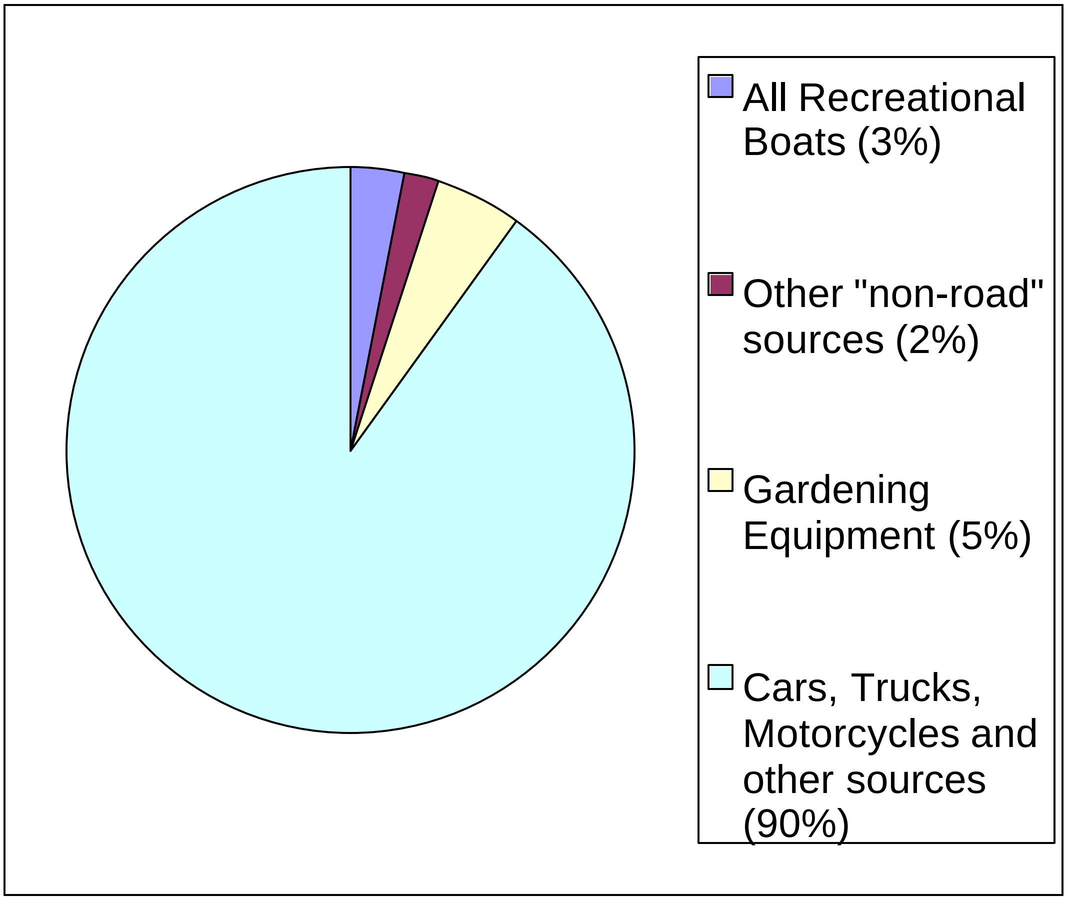
U.S. HYDROCARBON STATISTICS

Source: U.S. Environmental Protection Agency



***All recreational motorboats in the United States account for only 3% of the total Hydrocarbon emissions.**

*** Personal Watercraft make up only 8% of the recreational motor boat fleet in the United States (*Source: National Marine Manufacturers Association*).**

*** Personal Watercraft only account for approximately .024% of the total Hydrocarbon Emissions annually in the United States.**

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
ANN ARBOR, MICHIGAN 48105

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MEMORANDUM

SUBJECT: The Effects of Marine Engine Exhaust Emissions on Water Quality: Summary of Findings of Various Research Studies

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TO: Public Docket No. A-92-28

1. Brief Overview

EPA is currently in the proposal stage of a rulemaking that seeks to regulate emissions of pollutants from new nonroad spark-ignition and compression-ignition marine engines. That rulemaking, which is the subject of this docket, addresses the problem of marine engine pollution primarily by examining the effects of these emissions on ambient air quality. The regulations, test procedures and standards focus on measuring and reducing pollutants released into the air, not into the water.

