0.09	2.31E-05	3.05	8.10E-05	2.53	3.33E-05	0.07	4.96E-06
51 - 120	2013 - 2014	0.09	2.31E-05	3.05	8.10E-05	2.53	3.33E-05	0.01	9.33E-07
51 - 120	2015 - 2020	0.07	1.74E-05	3.05	8.10E-05	1.4	1.84E-05	0.01	9.33E-07
121 - 175	<= 1969	1.32	6.11E-05	4.4	1.16E-04	14	3.24E-04	0.77	5.60E-05
121 - 175	1970 - 1971	1.1	5.09E-05	4.4	1.16E-04	13	3.01E-04	0.66	4.80E-05
121 - 175	1972 - 1979	1	4.63E-05	4.4	1.16E-04	12	2.78E-04	0.55	4.00E-05
121 - 175	1980 - 1984	0.94	4.35E-05	4.3	1.14E-04	11	2.54E-04	0.55	4.00E-05
121 - 175	1985 - 1987	0.88	4.07E-05	4.2	1.11E-04	11	2.54E-04	0.55	4.00E-05
121 - 175	1988 - 1996	0.68	3.15E-05	2.7	7.14E-05	8.17	1.89E-04	0.38	2.76E-05
121 - 175	1997 - 2002	0.68	3.15E-05	2.7	7.14E-05	6.9	1.60E-04	0.38	2.76E-05
121 - 175	2003	0.33	2.79E-05	2.7	7.14E-05	5.26	9.64E-05	0.24	1.70E-05
121 - 175	2004	0.22	2.63E-05	2.7	7.14E-05	4.72	7.52E-05	0.19	1.35E-05
121 - 175	2005 - 2006	0.16	2.57E-05	2.7	7.14E-05	4.44	6.46E-05	0.16	1.18E-05
121 - 175	2007 - 2011	0.1	2.50E-05	2.7	7.14E-05	2.45	3.20E-05	0.14	1.00E-05
121 - 175	2012 - 2014	0.09	2.17E-05	2.7	7.14E-05	2.27	2.96E-05	0.01	4.67E-07
121 - 175	2015 - 2020	0.05	1.17E-05	2.7	7.14E-05	0.27	3.56E-06	0.01	4.67E-07
176 - 250	<= 1969	1.32	6.11E-05	4.4	1.16E-04	14	3.24E-04	0.77	5.60E-05
176 - 250	1970 - 1971	1.1	5.09E-05	4.4	1.16E-04	13	3.01E-04	0.66	4.80E-05
176 - 250	1972 - 1979	1	4.63E-05	4.4	1.16E-04	12	2.78E-04	0.55	4.00E-05
176 - 250	1980 - 1984	0.94	4.35E-05	4.3	1.14E-04	11	2.54E-04	0.55	4.00E-05
176 - 250	1985 - 1987	0.88	4.07E-05	4.2	1.11E-04	11	2.54E-04	0.55	4.00E-05
176 - 250	1988 - 1995	0.68	3.15E-05	2.7	7.14E-05	8.17	1.89E-04	0.38	2.76E-05
176 - 250	1996 - 2002	0.32	1.48E-05	0.92	2.43E-05	6.25	1.45E-04	0.15	7.96E-06
176 - 250	2003	0.19	2.09E-05	0.92	2.43E-05	5	9.05E-05	0.12	6.51E-06
176 - 250	2004	0.14	2.30E-05	0.92	2.43E-05	4.58	7.23E-05	0.11	6.03E-06
176 - 250	2005 - 2006	0.12	2.40E-05	0.92	2.43E-05	4.38	6.33E-05	0.11	5.79E-06
176 - 250	2007 - 2010	0.1	2.50E-05	0.92	2.43E-05	2.45	3.18E-05	0.11	5.59E-06
176 - 250	2011 - 2013	0.07	1.83E-05	0.92	2.43E-05	1.36	1.77E-05	0.01	4.55E-07
176 - 250	2014 - 2020	0.05	1.17E-05	0.92	2.43E-05	0.27	3.56E-06	0.01	4.55E-07

Table D-7 – Diesel Emission Factors (Continued)

