July 9, 1998
MSC #98-14

To: All Interested Parties

SUBJECT: PROPOSED PLEASURE CRAFT EXHAUST EMISSIONS INVENTORY

The staff of the Air Resources Board (ARB) is in the process of updating the exhaust emission estimates of off-road mobile sources using a new model called OFFROAD. Pleasure craft is one of the categories included in the OFFROAD model. This document describes the details related to the various input factors such as population, emission factors, activity and useful life needed to estimate the emissions inventory. The methodology to calculate exhaust emissions in the new OFFROAD model is described in Attachment 1.

It is the practice of ARB staff to present major emission inventory changes to the Board for its approval. As such, staff plans to take the pleasure craft inventory to the Board before the end of 1998.

Before finalizing the emissions inventory, staff is requesting your comments. In order to give consideration to your concerns, we request that you provide your comments in writing by August 24, 1998. If you do not agree with certain input factors, staff would appreciate it if you could provide the data/basis that supports your position. Written comments should be submitted to the following address:

Mark A. Carlock
Mobile Source Control Division
9528 Telstar Avenue
El Monte, CA 91731

If you have questions or need further clarification, please call Archana Agrawal, Manager of the Inventory Assessments section, at (626) 450-6136.

Sincerely,

Mark A. Carlock, Chief
Motor Vehicle Analysis Branch
Mobile Source Control Division

Equipment Types

The pleasure craft category consists of all recreational and commercial boats registered by the California Department of Motor Vehicles (DMV). There are six equipment types in the pleasure craft category. The equipment types are listed in Table 1 by fuel and engine type. The 1990 base year population data is included in the table as well.

Table 1. Equipment types and population.

Equipment Type	Fuel/Cycle	1990 Population
Vessels w/Outboard Engines	G2	373,118
Sailboat w/Auxiliary Engines	G2	7,198
Personal Water Craft	G2	67,789
Vessels w/Inboard Engines	G4	61,275
Vessels w/Outboard Engines	G4	19,140
Sailboat w/Auxiliary Engines	G4	5,745
Vessels w/Sterndrive Engines	G4	236,744
Vessels w/Inboard Jet Engines	G4	27,640
Vessels w/Inboard Engines	D	8,524
Sailboats w/Auxiliary Engines	D	11,610

G2 - Gasoline, 2-stroke engine
G4 - Gasoline, 4-stroke engine
D - Diesel engine

Population

Methodology

The OFFROAD model contains growth factors and scrappage curves that are used to derive an engine specific model year population distribution for calendar years from 1970 through 2020. The methodology is described in detail in a document entitled, "Documentation of Input Factors for the New Off-Road Mobile Source Emissions Inventory Model," prepared by Energy and Environmental Analysis, Inc. (EEA), dated February 1997.

Sources

The statewide equipment population for pleasure craft was obtained from the DMV statistical records on registered vessels for calendar years 1990 to 1997. Since DMV's statistical records contain information on registered vessels by type of equipment and length and not by engine types, classification and quantification of equipment population by gasoline 2- and 4-stroke engine cycles or diesel engines was not possible. These splits at the statewide level, were determined from the Systems Applications International (SAI) report prepared for the ARB entitled "Development of an Improved Inventory of Emissions from Pleasure Craft in California", dated June 1995. This split was held constant for all calendar years. In addition, DMV's population data did not explicitly specify the personal watercraft (pwc) population, therefore, all boats powered by jet-propulsion (jetboats) in the DMV database under sixteen feet in length were considered to be two-stroke pwc and the rest were considered to be four-stroke inboard jetboats. The smaller jetboats with two-stroke engines were assumed to fall into the pwc category.

Further, the registered vessels population obtained from DMV was converted to total engine population using a weighting scheme provided by EEA to the ARB in their February 1997 report. Table 2-13 from the EEA report presents this weighting scheme and is shown in Appendix A of this document.

Growth and Scrappage

Methodology

Statewide growth factors were calculated for each equipment type based on DMV population data. Growth factors are the same within each equipment type regardless of engine or fuel type. The statewide growth factors for calendar years (CY) 1990 to 1997 were calculated by normalizing actual calendar year populations to the CY 1990 statewide population. Since county specific data could not be obtained from the DMV in time for this report, a relationship between statewide growth factors and county specific growth factors was determined from growth data included in a report entitled, "A Study to Develop Projected Activity for 'Non-Road Mobile' Categories in California, 1970-2020", prepared by California State University, Fullerton, in October of 1994.

