EPA-670/2-75-064
June 1975

PB242177

ANALYSIS OF POLLUTION FROM MARINE ENGINES AND EFFECTS ON THE ENVIRONMENT

Summary Report

By

Boating Industry Associations
Chicago, Illinois 60611

Grant No. R-801799
Program Element No. 1BB038

Project Officer

Leo T. McCarthy, Jr.
Industrial Waste Treatment Research Laboratory
Edison, New Jersey 08817

NATIONAL ENVIRONMENTAL RESEARCH CENTER
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REVIEW NOTICE

The National Environmental Research Center, Cincinnati, has reviewed this report and approved it for publication in order that the data may be made widely available and serve as a basis for future studies by others, should they be desired. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency nor does mention of trade names or commercial products constitute endorsement or recommendation for their use.

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water and land. The National Environmental Research Centers provide the multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The northern lakes, southern lakes and laboratory studies were conducted by independent consultants who were subcontractors to the Boating Industry Associations. The project design was approved by the U. S. Environmental Protection Agency and monitored during the course of the study by EPA personnel. As a result of the studies and the contractors' analysis of the data, no significant environmental impacts from outboard motor boating activity were found under the study conditions. However, since it was impossible in this study to cover fully all the diverse factors which may be impacted by emissions from outboard motors, care should be taken in extrapolating the results to situations other than those covered by this specific study. These data are being presented in order that they may be widely available and serve as a basis for possible future studies by others should they be required in considering the implementation of regulations relating to the recreational utilization of the Nation's waters.

A. W. Breidenbach, Ph.D.
Director
National Environmental Research
Center, Cincinnati

ABSTRACT

This is a Summary Report of a research project which began in April 1971. The objective of the research was "to obtain sufficient laboratory and field data to be able to predict the number of outboard engines which can be operated on any particular body of water without causing adverse effects on the aquatic environment."

The project involved laboratory and field investigations. The laboratory phase was conducted by the departments of Civil and Mechanical Engineering of the University of Michigan. The northern lakes--field study was conducted by Environmental Control Technology Corporation, Ann Arbor, Michigan. The southern lakes--field study was conducted by Environmental Science and Engineering, Inc., Gainesville, Florida.

To achieve the project objective four ponds were subjected to outboard engine emissions at a rate calculated to be three times greater than that from saturation boating levels. Some marginal changes in the lakes biota were noted 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 effect 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.

This report was submitted in fulfillment of Grant Number R-801799 by The Boating Industry Associations under the partial sponsorship of the Environmental Protection Agency. Field and laboratory work was completed as of December 1975.

CONTENTS

FIGURES

TABLES

SECTION I

CONCLUSIONS

LABORATORY STUDY

1. Gas-phase carbon monoxide concentrations were closely related to the fuel/air ratio supplied by the carburetor, and ranged from less than 2 percent at 1,000 rpm for a 6 hp Evinrude engine to greater than 9.5 percent at 3,000 rpm for a 35 hp Chrysler engine. Dynamic fish toxicity studies showed that carbon monoxide, even at near-saturation levels, did not produce fish mortality.

2. Gas-phase carbon dioxide concentrations ranged from a low of approximately 3.5 percent to more than 9.5 percent, and were also principally a function of the fuel/air ratio.

3. No trend with speed and load was observed for either carbon monoxide or carbon dioxide emissions.

4. Total gas-phase hydrocarbon emission concentrations range from a low of 4,500 ppm measured as C_6H_{14} to a high of 10,000 ppm as C_6H_{14}. These concentrations, attributable to overscavenging, which in turn is related to engine trapping efficiency, generally decreased with increasing speed and load.

5. Engine trapping efficiency ranged between 50 and 80 percent and in general was observed to increase with engine speed.

6. Mass emission rates of both carbon monoxide and unburned hydrocarbons increased with increasing speed and load in the test engines. For example, the total hydrocarbon emissions ranged from less than 0.02 kg/hour for an Evinrude 6 hp engine at 1,000 rpm (0.2 bhp) to approximately 3 kg/hour for a 105 hp Chrysler engine at 4,000 rpm (50 bhp).