However, marine engine exhausts may also have an impact on water quality. Many marine engines are designed to vent exhaust gases directly into the water. Other marine engines, those designed to vent exhaust gases into the air, may also affect water quality given the close proximity of exhaust release to the water. Thus, it can be argued that a rulemaking that seeks to control emissions of pollutants from marine engines should consider their impact on water quality as well as air quality.

This memo explores the necessity of explicitly considering, in the context of the proposed marine engine rulemaking, the effects of marine engine exhaust emissions on the marine environment. It consists of a summary of findings of several research studies that examine the effects of those exhaust emissions on water quality.

Several of these authors find that concentrated levels of marine engine exhaust emissions do have an impact on marine ecosystems. However, at the concentrations at which they actually occur, most researchers conclude that these effects are small and, in most cases, do not adversely affect most marine plants and animals.

These studies suggest that the impact of the exhaust from these engines on the marine environment may not be large enough to warrant additional regulations to address water quality separately. In addition, efforts made, through the marine engine rulemaking, to reduce the levels of pollutants in marine engine exhaust that are released into the air will also act to reduce the levels of these pollutants that are released into the water. As a result, the proposed regulations will lessen any adverse impact those emissions currently have on water quality.

The remainder of this memo consists of six sections. Section two discusses the nature of the studies examined. Section three briefly describes how marine engine exhaust emissions enter the ecosystem, and how their effects are reduced by evaporation, lessening water quality impacts while increasing air quality impacts. Section four discusses several crude pollution level thresholds that have been estimated by various authors and how they can be interpreted with regard to water quality. Section five examines in greater detail the impact of marine exhausts on specific elements of the marine environment: water quality, sediments, flora and fauna. Section six discusses the extent to which it is possible to separate the effects of marine engine exhaust pollution from other sources of the same pollutants. Finally, section seven summarizes EPA's conclusion on this issue.

2. Description of Studies Examined

To assess the impact of marine engine exhaust emissions on water quality, I examined the eleven articles enumerated in the attached bibliography. These articles vary in scope from the examination of the specific conditions of particular lakes to laboratory studies. Although the articles surveyed are not an inclusive list of all research on this topic, three of the sources (Milliken, Wagner and Chmura) are summaries of other studies which, I believe, sufficiently capture the consensus of the literature they review[1].

The subjects, as well as the research techniques, vary from study to study. Some researchers focused their attention on the properties of sediments, as evidenced in core samples, while others

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[1]In several instances, the studies surveyed in these summaries overlapped. In those cases, the studies are described in similar fashion, increasing my confidence in the descriptions of their content and conclusions.

were more interested in general water quality, as evidenced by the presence of pollutants in the water, plants and animals, as well as sediments. Some studies focus on the presence of lead or other trace metals, others on hydrocarbons.

Because of the diversity of the studies surveyed, it is not possible to pool their data and draw any overarching conclusions. The authors were studying different lakes, different conditions, and different organisms at different times. Therefore, the analysis in this memo focuses on a comparison of the conclusions of these studies, and not specifically on their data analysis or research conditions. Before turning to a description of these conclusions, the next section briefly describes how marine engine exhaust emissions enter the marine environment, and how some of their effects are mitigated by evaporation.

3. Sources of Pollution

Marine engine exhaust emissions pose a special environmental problem because they consist not only of the gaseous exhaust from the combustion process but also, especially in the case of two-stroke engines, a mixture of unburned oil and fuel. Current technology spark-ignition two-stroke engines, which are widely used in marine vessels, do not use fuel efficiently. An unburned fuel/oil/air mixture is used to push the exhaust gas out of the cylinder (this is called "scavenging"). As a result, a substantial portion of the unburned fuel and oil is pushed out of the cylinder with the exhaust gases. As much as 25 percent of the fuel consumed is wasted in this way. Many studies of the impact of marine engine exhaust emissions focus on the impact of this unburned oil and fuel rather than on gaseous emissions. There are at least two implications of these discharges of unburned fuel and oil, regarding their evaporation and the impact of the proposed regulations.

First, the impact of these emissions on the aquatic environment is mitigated to a large extent by the evaporation process. Oil and fuel are volatile compounds that evaporate into the air, which reduces the amounts of these compounds that persist in water and that can reach levels concentrated enough to pose danger to the marine environment. Based on their study of evaporation rates, the Rensselaer report concludes that "a considerable fraction of exhaust products can be expected to evaporate from the water surface to the air at temperatures normally encountered during periods of the year when boating is at a maximum level. For the exhaust products studied, it was found that approximately 65% was removed from the surface by this mechanism" (Rensselaer, 1974, p. 2). The following table, taken from that study, shows that considerably more can be removed, depending on the type of fuel and the temperature conditions. This table reflects the results of several tests that were performed to determine the evaporation rates for four compounds: undiluted

Mobil gasoline, exhaust products from a 33 hp Evinrude engine operating at 1200 rpm, a mixture of gasoline and oil (50:1 mix), and undiluted Mobil outboard super oil SAE 40.