Based on DMV's population estimates, an average of the percentage growth in population between two consecutive calendar years was used to estimate the future (1997+) population of each equipment type as shown in Figure 1. The only exception was pwc equipment which experienced tremendous growth during the early 1990's with the population doubling in less than six years. Since the average percentage growth from year to year would increase the future pwc population to a unrealistic level, staff used their judgment to predict pwc population growth from 1998 through 2020. It was assumed that there will be no significant increase in the pwc population in California until 2002 because of uncertainty of various environmental, noise and usage related restrictions. After 2002, pwc population was assumed to grow again at an average rate based on DMV pwc data (from CY1990 to 1997) this growth was assumed to continue until about 2006 when the market was assumed to become saturated. For 2006 and beyond the growth was assumed to slow down. Staff used outboard engine population growth as a surrogate for the pwc population growth beyond 2006. In future years these numbers will be updated as actual DMV data is received. The DMV population from 1990 to 1997 is shown in Figure 2. Growth factors by equipment type are shown in Appendix B.

Scrappage rates and useful life estimates were obtained from data gathered through surveys of engine manufacturers by Power Systems Research (PSR), a market research firm. Scrappage or fleet turnover rate depends on the average useful life of an equipment type. The useful life describes the point in time when half of the engines sold in a particular year are assumed to be either scrapped or rebuilt. At two times the useful life all of the engines of that year is assumed to be scrapped. Based on information provided by PSR, the useful life is determined by taking the useful life in hours and dividing it by the load factor and activity in hours per year. If the useful life is determined to be over sixteen years then sixteen years is used as the useful life. All pleasure craft were

determined to have a useful life of sixteen years except pwc which have six years as their useful life.

Activity

Methodology
The OFFROAD model has datafiles which contain activity parameters such as usage in hrs/year, average maximum horsepower ratings, and load factor by equipment and horsepower group. Pleasure craft usage is measured in annual average use hours.

Sources
All activity data, with the exception of usage, were obtained from the PSR database. Equipment with sterndrive and inboard jet engines were considered to be in the powerboat category in the PSR database, so they are all assumed to have the same activity.

An alternative source for usage data was available from the SAI report mentioned earlier in this document. In the survey done for this report, boat owners were asked how often they used their pleasure craft engine in a two week period. These surveys were sent out at various times of the year to remove seasonal bias and obtain yearly averages. The surveys responses used for the SAI report are shown in Table 2.

Table 2. Activity of pleasure craft in hours/year using the SAI report.

Equipment type	Usage (hrs/year)
Vessels w/Inboard Engines (gasoline)	93
(diesel)	88
Vessels w/Outboard Engines	48
Vessels w/Sterndrive Engines	73
Sailboat Auxiliary Engines (gasoline)	10
(diesel)	10
Personal Water Craft	65
Vessels w/Inboard Jet Engines	73

Staff chose to use the data from the SAI report because it reflects California specific usage, rather than PSR data which is based on nationwide surveys.

The statewide population was allocated to the air basin and county level using county specific fuel usage data from Table 3-6 in the SAI report. This allocation reflects pleasure craft usage, rather than registration, by air basin and by county. The allocation file used in the model is shown in Appendix C.

Seasonal and Temporal Parameters

Seasonal and temporal factors are used to adjust for the differences between summer, wintertime, weekend and weekday usage. These factors were obtained from Appendix H in the SAI report and are shown in Appendix D of this document.

Emissions

Hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NOx) , and particulate matter (PM) emission factors for pleasure craft built before US EPA's marine rule was implemented were obtained from the SAI report. These emission factors are based on the 5-mode marine cycle. Exhaust emissions are dependent on the horsepower (hp) and the load factors (LF) of the equipment being considered. The load factor is defined as the fraction of full power typically used by the engine of a specific equipment type. Emission factors for pleasure craft are shown in Tables 3a and b. The average hp and load factors are shown in Table 4.

The average hp rating is assumed to remain constant through time for all equipment types with the exception of pwc. Based on meetings with engine manufacturers, staff has determined that in the case of pwc, the demand has changed from a one-person stand-up model to two- and three-person seated models, and will continue to change with more of the larger models becoming popular. Along with the demand for increase in size, there has also been a demand for increase in power and speed. Due to these reasons, the average hp for pwc has increased from about 45 hp in 1990 to 82 hp in 1997. For these calendar years the average hp's were taken from the PSR database. Staff estimates that starting in year 2003 the average hp will increase to about 100 hp, so for calendar years 1998 to 2002 the average hp was linearly interpreted between 82 hp and 100 hp, and for the calendar years 2003+, the average hp was considered to remain at 100 hp.