7. The composition of the gas-phase exhaust hydrocarbons resembled the composition of the fuel with the principal exceptions that the olefin concentration was greater and the paraffin concentration slightly less than in the test fuel. A moderate variation in composition was evident from engine to engine.

8. The condensable material from outboard engine exhaust was found to contain paraffinic, olefinic and aromatic hydrocarbons as well as small amounts of phenols and carbonyl compounds.

9. The composition of the total combined condensate was very similar to that of the fuel. Aromatic compounds constitute 20-25 percent of the total condensed hydrocarbon amount. Toluene is slightly lower on a percentage basis in the condensate than in the fuel, and binuclear aromatics are slightly higher.

10. The total amount of condensable material which can reasonably be expected to be condensed in a boating situation varied from about 1.5 - 7 percent of the fuel used.

11. Three engines were investigated for crankcase drainage: all exhibited the general trend of decreasing drainage with increasing engine speed and load.

12. At low speed and load test conditions the spread of the drainage results were relatively large. For example, at 1,500 rpm the average drainage for an 18 hp Evinrude was approximately 60 grams per hour whereas drainage from a 35 hp Chrysler was in excess of 275 grams per hour. At the 1,500 rpm test condition drainage, expressed as a percent of the fuel used, ranged from 3 percent for a 50 hp Mercury to in excess of 8 percent for a 35 hp Chrysler engine.

13. The oil composition of the crankcase drainage was about 20-30 percent. Since the ratio of oil to gasoline in the fuel was 1:50, crankcase drainage represents a 10-15 fold increase in oil content over the mixture fed to the engine.

14. Maintenance in the form of a conventional "tune-up" had little influence on either the gaseous or condensable emission characteristics of two field engines tested.

15. The aromatic constituents of the first stage condensate have an evaporation half-life of about 11 days in a lake or other water body, assuming conservatively, a quiescent body of water at 20°C, the condensate being uniformly distributed initially to a depth of one meter.

16. There is a small, non-volatile hydrocarbon fraction which is not removed by evaporation from water exposed to submerged two-cycle engine exhaust emissions.

17. 96-hour TL_M values for goldfish mortality were determined in dynamic bioassay tests as 9-10 ppm as toluene for outboard engine condensate.

NORTHERN LAKE STUDY

18. No significant differences were seen in periphyton diatom richness and species distribution between ponds during two years of study.

19. Although variable, organic production was not significantly different nor was chlorophyll a production different between ponds. However, when placed in the ratio of the autotrophic index there was a significant difference between the control and non-loaded treatment sections during the 1972 sampling period. These differences, reflected by higher index values in the treatment section, indicated more heterotrophic (nonalgal) communities under outboard engine stress conditions. This trend remained in 1973 but was not statistically significant.

20. Short term phytoplankton variations in species association between ponds were not significant. Species richness and population similarity never varied to a significant degree throughout the two year period.

Phytoplankton species associations varied annually in a manner indicative of natural lake systems.

21. Phytoplankton productivity measured by ^{14} carbon fixation indicated lower photosynthetic carbon production in both the non-leaded and leaded stress sections when compared to their respective control sections in most collections during 1971, 1972, and 1973. Of these differences, only the lower carbon production in the non-leaded stress section compared to its control during 1972 was significant. These differences cannot be directly attributed to natural population variations as species associations and richness were similar throughout the pond system during this study.

22. Chlorophyll a measurements of the phytoplankton recorded during 1973 showed no significant difference between the non-leaded test pond and its control pond. During 1973 a significant difference was recorded in chlorophyll a measurements between the leaded stress pond and its adjacent control pond.

23. Phytoplankton productivity index values showed no photosynthetic inhibition in terms of a ^{14} carbon production to chlorophyll a. Although only a few data points were anlayzed this index is felt to be legitimate and useful in studies of primary productivity.

24. Zooplankton population dynamics, comparative species richness, abundance, and occurrance were indicative of normal temporal periodicity encountered in small temperate lakes. No statistically significant effects on the zooplankton community can be attributed to the outboard motor emissions in the northern ponds.

25. The benthic macroinvertebrate community demonstrated normal variations in population compositon and dynamics. The 1972 shift in dominant organisms composing the benthic faunal assemblage was commensurate with the change in trophic structure of the ponds and could not be correlated with stressing by outboard motor emissions.