Table 1
Evaporation Rates for Various Compounds

Substance	Temperature (°C)	Cumulative Time (hours)	Cumulative Evaporation (percent)
Mobil Gasoline	5	1.1 - 1.4	63 - 65
	10	1.2 - 1.5	60 - 68
	15	1.2	73 - 74
	20	1.1 - 1.2	72 - 76
	25	1.2	82
	30	1.2	88
Exhaust products 33 hp Evinrude @ 1200 RPM	5	1.5	28
	10	1.5	32
	15	1.4	38
	20	1.5	45
	25	1.5	53
	30	1.4	60
Gasoline plus oil (50:1) mix	5	1.2	63
	10 50	1.3	62
	15 59	1.2	70
	20 68	1.2	73
	25 77	1.2	78
	30 86	1.2	84
Mobil outboard super oil SAE 40	25	1.3	0.2
	30	1.3	0.01 - 0.01

(From Rensselaer, pp. 209-215)

This table illustrates that undiluted gasoline, exhaust emissions, and oil/gas mixtures evaporate quickly, while undiluted oil takes much longer. The authors note, however, that caution needs to be exercised in interpreting the results in this table:

> ... the evaporation rates reported here must be considered specific to the materials and conditions used in these tests. It would be expected that other gas/oil rations, other brands of fuels, other engines, and other operating conditions would give different specific rates. The trends reported here, however, are considered to be significant and typical of the rates of evaporation to be expected of the exhaust products discharged (Rensselaer, p. 231).

This is especially important since the formulation of Mobil gasoline and/or outboard super oil, for example, have undoubtedly changed since the time of their research (early 1970s), which would also have an impact on the results for the exhaust products from the Evinrude 33 hp engine.

The Boating Industrial Association study reports somewhat different evaporation rates for exhaust products, but they also used a much simpler test process and a 1.5 hp engine. The important difference is that these authors find a much slower evaporation rate for quiescent, as opposed to aerated, water: "the half life for volatile aromatics uniformly dispersed to a depth of 1 meter in a quiescent body of water at a temperature of 20°C was determined to be approximately 11 days" (Boating Industrial Association, p. 36). However, they note that "this condition of no turbulence would be most unusual in a natural lake situation. A fairly rapid disappearance of volatile aromatics from the condensable phase can therefore be expected in the natural water systems" (ibid). This is because turbulence from the boats, as well as natural processes, keep the water moving. In this study, the difference in half life in laboratory conditions was 11 days for quiescent water, as opposed to less than a day for aerated water (Boating Industrial Association, table p. 37).

The second implication concerns the impact of the proposed regulations on marine engine exhaust emissions. Specifically, the amounts of these compounds entering the marine environment through the exhaust process will be greatly reduced by the proposed regulations, because emissions of such magnitude would fail to meet the proposed standards. As proposed, emissions will be measured before they enter the water; therefore, the amount of emissions in the air and water will be greatly reduced. Since the test procedure will catch all emissions from the engine, those entering the air as well as those entering the water, the regulations will not create an incentive for manufacturers to solve the air exhaust emission problem by making the water emission problem worse. Finally, implementation of the proposed regulations is likely to encourage the widespread use of 4-stroke technology, direct injection technology, or other "clean" technologies. These technologies use a more complete combustion process and do not use air/fuel scavenging of exhaust. As a result, more fuel will be burned in the engine instead of being exhausted unburned, which will mean less oil and fuel in the water.

The next two sections discuss the effects of the portion of the marine engine exhaust emissions that do not evaporate but, rather, persist in the water. The following section contains a discussion of various threshold levels. The section after that examines the effects of marine exhaust emissions on water quality, sediments, flora and fauna.