The load factor of the marine test cycle is 0.209. Staff believe that emissions data collected with this LF is appropriate for all equipment types in the Pleasure Craft category with the exception of pwc where the usage pattern demands more power than what is reflected in the marine cycle. Due to lack of any other information, staff proposes to use emission factors based on the marine cycle for emissions calculation purposes.

Table 3a. Emission factors for two-stroke engine in the pleasure craft category (g/bhp-hr).

Engine Size Category (hp)	HC exhaust	CO exhaust	NOx exhaust	PM exhaust
< 2	275	369	0.7	7.1
2 - 15	198	320	1.1	7.1
15 - 25	129	276	1.6	7.1
25 - 50	117	208	1.1	7.1
50 - 120	107	213	1.7	7.1
120 - 175	106	244	1.1	7.1
175 - 250	107	215	1.1	7.1
250 - 500	109	210	1.1	7.1

Table 3b. Emission factors for personal watercraft, four-stroke engines, and diesel engine in the pleasure craft category (g/bhp-hr).

Equipment type	HC exhaust	CO exhaust	NOx exhaust	PM exhaust
PWC	144	263	0.84	6.9
4-stroke gasoline engine	9.1	151	5.4	0.07
diesel engine	2.6	4.7	11.3	0.34

Table 4. Average horse power and load factors for pleasure craft.

Equipment Type	Average Horse Power	Load Factor(%)
Vessels w/Inboard Engines (gasoline)	164	38
(diesel)	244	35
Vessels w/Outboard Engines (2-stroke) < 2 hp	2	32
2 - 15 hp	6	32
15 - 25 hp	20	32
25 - 50 hp	37	32
50 - 120 hp	79	32
120 - 175 hp	145	32
175 - 250 hp	196	32
250 - 500 hp	274	32
(4-stroke)	36	32
Vessels w/Sterndrive Engines	164	38
Sailboat Auxiliary Engines (gasoline)	10	35
(diesel)	27	32
Personal Water Craft (1990)	45	76
(1991)	46	76
(1992)	48	76
(1993)	51	76
(1994)	57	76
(1995)	66	76
(1996)	77	76
(1997)	82	76
(1998)	85	76
(1999)	88	76
(2000)	91	76
(2001)	94	76
(2002)	97	76
(2003 +)	100	76
Vessels w/Inboard Jet Engines	164	35

The rate at which an engine increases in emissions over time is called a deterioration rate. Deterioration rates were determined for pleasure craft with four-stroke engines. These were estimated using uncontrolled on-road vehicle emission deterioration rates. The deterioration rate was calculated by assuming that the useful life of a 1974 model-year on-road passenger vehicle was 100,000 miles and the total deterioration for the life of that vehicle would be the same as the useful life of the four-stroke pleasure craft. Deterioration rates are presented in Table 5.

Table 5. Deterioration rates of four-stroke pleasure craft in g/bhp-hr^2.

HC	CO	NOx
0.005	0.02906	0.00068

Fuel correction factors were incorporated into the OFFROAD model to account for the expected changes in the emission rates due to the use of California's Phase 1 Fuel, Cleaner Burning Gasoline, and Clean Diesel Fuel. The fuel correction factors were adopted from the on-road, non-catalyst equipped vehicle correction factors. These correction factors are shown in Table 6 for gasoline correction factors and Table 7 for diesel correction factors.

Table 6. Fuel correction factors for gasoline powered pleasure craft.

Calendar Year	Summer			Winter		
	HC	CO	NOx	HC	CO	NOx
Pre-1992	1	1	1	1	1	1
1992-1995	0.988	0.994	0.997	0.963	0.895	0.997
1996+	0.921	0.848	1.025	0.921	0.848	1.025

Table 7. Fuel correction factors for diesel powered pleasure craft.