26. A single fish taste test in 1971 showed an alteration in the taste of fish taken from the stressed ponds at a treatment level of 32 gallons of fuel burned per million gallons. Subsequent fish taste studies during 1972, at treatment levels of 1.4, 1.5, 2.8, 4.0, 4.2, 11.2, 76.9 and 110.5 gallons of fuel burned per million gallons showed no taste alteration in the fish population.

27. No major variation in the general water quality of the test pond were observed as a result of stressing.

28. Field and laboratory studies during 1971 and 1972 on aromatic hydrocarbons (gasoline fraction) using the cyclohexane extraction - UV spectrophotometric procedure indicated little difference between stressed and control sections. The maximum concentration observed was 50 ug/l (as toluene) in the stress ponds. Both field and laboratory results indicate that the majority of these aromatic hydrocarbons remain in the water

column for a relatively short time, less than a day under conditions normally encountered in natural water systems, before they are removed by natural physical (evaporation), chemical (adsorption) and/or biological (bioxidation) processes.

29. No significant change in the concentration of saturated hydrocarbons with boiling points in the range of 175° to 400°C (corresponding to in molecular weight C_{10} to C_{24} n-paraffins) in the water column was observed as a result of three years of outboard engine stressing.

30. No statistically significant (95 percent confidence level) buildup of saturated hydrocarbons was observed in the test ponds sediments after three years of engine operation. The data collected in this investigation cannot rule out the buildup of these materials in the sediments. The research data collected to date indicate that any increase in saturated hydrocarbons present in the sediments involves saturates with carbon numbers C_{17} and above.

31. In the leaded fuel stress pond an increase in lead in the water column from an average background value of 4.3 to 5.7 parts per billion (ppb) was observed and is directly attributed to stressing by outboard engines using leaded fuels. In hard water lakes such as the northern study ponds, the concentration of lead in the water column is limited to approximately 10^{-7} M (20 ppb). In fact, during the study the maximum lead level observed in the leaded stress pond was 11.0 ppb. Consequently, under these conditions the effect of stressing with leaded fuel is minimal on the quality of the water column.

32. The use of leaded fuel in outboard engines may increase the level of lead in the bottom sediments. Results from this study, through not conclusive, do indicate that this may be taking place in the leaded test section.

SOUTHERN LAKE STUDY

33. The phytoplankton in the limnetic zone of the southern test lakes showed some temporal changes in species composition, standing crop, species diversity and primary productivity. These changes were primarily due to seasonal variations in temperature, light, and nutrient levels, and cannot be conclusively correlated with treatment effects of outboard motor operation.

34. Phytoplankton bioassays conducted *in situ* on a limited basis in the southern test lakes show outboard motor exhaust water at a ratio of 1:24 (ratio of exhaust water to lake water) to inhibit photosynthesis. This treatment level is 520 times the exhaust gas water concentration anticipated in waters receiving normal outboard motor usage. It is unrealistic to think that boat usage would reach this level on any recreational lake.

35. Growth rates and biomass of periphyton culture in the limnetic zone on artificial substrates were not affected by outboard motor operation in the southern test lakes.

36. In the southern test lakes, distribution, species composition and diversity of benthic macroinvertebrates were not affected by motor operation except in a small area immediately beneath the permanently mounted motors where scouring of the bottom sediments resulted from motor operation.

37. Motor operation in the southern lakes increased the concentration of dissolved aromatic hydrocarbons, mixed and circulated the lake water, and therefore distributed the hydrocarbon emissions as well as other emissions throughout the lakes. The concentration of aromatic hydrocarbons increased from background levels of less than 0.01 mg/l to levels of 1.0 mg/l during motor operation. When the motors were not operated for two days, hydrocarbon levels declined to less than 0.1 mg/l.

38. The level of dissolved organic carbon in the limnetic zone of the southern lake treated with drained type engines was significantly greater than both the control lake and the lake treated with drainless type engines. The drainless type engine has a recirculating device which eliminates crankcase drainage. The drained type engine does not have this device and therefore emits a greater amount of unburned fuel.

39. Fish tastes conducted by the University of Florida Food Sciences Department have demonstrated no evidence of tainting by outboard motor emissions even at treatment levels far in excess of those in the U.S. Public Health Service study where tainting was observed.