4. Thresholds

A simple way to examine the effects of marine engine exhaust emissions on water quality is to look at thresholds for easily observable phenomena, such as detectable odor and oil film, and assess their consequences for fish flesh tainting. While this type of analysis is admittedly crude, since these thresholds may or may not correspond to pollution levels that adversely affect marine life in more profound ways, observable thresholds are an indicator to most people that a potential environmental danger is present.

a) Odor Threshold

With regard to detectable odor, estimated threshold dilution rates range from approximately 1.3 million to 3 million gallons of water to 1 gallon of fuel burned (English et al. and Kuzminski et al., cited in Wagner, p. 80, Milliken, p. 5, and Chmura, p. 20; US EPA, cited in Milliken, p 5). This is approximately equivalent to 3.7 million to 9.3 million gallons of water to 1 gallon of exhaust discharge (Kuzminski et al, cited in Wagner, p. 80). To achieve this threshold, Wagner estimates that, for "an average fuel consumption of 0.5 gallons per hour (typical range for smaller recreational boats = 0.1 to 1 gal/hr), 2.6 million gallons of dilution water would be needed per hour of operation." At that rate, "[a] 100-acre lake with an average epilimnetic (mixed) depth of 20 feet ... *without considering flushing rate or decomposition of discharged fuel* ... could support over 250 hours of boat operation without acquiring a detectable odor" (Wagner, p. 80, emphasis added). Thus, if it were possible to control a sample lake such that there was no flushing and no dissipation of discharged fuel, the lake could tolerate 250 hours of boating activity before an odor would be noticed.

Wagner further indicates that this threshold is not likely to be achieved in actual lake conditions. He states that

> ... the quantities [of exhaust discharge] necessary to impart a perceptible taste or odor would necessitate a high density of motorized watercraft. While the need for millions of gallons of dilution water per gallon of

exhaust discharge may seem high, the water volumes typically encountered in the open lake environment are far greater (Wagner, p. 86).

This threshold for odor yields a first-cut impression of the level of activity needed to produce an easily discernable level of fuel and oil pollution. The two caveats noted by Wagner (no flushing on the lake and no dissipation of discharged fuel) suggest that an actual lake with the described characteristics could support a concentration higher than 250 hours without odor problems, because there would be flushing and dissipation. However, it should be noted that this refers to conditions on the lake and not in a marina. In a marina, boat activity is more concentrated and odor effects are likely to be more noticeable.

b) Oil Film Threshold

With regard to oil film, it takes approximately 25 gallons of fuel per square mile (640 acres) to generate a barely perceptible surface film, 100 gallons of fuel per square mile for a colored sheen, 200 gallons of fuel per square mile for a very visible film, and 1,332 gallons of fuel per square mile for an oil slick (Jackivicz and Kuzminski, cited in Wagner, p. 80). Rensselaer indicates that it takes approximately 38 mg of oil per square meter to produce a barely visible film, which is approximately the same as 25 gallons of fuel per square mile (Rensselaer, p. 33).

According to Wagner, "[a]t the 10 percent waste level and a fuel consumption rate of 1.0 gallons per hour, a motorized watercraft operating for 8 hours would release 0.8 gallons of fuel; therefore over 31 such motorized watercraft would have to operate continuously for the same 8-hour period in a 640-acre area to produce a barely evident film" (Wagner, p. 80). He notes that

> [g]iven the volume of fuel necessary to produce a visible oil film, visual detection of motorized watercraft impacts outside of marinas is unlikely. Even within a marina, runoff from adjacent parking lots may prove to be a greater source of hydrocarbon films than watercraft (Wagner, p.84).

This is illustrated by the oil measurements taken at Lake George, described in the Rensselaer study. Lake George, located in Upper State New York, measures approximately 44 square miles (28,160 acres). On a typical holiday weekend in the early 1970s, this lake hosted 12,000 to 14,000 boats with an average hourly loading of 800 to 1,000 boats (Rensselaer, p. 6), for a boating activity level of approximately 3 to 5 boats per 100 acres. This activity level is well below that needed to exceed either the odor or oil film thresholds and, in fact, this study reports a measured oil level of 5 mg oil per square meter, which is "well below that found to cause a 'barely visible' film" (<u>i.e.</u>, 38 mg per square meter, Rensselaer, p. 33). This level increased over holiday weekends, which have more congested boating activity, to as high as 22 mg/m^2, which is still lower than the level found to cause a barely visible film (ibid).

c) Effects of Boating Activity Levels

As indicated above, exceeding threshold for either odor or oil film depends a great deal on boating activity levels. With regard to the odor threshold, Wagner notes that a 100-acre lake with an average depth of 20 feet can support 250 hours of activity before the odor threshold is reached, not considering flushing or decomposition. This represents approximately 31 boats operating continuously over an 8-hour period on such a lake, yielding a density of 31 boats per 100 acres. For a more shallow lake, however, the tolerable level of activity would be lower. For example, a lake with an average depth of 10 feet could support only approximately 15 boats running continuously over an 8-hour period before the water acquires an off taste, again not considering flushing or decomposition. At the same time, when flushing occurs and when the decomposition of discharged fuel is considered, the number of boats operating continuously that would result in an exceedence of the threshold would certainly be higher.