Calendar Year	NOx	PM
1993 +	0.9425	0.8012

Incorporating US EPA spark engine rule

The emission standards finalized today for outboards, personal watercraft, and jetboats require a very large reduction in hydrocarbon emissions on a brake specific basis (i.e., g/kw-hr) with only a slight increase in NOx emissions. The standards require increasingly stringent HC control over the course of a nine-year phase-in period beginning in model year 1998. By the end of the phase-in, each manufacturer must meet an HC+NOx emission standard on a corporate average basis that represents a 75 percent reduction in HC compared to unregulated levels. EPA's administrative program requirements are designed to ensure that the targeted reductions actually occur by making manufacturers responsible for testing engines, reporting the results to EPA, and demonstrating compliance with the emission standards. The regulation includes a corporate average standard, a nine-year phase-in, and a HC+NOx emission standard. It does not include a carbon monoxide standard. (US EPA, October 1996)

The HC+NOx emission standard is determined by an equation shown in Appendix E in this document. In order to reflect the US EPA's rule in California's pleasure craft

baseline inventory, staff replaced the uncontrolled 1998+ emission rates with US EPA's standards calculated based on the equation adopted in US EPA's rule. Since the US EPA has a combined HC+NOx standard, staff realized that the HC to NOx ratio should be different than the HC to NOx ratio for uncontrolled engines. The only data available to staff to make any adjustment was the US EPA's 1998 certification data where due to US EPA's trading and banking rule manufacturers had certified engines ranging from 6.68g/bhp-hr to 599.39 g/bhp-hr emissions level. Staff compared each calendar year's emission standard against similar certification test data to adjust the HC to NOx ratio. This methodology was used for each hp group of the pleasure craft category. The US EPA's emission standard based emission rates reflected in the emission inventory for 2010 are shown in Appendix F. Because the number of four-stroke engines being introduced to meet the US EPA rule is unknown, no deterioration was assumed for 1998+ model year emissions from outboard engines or pwc.

Tables 8 and 9 show the statewide population, usage and uncontrolled emission estimates in tons/day for CY 1990 and 2010, respectively. Emission estimates for CY 2010 which reflect US EPA's regulation for spark-ignition marine engines are shown in Table 10.

Table 8. Statewide exhaust emissions in tons/day for calendar year 1990.

Equipment Type	Fuel/ Cycle	Population	Usage (hrs/yr)	ROG	CO	NOx	PM
Vessels w/Outboard Engines	G2	373,118	48	66.712	133.17	0.745	4.012
Sailboat w/Auxiliary Engines	G2	7,198	10	0.147	0.27	0.001	0.008
Personal Water Craft	G2	67,789	65	64.945	119.68	0.381	3.141
Total	**G2**	**448,105**		**131.804**	**253.12**	**1.127**	**7.161**
Vessels w/Inboard Engines	G4	61,275	93	13.407	207.79	6.454	0.075
Vessels w/Outboard Engines	G4	19,140	48	0.338	5.77	0.183	0.002
Sailboat w/Auxiliary Engines	G4	5,745	10	0.005	0.10	0.003	0.000
Vessels w/Sterndrive Engines	G4	236,744	73	37.860	611.16	19.167	0.228
Vessels w/Inboard Jet Engines	G4	27,640	73	4.420	71.35	5.238	0.027
Total	**G4**	**350,544**		**56.030**	**896.17**	**28.045**	**0.332**
Vessels w/Inboard Engines	D	8,524	88	0.403	0.96	2.310	0.070
Sailboats w/Auxiliary Engines	D	11,610	10	0.006	0.01	0.034	0.001
Total	**D**	**20,134**		**0.409**	**0.97**	**2.344**	**0.071**
GRAND TOTAL		**818,783**		**204.900**	**1187.52**	**31.634**	**8.540**

Table 9. Statewide uncontrolled exhaust emissions in tons/day for calendar year 2010.

Equipment Type	Fuel/ Cycle	Population	Usage (hrs/yr)	ROG	CO	NOx	PM
Vessels w/Outboard Engines	G2	348,606	48	58.338	109.02	0.708	3.748
Sailboat w/Auxiliary Engines	G2	4,780	10	0.094	0.16	0.001	0.005
Personal Water Craft	G2	293,485	65	574.321	974.56	3.748	30.151
Total	**G2**	**646,871**		**632.753**	**1083.74**	**4.457**	**33.904**