40. As a result of background sampling before treatment large amounts of lead (8 to 90 mg Pb/kg of dried plant tissue) were detected in the rooted vegetation of the grass bed community. Therefore, the effects of lead emissions on the southern lakes were not studied.

41. There was no overt evidence that treatment significantly affected the levels of the following chemical parameters in the southern lakes: iron, magnesium, chloride, sulfate, fluoride, total solids, suspended solids, dissolved solids, total hardness, conductivity, turbidity, pH, biochemical oxygen demand, and chemical oxygen demand.

42. Except for carbon, there was no direct evidence of difference in the nutrient regimen of the southern lake systems associated with treatment.

43. Outboard motor operation probably increased grass bed productivity in the southern test lakes. The drained engine test lake exhibited a significantly higher (approximately 100 percent) grass bed productivity and biomass than the control lake. The grass bed productivity of the drainless engine lake, although not statistically significant, averaged approximately 10 percent higher than the control lake. Biomass in the control lake and in the drainless engine lake was similar.

44. The effects of outboard motor emissions on the aquatic ecosystem in the southern lakes could not be discerned from the turbulent effects of mixing and stirring induced in the lakes by outboard motor operation.

SECTION II

RECOMMENDATIONS

1. The effects of outboard marine engine exhausts on phytoplankton productivity is worthy of further investigation. The data have shown reduced ^{14}carbon fixation by the phytoplankton under the treatment conditions of non-leaded and leaded fuels, the former showing statistical significance. This phenomenon could be more closely observed under algal assay and continuous flow laboratory bioassay conditions where prepared media and natural waters are exposed to various levels of outboard engine treatment and fuels. Various growth rate and productivity measurements can be taken to relate carbon production on a per cell basis or per unit chlorophyll a and expressed as a productivity index. Such expressions indicate phytosynthetic efficiency or inhibition, and under controlled assay conditions can be related directly to the stress variable being applied in the experiment.

2. Chemical analysis of the culture material should also be undertaken to determine hydrocarbon and heavy metal sorption or uptake by algal cells. These analyses could identify the exhaust fraction involved in photosynthetic inhibition if this is indeed a real phenomenon.

3. Experimental stressing of natural waters with outboard marine engines influenced the periphyton communities under study. Although no significant variations were seen in the species associations of the photoautotrophic organisms (diatoms), differences were seen in the production of organic biomass and chlorophyll a. When applied in a ratio as the autotrophic index the data reflected more hetertrophic periphyton communities under treatment conditions. The speculation being that there was greater microbial activity, i.e., bacteria and fungi, in the stress sections of the northern field study. Experimentation should be conducted to determine if this is the result of selective enrichment where the hydrocarbons of the exhaust emissions provide a carbon source for bacteria and fungi. This aspect should be studied under continuous flow bioassay conditions where natural water would be treated with outboard engine exhausts and fed through the bioassay system.

4. The zooplankton community demonstrated no effects observable at this level of study, i.e., gross population monitoring. It is felt then, that the zooplankton could be studied on a more individual manner, such as their robustness, fecundity and fertility. Gut analysis on the Rotifera, in a stressed situation, should also be undertaken to determine if the ratio of small alga (i.e., Chlorella sp.) to suspended detrital matter is concomitant with populations of unstressed lakes.

5. The benthic macroinvertebrates should be studied in light of their preferred habitat; the sediment. It should be determined, in a continuous flow bioassay unit using natural lake water as the diluent, if the population of Chironomidae demonstrate a reduced ability to exchange gases (O_2 CO_2 etc.) due to hydrocarbon build up. Biochemical analysis of the body tissues should then be performed to determine variations in lead, and the various hydrocarbons associated with the flesh of the organism. In the bioassay unit, the duration of the larval stage should also be determined. Species of macroinvertebrates less anatomically amorphous should also be observed and chemically analyzed on an anatomical basis: i.e., gills, body covering (chitin), and viscera. The icthyopopulation should be studied with particular reference to their gills and the possible build up of the heavy metals, and lead. A simple bioassay-animal dissection coupled with atomic absorption spectrophotometric determinations would yield information in this area.