The oil film threshold is exceeded at lower levels, according to Wagner. As noted above, a 640 acre (1 square mile) lake can support 31 boats operating constantly for 8 hours before a barely perceptible oil film is produced. This is an activity level of approximately 5 boats per 100 acres. To achieve the detectable oil film threshold would require 100 boats operating constantly on the same lake, or an activity level of approximately 15 boats per 100 acres.

To determine whether these levels of activity are typical, they must be compared with actually boating activity. Assessing boating activity is beyond the scope of this memo and requires examining the activity of specific lakes at specific times. However, an idea of boating activity levels can be obtained by looking at surveys that measure the level of boating activity that boat operators prefer. Wagner indicates that, according to a 1990 poll, recreational boat users prefer a density of 4 boats or less per 100 acres for all purposes and 10 boats per 100 acres for racing; at 20 boats per acres "nearly all motorized watercraft users feel crowded" (p. 80; Baystate notes that "boaters like approximately 10 acres to themselves" (p. 173)). The odor threshold of 31 boats per 100 acres based on an average lake depth of 20 feet is well above these preferred activity levels; the threshold of 15 boats per 100 acres based on an average lake depth of 10 feet is not.

For comparative purposes, these hypothetical average lake sizes should be compared to actual average lake sizes. Again, it is beyond the scope of this memo to estimate average lake surface and depth for all lakes. However, these hypothetical values can be compared to the measurement of lakes in the State of Wisconsin. According to the most recent data on lake characteristics compiled by the Wisconsin Department of Natural Resources (1991), the average surface area of the 14,974 lakes in the State of Wisconsin is 85 acres, broken down as follows:

Table 2
Average Lake Size - State of Wisconsin

Lake Size (acres)	Total	Unnamed		Named	
0-24	11,821	8802	74.4%	3019	25.6%
25-49	1,131	125	11%	1006	89%
59-99	829	25	3%	804	97%
100-199	511	0	0	511	100%
200-499	414	0	0	414	100%
500+	268	0	0	268	100%
TOTAL	14,974	8,952	60%	6,022	40%

(Source: Wisconsin DNR, pp. 6-11).

The depth of Wisconsin lakes ranges from 1 feet to 236 feet. Average lake depths are not provided for all lakes. However, for those provided, average depth is approximately 12 feet.

This means that the 15 boat per 100 acre estimate is probably the boat activity density level that should be used to consider if the odor threshold is likely to have been surpassed for an unflushed lake without considering decomposition. Again, the tolerated level is likely to be higher on a lake that is flushed and when decomposition of fuel is taken into consideration. When these are considered, the density level is probably one at which boaters do not feel comfortable operating their boats (20 or more boats per 100 acres).

d) Fish Flesh Tainting

There is some disagreement with regard to the threshold levels of fuel and exhaust for fish flesh tainting. These range as low as 6 ppm of fuel burned (6 gallons of fuel burned per million gallons of water, English, et al., cited in Wagner, p. 90), 8 ppm (English et al., cited in Milliken, p. 5), to as high as 110 ppm (Boating Industry, p. 47). However, the Boating Industry report does not describe how those taste tests were performed, and it could be that the high 110 ppm value was due to the nature of the testing process.

Regardless of which measure is used (6 ppm or 110 ppm), it is clear that fish tainting is unlikely to occur without there also being a perceptible odor. As noted above, it takes only 1.3 ppm to 3 ppm of fuel burned to produce an odor, while it takes 6 ppm or 110 ppm of fuel burned to produce an off taste in fish. Therefore, as Wagner notes, "if there is no water odor, fish flesh tainting is unlikely" (Wagner, p. 90). Based on the above discussion, this is unlikely to occur at a boating activity level at which boaters are comfortable.