		(g/hp-hr)	(g/hp-hr^2)	(g/hp-hr)	(g/hp-hr^2)	(g/hp-hr)	(g/hp-hr^2)	(g/hp-hr)	(g/hp-hr^2)
HP	**Year**	**HC**	**HC det**	**CO**	**CO det**	**NOX**	**NOX det**	**PM**	**PM det**
251 - 500	<= 1969	1.26	4.39E-05	4.2	8.32E-04	14	2.33E-04	0.74	3.93E-05
251 - 500	1970 - 1971	1.05	3.66E-05	4.2	8.32E-04	13	2.16E-04	0.63	3.34E-05
251 - 500	1972 - 1979	0.95	3.31E-05	4.2	8.32E-04	12	2.00E-04	0.53	2.81E-05
251 - 500	1980 - 1984	0.9	3.14E-05	4.2	8.32E-04	11	1.83E-04	0.53	2.81E-05
251 - 500	1985 - 1987	0.84	2.93E-05	4.1	8.12E-04	11	1.83E-04	0.53	2.81E-05
251 - 500	1988 - 1995	0.68	2.37E-05	2.7	5.35E-05	8.17	1.36E-04	0.38	2.02E-05
251 - 500	1996 - 2000	0.32	1.12E-05	0.92	1.82E-05	6.25	1.04E-04	0.15	7.96E-06
251 - 500	2001	0.19	1.95E-05	0.92	1.82E-05	4.95	7.34E-05	0.12	6.51E-06
251 - 500	2002	0.14	2.22E-05	0.92	1.82E-05	4.51	6.32E-05	0.11	6.03E-06
251 - 500	2003 - 2004	0.12	2.36E-05	0.92	1.82E-05	4.29	5.81E-05	0.11	5.79E-06
251 - 500	2005	0.1	2.50E-05	0.92	1.82E-05	4	5.30E-05	0.11	5.55E-06
251 - 500	2006 - 2010	0.1	2.50E-05	0.92	1.82E-05	2.45	3.18E-05	0.11	5.55E-06
251 - 500	2011 - 2013	0.07	1.83E-05	0.92	1.82E-05	1.36	1.77E-05	0.01	4.55E-07
251 - 500	2014 - 2020	0.05	1.17E-05	0.92	1.82E-05	0.27	3.56E-06	0.01	4.55E-07
501 - 750	<= 1969	1.26	4.39E-05	4.2	8.32E-04	14	2.33E-04	0.74	3.93E-05
501 - 750	1970 - 1971	1.05	3.66E-05	4.2	8.32E-04	13	2.16E-04	0.63	3.34E-05
501 - 750	1972 - 1979	0.95	3.31E-05	4.2	8.32E-04	12	2.00E-04	0.53	2.81E-05
501 - 750	1980 - 1984	0.9	3.14E-05	4.2	8.32E-04	11	1.83E-04	0.53	2.81E-05
501 - 750	1985 - 1987	0.84	2.93E-05	4.1	8.12E-04	11	1.83E-04	0.53	2.81E-05
501 - 750	1988 - 1995	0.68	2.37E-05	2.7	5.35E-05	8.17	1.36E-04	0.38	2.02E-05
501 - 750	1996 - 2001	0.32	1.12E-05	0.92	1.82E-05	6.25	1.04E-04	0.15	7.96E-06
501 - 750	2002	0.19	1.95E-05	0.92	1.82E-05	4.95	7.34E-05	0.12	6.51E-06
501 - 750	2003	0.14	2.22E-05	0.92	1.82E-05	4.51	6.32E-05	0.11	6.03E-06
501 - 750	2004 - 2005	0.12	2.36E-05	0.92	1.82E-05	4.29	5.81E-05	0.11	5.79E-06
501 - 750	2006 - 2010	0.1	2.50E-05	0.92	1.82E-05	2.45	3.18E-05	0.11	5.55E-06
501 - 750	2011 - 2013	0.07	1.83E-05	0.92	1.82E-05	1.36	1.77E-05	0.01	4.55E-07
501 - 750	2014 - 2020	0.05	1.17E-05	0.92	1.82E-05	0.27	3.56E-06	0.01	4.55E-07
751 - 9999	<= 1969	1.26	4.39E-05	4.2	8.32E-04	14	2.33E-04	0.74	3.93E-05
751 - 9999	1970 - 1971	1.05	3.66E-05	4.2	8.32E-04	13	2.16E-04	0.63	3.34E-05
751 - 9999	1972 - 1979	0.95	3.31E-05	4.2	8.32E-04	12	2.00E-04	0.53	2.81E-05
751 - 9999	1980 - 1984	0.9	3.14E-05	4.2	8.32E-04	11	1.83E-04	0.53	2.81E-05
751 - 9999	1985 - 1987	0.84	2.93E-05	4.1	8.12E-04	11	1.83E-04	0.53	2.81E-05
751 - 9999	1988 - 1999	0.68	1.12E-05	2.7	5.35E-05	8.17	1.36E-04	0.38	2.02E-06
751 - 9999	2000 - 2005	0.32	1.12E-05	0.92	1.82E-05	6.25	1.04E-04	0.15	7.96E-06
751 - 9999	2006	0.19	1.95E-05	0.92	1.82E-05	4.95	7.34E-05	0.12	6.51E-06
751 - 9999	2007	0.14	2.22E-05	0.92	1.82E-05	4.51	6.32E-05	0.11	6.03E-06
751 - 9999	2008 - 2009	0.12	2.36E-05	0.92	1.82E-05	4.29	5.81E-05	0.11	5.79E-06
751 - 9999	2010	0.1	2.50E-05	0.92	1.82E-05	4.08	5.30E-05	0.11	5.55E-06
751 - 9999	2011 - 2014	0.1	2.50E-05	0.92	1.82E-05	2.36	3.06E-05	0.06	2.78E-06
751 - 9999	2015 - 2020	0.05	1.17E-05	0.92	1.82E-05	2.36	3.06E-05	0.02	1.11E-06