6. There is some uncertainty concerning the build-up of lead in the bottom sediments as a result of outboard engine operation using leaded fuel. Consequently, further study should be made of the mechanisms of transport by which any significant concentration could occur, e.g. sedimentation. However, this potential environmental problem should be eliminated in the near future with the advent of non-leaded fuels and the development of two-cycle outboard engines capable of operating on such fuels.

7. The fate of hydrocarbons in the aquatic environment is still not well understood. The data presented in this report suggests the need for further study in the area. Such studies should focus on the physical, chemical and biological degradation of hydrocarbons in the aqueous and sediment phases as well as the mechanism of hydrocarbon transport between the two phases. This aspect should be looked at for "long-term effects". Probably, not as important per se for outboard motor emissions as much as aiding in ascertaining the environmental impacts of the total hydrocarbon input from man's activity on natural water systems.

8. An investigation to assess the effect of outboard motor operation on the carbon dioxide budget should be conducted in carbon limiting lakes. Emphasis should be placed on the effects of carbon enrichment on primary productivity and plant biomass. Carbon dioxide pathways (e.g. mass transport of carbon dioxide via water circulation, dissolved carbon dioxide emissions, atmospheric diffusion of carbon dioxide) should be traced and quantified with the use of a NDIR carbon dioxide gas analyzer.

9. Experiments should be designed to discern between the effects of motor emissions and the effects of mixing and stirring on lakes such as those experienced in the southern study.

SECTION III

INTRODUCTION

GENERAL

This summary presents the results and conclusions of a three year research project designed to ascertain the pollutional effect of two-cycle outboard engines emissions on the aquatic environment. The study entitled "Analysis of Pollution from Marine Engines and Effects on the Environment" (EPA Grant No. R-801799) was directed by personnel of the Industrial Waste Treatment Research Laboratory, Edison, New Jersey (a division of the National Environmental Research Center, United States Environmental Protection Agency, Cincinnati, Ohio). Financial support for the project came from the United States Government and the Boating Industry Association. The field investigations were conducted by Environmental Control Technology Corporation of Ann Arbor, Michigan and Environmental Science and Engineering, Incorporated of Gainesville, Florida. The laboratory investigations were performed by the staffs of the Environmental and Water Resources Engineering and the Automotive Engineering Laboratories of the University of Michigan, Ann Arbor, Michigan.

This summary is a digest of a considerable body of data collected over the course of the project. A complete compilation of data is provided by each of the above research groups, in separate reports to the United States Environmental Protection Agency.

OBJECTIVES

The main objectives of the study were:

1. To determine the effects of two-cycle outboard engine emissions on the aquatic ecosystem. This included not only determining whether any detrimental effects occurred, but also pin-pointing that portion or portions of the food chain which might be most seriously affected.

2. Quantitative and qualitative characterization of the exhausts from two-cycle outboard engines. Particular emphasis being placed on those exhaust components which tend to remain in the aqueous phase. The characterization studies included variations due to engine horsepower, age and maintenance, as well as, manufacturers design.

SCOPE OF WORK

Basically, the project was divided into two distinct parts, namely, a laboratory study and a field study.

The laboratory studies were conducted under controlled conditions in order to optimize the collection and characterization of components in outboard motor emission water (OME water). The laboratory approach was necessary, in this regard, as it was the only practical way of obtaining the data and it reduced or eliminated many of the analytical problems associated with the characterization of the OME water in a natural water system.

The field studies, on the other hand, were designed to ascertain the environmental impact of two-cycle outboard motor emissions on the chemical and biological quality of natural lake systems. In this instance, it was felt that laboratory scale studies would be inappropriate due to the inherent difficulties that would be associated with extropolating the data to "real world" conditions. In like manner, field studies of large lake systems was prohibitive from both an economic and time standpoint. Therefore, it was decided to perform the field studies on small ("mini") lakes. This "mini" lake concept allowed for the field investigations to be carried out on water bodies of manageable size. This approach also permitted simulation of long term stressing by two-cycle outboard engines to be accomplished over a relatively short period of time.