5. Impact of Marine Engine Exhausts on the Marine Environment

While thresholds of easily observable phenomena may be useful for detecting gross environmental dangers and the likelihood of fish flesh tainting, they are not sufficient for detecting the more subtle effects that marine engine exhausts may have on the marine environment and the organisms that inhabit it. In fact, lesser amounts of these pollutants may cause serious harm to marine plants and animals. However, most studies indicate that, although many of these pollutants are potentially harmful, they do not occur in concentrations high enough to cause serious environmental damage.

a) Water Quality Effects

Based on the studies reviewed for this report, the overall water quality effects of marine engine exhaust gases do not appear to be significant in general. Hydrocarbon emissions similar to those of motor vehicles do not pose the same danger to water as they do to the air since, because of their volatility characteristics and natural degradation processes, they do not remain in the water (Wagner, p. 84; see discussion on evaporation above). In addition, Wagner notes that although "phenolic compounds have been cited as the most troublesome exhaust component" in earlier studies, the problem has been alleviated by engineering advances (English and Kuzminski, cited in Wagner, p. 84).

Rensselaer concurs with this conclusion. Their study of Lake George found "the presence of very little soluble or dispersed products from exhaust. Levels were generally less than 0.1 ppm" (p. 1).

Finally, although Trocine and Trefry discovered elevated trace metal concentrations in water in connection with their research on the Indian River Lagoon System in Florida, they note that the likely sources are antifouling paints, runoff, and power generation wastes, not recreational marine engine exhaust emissions (Trocine, p. i).

b) <u>Sediments Effects</u>

Studies of the effects of marine engine exhausts on sediment quality based on field work generally find the presence of some objectionable compounds in the sediments. However, these studies also note that marine engine exhausts are not the sole source of these compounds. Also, it should be noted that the effects of engine exhaust products and fuel spills on sediments depends on the characteristics of the sediments, as to their size and chemical makeup (Wagner, p. 81).

With regard to sources of phenolic compounds, spills are a likely source. Again, spills have only limited impacts on recreational lake water quality. Wagner finds that it is not likely that spills will occur that are large enough to damage sediments in freshwater lakes, outside of marinas. Also, fuel spills are less dangerous than crude oil spills, in that fuel spills generally evaporate "or form an emulsion with water and never reaches the lake bottom" (Wagner, p. 86-7). This does not mean, however, that there is no potential for contamination. However, it is not likely to occur as a result of typical usage of marine vessels.

One clear danger from the discharge of engine exhausts from pleasure craft comes from the presence of lead in the fuel. However, this was more of a problem in the past, when unleaded fuel was used more commonly. Also, as Wagner points out, there are other, perhaps more important sources of this and other metals, such as runoff or atmospheric deposition (Wagner, p. 87).

Empirical studies confirm many of the above observations. For example, the Baystate study of Watchaug Pond in Rhode Island finds that, pursuant to their examination of core samples of sediments,

> ... 10 polyaromatic hydrocarbon compounds (PAH's) were found in detectable quantities in the upper 8-10 cm of the cores. This represents at least a 30 to 50 years time period... The detected PAH's are generally combustion products which could have entered the pond via motorized watercraft, runoff from surrounding land, or atmospheric deposition. It is assumed that motorized watercraft are at least partially responsible for the observed concentration, which were distinctly above anticipated background levels for pristine systems but not high enough to represent a clear ecological or human health hazard (Baystate, p. 173).

In their research regarding the Indian River Lagoon System in Florida, Trocine and Trefry found that, in general, the levels of many trace metals in sediments (Cd, Cr, Cu, Pb and Zn) did not exceed Florida guidelines for natural sediments. Those areas showing elevated levels were areas with high concentrations of industrial, marine and wastewater activities (p. i; the marine sources are generally ports and harbors). In their review of the literature, they cite a 1980 study that found "a dramatic increase in copper concentrations in the harbor environment [sediments]," but those concentrations were attributed to marine anti-fouling paints and not to marine engine exhaust emissions (Trocine, p. 78).

Rensselaer also examined sediments, in connection with their study of the effects of exhaust emissions on Lake George. They conclude that "the hydrocarbons detected in Lake George sediment extracts are 'native' or natural to these sediments - that their presence in the sediment was not due to man-induced sources" (p. 183).

Pecor also examined lead concentrations in sediments, in Lake Houghton, Michigan. He found that only seven of his twenty samples "had detectable lead concentrations" and that those levels (8.1 to 93.0 ppm dry weight) "were within the range found at background stream water quality stations throughout Michigan" (1.0 to 96.0 ppm dry weight, p. 26). He also did not find unusually high lead elevations near marinas, where he found lead concentrations of 5.9 and 65.0 ppm dry weight (ibid). Chmura and Ross, citing Kuzminski and Mulcahy, indicate that "almost all of the lead discharged eventually reaches bottom sediments (p. 19).

c) Effects on Flora

Most of the damage to flora attributed to marine craft is caused by propeller damage or turbulence (Wagner, pp. 87-8). However, Wagner argues that even this damage is "minor when compared to natural processes such as wind-induced mixing or massive rises in vacuolate cyanophites" (Wagner, p. 87, see also Chmura and Ross, pp. 16-17).