Growth

In April, 2005, the ARB agricultural advisory committee approved a set of growth factors for various types of agricultural equipment. For most categories, including irrigation pump engines, the growth factor selected was irrigated acreage, as collected by the California Department of Conservation's Farmland Monitoring and Mapping Program for the years 1996-2002 (reference 12). These growth factors are defined by county for the San Joaquin Valley; an average is used for the rest of the State. Table D-8 presents these growth factors. With the exception of Madera and Merced counties, the growth of irrigated acreage is declining.

Since usage of diesel agricultural irrigation pump engines is not only defined by the amount of agricultural acreage, but also by market forces including energy costs, the growth rate of these engines will be revisited in future years as the USDA publishes new Farm and Ranch Irrigation Surveys. These surveys are performed approximately every five years.

Table D-8 – Growth Rates by County

County Name	Growth Factor (per year)
Fresno	-0.73%
Kern	-0.33%
Kings	-0.14%
Madera	0.20%
Merced	0.03%
San Joaquin	-0.32%
Stanislaus	-0.12%
Tulare	-0.62%
All Other Counties	**-0.26%**

To calculate emissions growth for future years, the base year population was grown using the growth factors described above using the methodology used for the ARB OFFROAD model. Because the number of diesel irrigation engines increased dramatically between 1998 and 2003, the base year age distribution contains a large percentage of late model engines that declines in future years as these engines are retired.

RESULTS

Table D-9 shows the statewide emissions for the base year (2003) by local air district for all diesel pump engines. More than half of the emissions of diesel irrigation pump engines are in the San Joaquin Valley Unified APCD, due to both the large number of pump engines in that district and because wells on the west side of the district tend to be very deep and therefore require much larger engines. Table D-10 shows the statewide emissions by horsepower and by pump engine portability. About two-thirds of the statewide emissions are from stationary pump engines based on the Booz-Hamilton assumption presented in table D-1. Table D-11 shows the forecasted statewide emissions (does not include the benefits of the regulation). Emissions decline over time because of the negative growth rate which reflects the disappearance of agricultural land in California and because as time goes on, existing federal off-road compression ignition engine certification standards result in the replacement of older, dirtier engines with newer, cleaner engines. By 2025, emissions of all pollutants (except CO_2) are less than half those seen in 2003.

Table D-9 – 2003 Diesel Agricultural Irrigation Pump Engine Emissions By Local Air District (tons per day)

District Name	CO	CO2	DPM	HC	NOx	PM	PM10	PM25	ROG	SOx	TOG
Amador County APCD	0.0	3.4	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Antelope Valley APCD	0.1	7.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Bay Area AQMD	0.2	28.4	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.1
Butte County AQMD	0.7	85.4	0.1	0.2	1.4	0.1	0.1	0.1	0.1	0.0	0.2
Calaveras County AQMD	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Colusa County APCD	0.4	57.6	0.0	0.1	0.9	0.1	0.0	0.0	0.1	0.0	0.2
El Dorado County APCD	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feather River AQMD	0.7	86.5	0.1	0.2	1.4	0.1	0.1	0.1	0.1	0.0	0.2
Glenn County APCD	0.4	48.7	0.0	0.1	0.8	0.1	0.0	0.0	0.1	0.0	0.1
Great Basin Unified APCD	0.2	29.6	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0	0.1
Imperial County APCD	0.1	20.4	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.1
Kern County APCD	0.0	3.6	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Lake County AQMD	0.0	5.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Lassen County APCD	0.3	34.1	0.0	0.1	0.5	0.0	0.0	0.0	0.1	0.0	0.1
Mariposa County APCD	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mendocino County AQMD	0.0	4.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Modoc County APCD	0.2	21.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.1
Mojave Desert AQMD	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monterey Bay Unified APCD	0.8	122.0	0.1	0.2	2.0	0.1	0.1	0.1	0.2	0.0	0.3
North Coast Unified APCD	0.1	13.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Northern Sierra AQMD	0.1	9.7	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Northern Sonoma County APCD	0.0	3.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Placer County APCD	0.1	9.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Sacramento Metropolitan AQMD	0.1	16.9	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
San Diego County APCD	0.3	32.9	0.0	0.1	0.5	0.0	0.0	0.0	0.1	0.0	0.1
San Joaquin Valley Unified APCD	11.2	1451.2	1.1	2.4	22.9	1.3	1.1	1.1	2.1	0.1	3.5
San Luis Obispo County APCD	0.2	23.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.1
Santa Barbara County APCD	0.3	42.9	0.0	0.1	0.7	0.0	0.0	0.0	0.1	0.0	0.1
Shasta County AQMD	0.2	23.3	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.1
Siskiyou County APCD	0.4	48.5	0.0	0.1	0.8	0.0	0.0	0.0	0.1	0.0	0.1
South Coast AQMD	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tehama County APCD	0.3	39.2	0.0	0.1	0.6	0.0	0.0	0.0	0.1	0.0	0.1
Tuolumne County APCD	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ventura County APCD	0.2	29.1	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.1
Yolo/Solano AQMD	0.9	143.2	0.1	0.3	2.3	0.1	0.1	0.1	0.2	0.0	0.4
Statewide Total	**18.7**	**2452.1**	**1.9**	**4.2**	**39.0**	**2.3**	**1.9**	**1.9**	**3.7**	**0.2**	**6.1**