Vessels w/Inboard Engines	G4	88,699	93	17.465	252.51	9.510	0.109
Vessels w/Outboard Engines	G4	17,805	48	0.290	4.56	0.175	0.002
Sailboat w/Auxiliary Engines	G4	3,799	10	0.004	0.07	0.002	0.000
Vessels w/Sterndrive Engines	G4	236,743	73	34.869	518.26	19.646	0.228
Vessels w/Inboard Jet Engines	G4	25,925	73	3.840	56.89	2.155	0.025
Total	**G4**	**372,971**		**56.467**	**832.29**	**31.487**	**0.363**
Vessels w/Inboard Engines	D	12,237	88	0.578	1.38	3.286	0.097
Sailboats w/Auxiliary Engines	D	7,619	10	0.004	0.01	0.021	0.001
Total	**D**	**19,856**		**0.582**	**1.39**	**3.307**	**0.098**
GRAND TOTAL		**1,039,698**		**689.801**	**1917.43**	**39.252**	**34.365**

Table 10. Statewide exhaust emissions in tons/day for calendar year 2010 with US EPA regulation for spark-ignition marine engines.

Equipment Type	Fuel/ Cycle	Population	Usage (hrs/yr)	ROG	CO	NOx	PM
Vessels w/Outboard Engines	G2/G4	348,606	48	38.312	71.33	2.231	3.748
Sailboat w/Auxiliary Engines	G2/G4	4,780	10	0.064	0.11	0.003	0.005
Personal Water Craft	G2/G4	293,485	65	137.440	253.57	31.819	30.151
Total	**G2/G4**	**646,871**		**175.816**	**325.01**	**34.053**	**33.904**
Vessels w/Inboard Engines	G4	88,699	93	17.465	252.51	9.510	0.109
Vessels w/Outboard Engines	G4	17,805	48	0.290	4.56	0.175	0.002
Sailboat w/Auxiliary Engines	G4	3,799	10	0.004	0.07	0.002	0.000
Vessels w/Sterndrive Engines	G4	236,743	73	34.869	518.26	19.646	0.228
Vessels w/Inboard Jet Engines	G4	25,925	73	3.840	56.89	2.155	0.025
Total	**G4**	**372,971**		**56.467**	**832.29**	**31.487**	**0.363**
Vessels w/Inboard Engines	D	12,237	88	0.578	1.38	3.286	0.097
Sailboats w/Auxiliary Engines	D	7,619	10	0.004	0.01	0.021	0.001
Total	**D**	**19,856**		**0.582**	**1.39**	**3.307**	**0.098**
GRAND TOTAL		**1,039,698**		**232.895**	**1158.74**	**68.845**	**34.365**

The increase in total NOx emissions compared to uncontrolled 2010 level is due to the fact that emission rates reflecting US EPA's rule assume that the majority of the 2-stroke technology will shift to cleaner technology such as direct injection, Ficht, or 4-stroke technology.

Comparison with SIP Numbers

Table 11 contains the tons per day estimate from the 1994 State Implementation Plan (SIP) for the State of California for cy 1990. Compared to the 1990 ROG+NOx tpd inventory, the proposed inventory is 63% higher than the SIP inventory. SIP inventory is based on a study conducted by KVB, Inc. entitled "Inventory of Emissions from Boating Sources in California" dated 1980. The methodology used to calculate emissions estimates for pleasure craft for the SIP inventory is different than the methodology proposed in this document. The main differences are outlined below:

1. In SIP methodology, activity of boats is estimated in terms of fuel consumption by types of waterways which are lakes, rivers, delta areas and coastal areas . In current methodology, activity is estimated in hours per year usage by boat types which are outboards, pwc, sailboats, inboards etc. In order to assess the magnitude of changes in activity between SIP and current calculations, current activity estimates in grams per hour are converted to gallons per year. In SIP methodology, statewide fuel consumption for 1990 was estimated to 147,966K gallons per year compared to current estimates of 161,467K gallons per year. This accounts for 9% increase in fuel usage per the proposed methodology.

2. In SIP methodology, emissions factors in pounds per gallon by waterways are used compared to current methodology where emissions factors in grams per horsepower-hour are utilized. In order to directly compare emissions factors (as shown in Appendix G) between the two methodologies, emission factors for pwc are compared by obtaining current emission factors in pounds per gallon from SAI report and combining SIP emission factors by waterways as one composite emission factor. Analysis indicated that the SIP TOG+NOx emission factor is 562 pounds per 1000 gallon compared to current estimate of 2223 pounds per 1000 gallon . This accounts for 296% increase in emission factor per the current methodology.