With regard to algal growth, several studies find that concentrated levels of marine engine exhaust emissions can adversely affect these organisms. Wagner notes that "in standard bioassays, it took a dilution ratio of less than 13,333 gallons of water to one gallon of engine exhaust to inhibit the growth of *Selenastrum*, and a ratio of less than 3333:1 to kill the algae" (from Kuzminski and Fredette, 1974, cited in Wagner, p. 87). However, he notes, typical dilution ratios are much higher than this. Based on their study of Lake George, Rensselaer concludes that "the data do not afford any significant correlation between kinds and number of algae present, and boat traffic" (Rensselaer, p. 1).

d) Effects On Fauna

Much of the impact of motorized pleasure craft on fauna has to do with how they disrupt the natural habitat, with regard to turbulence, noise and disturbance of nesting areas, and not with exhaust emission effects (Wagner, p. 90). Nevertheless, exhaust emission compounds do have an effect on fauna, although, again, these effects are small. The following is a brief discussion of several studies that examine these effects.

With regard to habitat, Wagner finds that the substances discharged from motors are not generally toxic at occurring concentrations. Milliken's review of the literature indicates that "normal levels of outboard motor usage have not been shown to have a toxic effect on aquatic communities" (p. 5). Wagner notes that "typical dilution of engine exhausts in even a marina setting would result in exhaust concentration of far less than 1 percent, suggesting that observable mortality from chemical contamination of lakes by motorized watercraft is unlikely... Unless motorized watercraft use is persistently elevated in an isolated area with limited flushing, chronic effects are highly improbable" (Wagner, p. 90).

Many researchers have studied the effects of engine exhaust products on marine organisms and animals in laboratory settings, at high concentrations for long periods of time. For example, Tjarnlund finds adverse effects on DNA adducts in perch. Those fish were exposed to emission-tainted water at a level of 5-10 microliters fuel per liter of water for 54 days. Again, this level of exposure, approximately 5-10 ppm, is unlikely to occur without a corresponding visible oil film or perceptible odor, which is not the normal condition in most lakes. The authors themselves note that these levels of exhaust "would correspond to fish living in or rather close to the wake" (Tjarnlund, p. 2).

With regard to flesh tainting, Wagner notes that this can occur "after multiple weeks of exposure at dilution rations less than 6,000,000:1. The maximum dilution that produced flesh tainting is of the same magnitude as the odor threshold. Therefore, he notes, if there is no water odor, fish flesh tainting is unlikely" (Wagner, p. 90).

An interesting case with regard to the effects of marine engine exhaust emissions on fish is reported by Black with regard to the Fox River. This river had been subject to period fish kills for approximately 30 years, the largest one being over Memorial Day weekend in 1988, when approximately 30,000 fish died (Black, p. 6). An investigation revealed that the kills were due to exhausts from an outboard motor manufacturer test field. The firm in question "tests as many as a dozen prototype motors at a time. Mounted on boats that are tethered along the shore, they can collectively burn as much as 4,000 gallons of gas a day and generate up to 3,000 horsepower" (Black, p. 7-8). The study concluded that the fish died of carbon monoxide poisoning associated with the discharge of CO in the water from these engines. However, the fish kills were due to a combination of unusually high concentration of CO in the water due to the test facilities and warm weather. The study concludes that "the amount [of CO] put into lakes by normal outboard motors is generally so small and the lakes so large that there is little to be concerned about" (Black, p. 9).

Milliken notes that "toxic effects have been demonstrated from sustained low concentrations of petroleum in estuaries" (p. 5). The key here is *sustained* low concentrations, which are unlikely to occur outside of marinas.

Table 3
Estimated Toxic Concentrations of Soluble Aromatic Fractions of Petroleum Hydrocarbons for Marine Organism

Class of Organisms	Toxic Concentrations (ppm)
Larvae (all species)	0.1 - 1.0
Swimming crustaceans	1-10
Bottom-dwelling crustaceans	1-10
Other bottom-dwelling organisms (worms, etc).	1-10
Snails	1-100
Finfish	5-50
Bivalves	5-50
Flora	10-100

(Source: United Nations, 1982, in Milliken, p. 6.)