The field studies were conducted in "mini-lakes" (0.5 to 4 acres - 0.2 to 1.6 hectare)in both a northern and southern climate. All "mini-lake" systems, both control as well as "stressed" systems, had no prior boating activity on them and receive no other pollutional imputs other than the imposed stressing from two-cycle outboard engines operated under a predetermined schedule. The northern study dealt with the pollution impact of drainless two-cycle outboard engines using leaded and non-leaded fuels. The southern study investigated the pollutional impact of drain versus drainless two-cycle outboard engines using leaded fuel. Basically, the testing procedures were the same for both the northern and southern studies, except that the northern study underwent an enforced rest period due to ice cover during the winter, while the southern lakes were stressed year round.

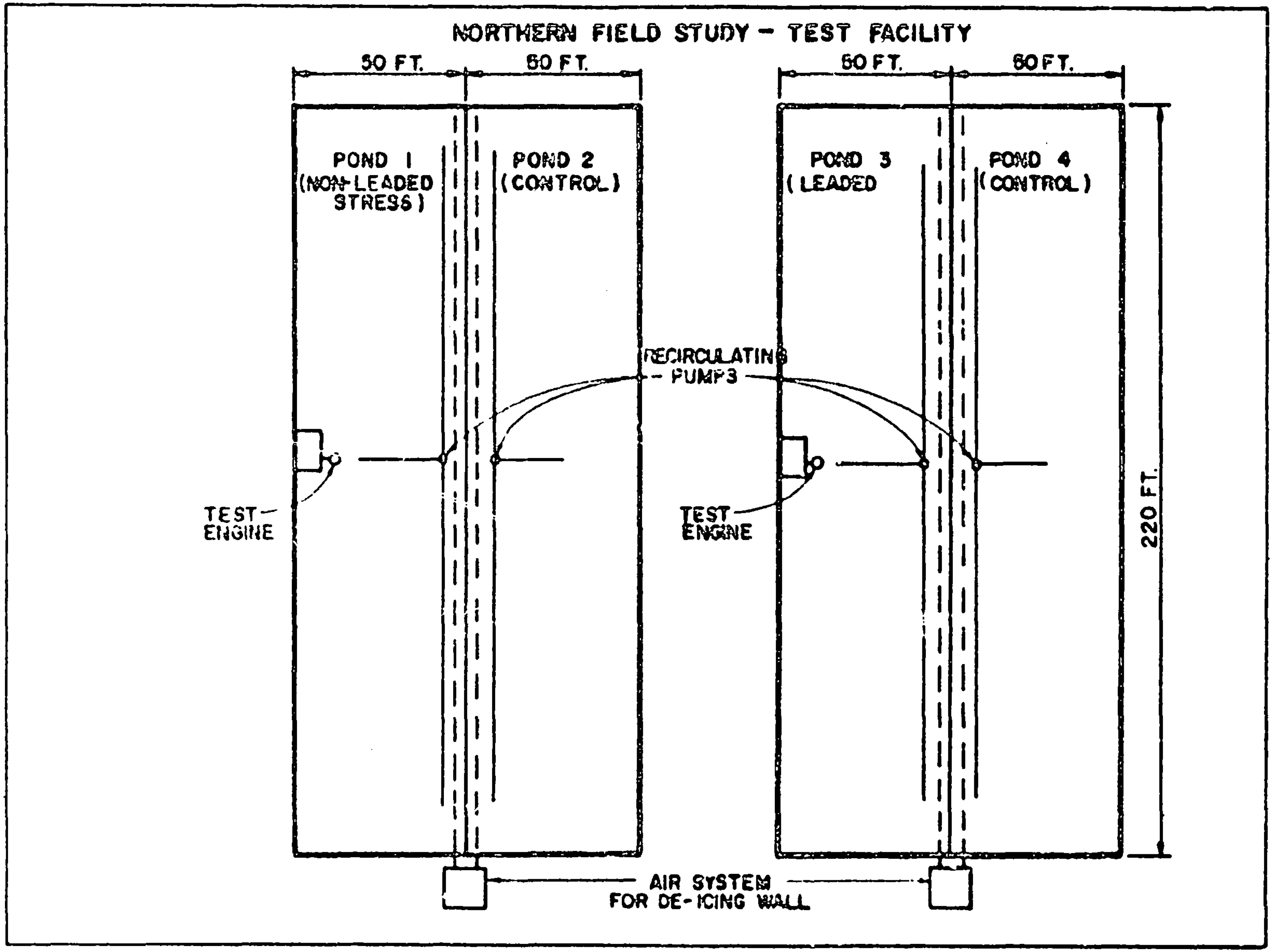
The northern field study was carried out in two one-half acre (0.20 hectare) ponds near Saline, Michigan. These ponds, part of the State of Michigan's Fisheries Research Station, are owned and maintained by the Department of Natural Resources - State of Michigan. Each of these ponds was divided by means of aluminum sheeting to provide two test ponds, each with its integral own control (Figure 1). These ponds or "mini-lakes" varied between four and nine feet (1.22 and 2.74 meters) in depth and have been in existence for over ten years.