Table 11. Statewide Exhaust Emissions Inventory of Pleasure Craft for Calendar Year 1990 used for the SIP.

Equipment Type	Fuel Type	ROG emissions	NOx emissions
Recreational Boat	Gasoline	122.46	16.03
Recreational Boat	Diesel	1.61	4.57
Recreational Boat	**Total**	**124.07**	**20.60**

Figure 1. Percentage Growth of Each Pleasure Craft Equipment Type

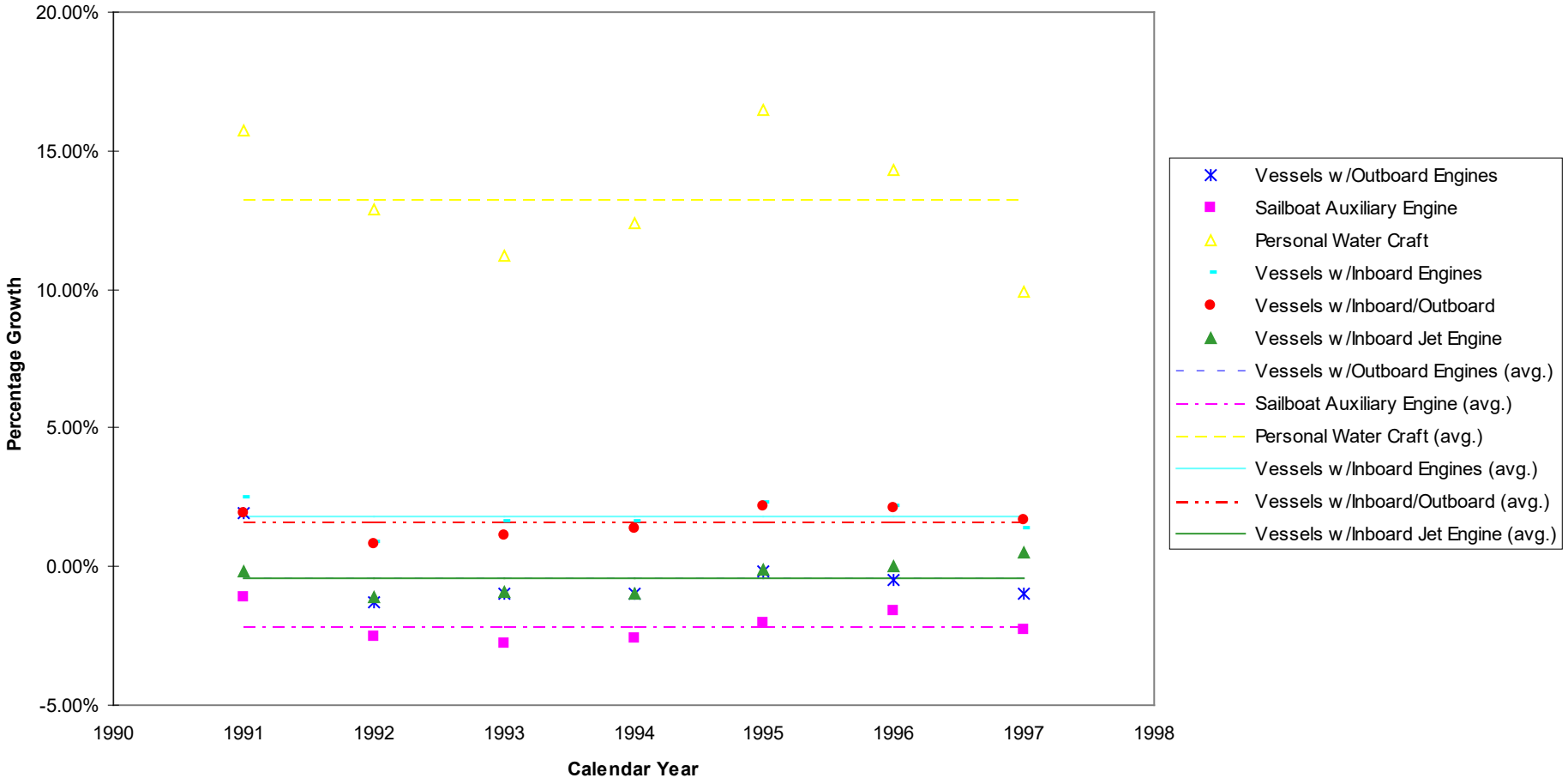

Figure 2. Pleasure Craft population from DMV database