Pecor's study of Lake Houghton, Michigan, found that "lead was detectable in a majority of macroinvertebrates and fish analyzed" (p. 26). In this case, he found that "lead levels appear to be higher in Houghton Lake fishes, but insufficient data prevented statistical analysis" (p. 27).

With regard to animal effects, Trocine and Trefry found evidence of trace metals in clams, the only marine life they examined. However, they note that the clams "were most contaminated in proximity to power generation facilities and stormwater outfalls" (p. 57). In their review of the literature with regard to Indian River Lagoon, they note that there was a large fish kill in 1980, when approximately 100 red drum fish died due to elevated levels of AS, Cu and Zn. However, it is unclear what was the source of those metals; the author of that report suggested the source was blue crabs (p. 75).

Rensselaer concluded, based on their study of the effects of engine exhausts on the benthic community (bottom animals), that "the diversity indices for all bays exceeded or bordered the values considered indicative of unpolluted waters. The taxonomic variation was extremely high and contained many forms generally considered intolerant of nutrient loadings and toxic conditions" (p. 166). This was true of shallow, as well as deeper, bays (p. 168).

The Boating Industrial Association also looked at the effects of engine exhaust on fish. Under laboratory conditions, fish were exposed to outboard engine exhaust condensate, diluted with dechlorinated tap water, in a controlled environment. They found that

> the [mean tolerance limit for 96-hour exposure] for the pure aromatics and the condensate are two to three orders of magnitude higher than those aromatic levels found in a test pond ... which had been subjected to outboard usage at very high levels. Carbon monoxide, even at near-saturation levels, did not produce fish mortality. Thus it is concluded that outboard exhaust is not implicated in acute toxicity (sic) under normal boating conditions (pp. 36-9).

They also looked at the effects of marine engine exhaust on various organisms in four ponds (two located in Michigan, two located in Florida). Their findings indicate "some marginal changes in the lakes' biota ... but the differences were such that it is not certain whether they were from natural or stress effects. As a result, it was not possible to determine conclusively the precise point at which outboard emissions affect the aquatic environment. Based on the results, it is plausible to conclude, however, that because of the high stress levels employed in this study, outboard motor emissions do not significantly affect aquatic ecosystems" (p. iv).

Thus, the above evidence confirms Wagner's conclusion that "unless motorized watercraft use is persistently elevated in an isolated area with limited flushing, chronic effects are highly improbable" (Wagner, p. 90).

6. Marine Motorcraft as a Source of Pollutants

As a final point, it should be noted that many authors are hesitant about attributing all of the measured levels of pollutants associated with exhaust products found in lakes to watercraft. As Wagner notes, "[e]ven within a marina, runoff from adjacent parking lots may prove to be a greater source of hydrocarbon films than watercraft" (Wagner, p. 84). He further notes that "similar impacts from other sources may overshadow those from motorized watercraft, and it is not always possible to separate the effects of motorized watercraft from those of other watercraft or land-based activities" (Wagner, p. 92).

Pecor also emphasizes the point that outboard engines are not the only source of lead found in water and streams. He states that "lead is contributed from a variety of sources (atmospheric fallout, surface drainage, snowmobiles, etc.) besides outboards" (Pecor, p. 27). The contribution of marine engines to lake and sediment lead levels is reduced through the use of unleaded gasoline.

Chmura and Ross also note that land-based activities can be an important source of pollutants. Surface runoff from marina facilities "can carry a variety of pollutants, including sediment, pesticides, oil and other road dirt, heavy metals, and nutrients, which are all capable of degrading water quality". They cite a 1972 study by Chen, Bowerman and Petridis, which found that storm sewers also contribute to the water quality problems in marinas: "heavy metals, such as mercury, cadmium and lead, precipitated and/or settled out of storm water within a short distance from its point of discharge," i.e., in the marina (Chmura, p. 4).

7. Conclusion

This memo has briefly evaluated the impact of marine engine exhaust emissions on water quality and the aquatic environment based on available studies. As described above, these exhaust emissions affect the marine environment in several ways: by producing an off odor, by producing an oil film, and by leaving traces of exhaust products that can adversely affect water quality, sediments, flora and fauna. At the same time, the studies examined appear to generally show that the levels of exhaust emissions found in most lakes are not so high as to impose harmful effects. In addition, it is not clear that presence of exhaust emission products is entirely due to boating activity; runoff, storm sewers and atmospheric fallout are other sources of these pollutants.

To the extent that marine exhaust emissions could cause some adverse water quality effects, these will be greatly reduced by the marine engine rulemaking, which will significantly reduce the amount of exhaust emissions entering the air and water.

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