Table D-10 – 2003 Diesel Agricultural Irrigation Pump Engine Emissions By Horsepower and Portability (tons per day)

Portability	Horsepower	CO	CO2	DPM	HC	NOx	PM	PM10	PM25	ROG	SOx	TOG
Portable	26 to 50 Horsepower	0.1	6.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Portable	51 to 120 Horsepower	1.9	231.8	0.3	0.6	4.1	0.4	0.3	0.3	0.5	0.0	0.9
Portable	121 to 175 Horsepower	1.1	162.5	0.1	0.3	2.7	0.2	0.1	0.1	0.3	0.0	0.4
Portable	176 to 250 Horsepower	0.5	98.8	0.1	0.1	1.5	0.1	0.1	0.1	0.1	0.0	0.2
Portable	251 to 500 Horsepower	0.6	55.8	0.0	0.1	0.8	0.0	0.0	0.0	0.1	0.0	0.1
Portable	501 to 750 Horsepower	0.1	7.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Portable Total		**4.3**	**563.0**	**0.6**	**1.2**	**9.3**	**0.7**	**0.6**	**0.6**	**1.0**	**0.0**	**1.7**
Stationary	26 to 50 Horsepower	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stationary	51 to 120 Horsepower	0.8	98.5	0.1	0.3	1.7	0.2	0.1	0.1	0.2	0.0	0.4
Stationary	121 to 175 Horsepower	4.4	649.9	0.5	1.2	10.6	0.6	0.5	0.5	1.0	0.1	1.7
Stationary	176 to 250 Horsepower	2.7	560.7	0.4	0.8	8.8	0.4	0.4	0.3	0.7	0.0	1.2
Stationary	251 to 500 Horsepower	5.6	505.3	0.3	0.7	7.4	0.3	0.3	0.3	0.6	0.0	1.0
Stationary	501 to 750 Horsepower	0.9	71.2	0.0	0.1	1.1	0.1	0.0	0.0	0.1	0.0	0.1
Stationary	>751 Horsepower	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stationary Total		**14.4**	**1889.1**	**1.4**	**3.0**	**29.7**	**1.6**	**1.4**	**1.3**	**2.6**	**0.1**	**4.4**
All Engines Total		**18.7**	**2452.1**	**1.9**	**4.2**	**39.0**	**2.3**	**1.9**	**1.9**	**3.7**	**0.2**	**6.1**

Table D-11 – Forecasted Diesel Agricultural Irrigation Pump Engine Emissions (tons per day)

Pollutant	2003	2005	2010	2015	2020
CO	18.7	17.7	15.0	12.9	11.3
CO2	2452.1	2439.4	2407.5	2375.6	2343.7
DPM	1.9	1.9	1.6	1.4	1.0
HC	4.2	4.1	3.6	3.0	2.4
NOx	39.0	37.6	32.5	26.3	19.3
PM	2.3	2.2	1.9	1.6	1.2
PM10	1.9	1.9	1.6	1.4	1.0
PM25	1.9	1.8	1.6	1.3	1.0
ROG	3.7	3.5	3.1	2.6	2.1
SOx	0.2	0.2	0.2	0.1	0.1
TOG	6.1	5.9	5.1	4.3	3.5

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