The southern "mini-lakes", situated west of Archer, Florida, were three separate lake systems located in close proximity to one another. The two test or "stress" ponds were three to four acres (1.2 to 1.6 hectares) in size while the control lake was approximately twelve to fifteen acres (4.8 to 6 hectares). Each of these southern "mini-lakes" varied between zero and twelve feet (0 to 3.66 meters) in depth, with an average depth of approximately six feet (1.83 meters).

Water levels in all "mini-lakes" systems, both north and south, were controlled strictly by evaporation and rainfall. There were no natural surface or sub-surface water flows to the systems. In the northern "mini-lakes", water levels, hence water volume, were held constant by periodic water input when evaporation and seepage exceeded rainfall. In the southern study water levels varied seasonally as there was no way to withdraw or add water to the "mini-lake" systems. "Mini-lake" water levels in the southern field studies varied between two feet (0.61 meters) below and three feet (0.9 meters) above the original water level datum at the outset of the study.

Stressing Levels

The first consideration in the field studies was to determine the amount of two-cycle outboard stressing that was to be applied to the test "mini" lakes. The amount of outboard stressing to be applied to each test system was approached by ascertaining, as closely as possible, the number of boats that resonably could be expected to occupy a given surface area of water under optimum use condition. Optimum use conditions being a "real-world" situation where the following conditions exist:



NORTHERN FIELD STUDY - TEST FACILITY
50 FT.
60 FT.
60 FT.
60 FT.
POND 1
(NON-LEADED
STRESS)
POND 2
(CONTROL)
POND 3
(LEADED
POND 4
(CONTROL)
RECIRCULATING
PUMPS
TEST
ENGINE
TEST
ENGINE
220 FT.
AIR SYSTEM
FOR DE-ICING WALL

FIGURE 1

a) diversity of boating activity taking place

b) lake surface large enough to have boats operating over a wide spectrum of horsepower loadings

c) lake should be at maximum usage capacity (saturation boating). Saturation boating being that situation where from a safety, aesthetic and recreational viewpoint the presence of more boats on the lake would cause:
    1. a problem of boating safety
    2. reduce one of the legimate use activities presently taking place
    3. reduce the recreational attractiveness of the lake

Thus, a literature review was undertaken to determine the spatial (surface area) requirements per boat based on a specific boating activity. In 1967, Threinen[1] reported on his findings of boating activity on Lake Geneva, Wisconsin. A review of Threinen's work indicated that the boating situation on Lake Geneva during a peak holiday weekend period (July 4th) was at or near optimum. This boating situation together with the size of Lake Geneva met all the necessary qualifications set forth previously, to define optimum use conditions. Therefore, the work of Threinen on Lake Geneva, Wisconsin was used as the base to determine what level of outboard motor stressing would be used in the field studies.

Schematic flow sheets of the instantaneous boat population and specific boating activities as developed from Threinen's work on Lake Geneva[1] are shown in Figures 2 and 3. Figure 2, which shows the average instantaneous boating activity from 1000 to 1800 hours, indicates that there is essentially total saturation with respect to motorboat usage during this period.

Using the data from these two figures (Figures 2 and 3), and making the following assumptions for average brake horsepower (bhp) output for the various boating activities:

water skiing - 40 bhp

boating - 10 bhp

trolling - 5 bhp

a total brake horsepower input of 61,800 hours for the peak

Figure 2

SIMULATED MOTORBOAT EMISSION LOADING

Spatial Consideration - Lake Geneva, Wisconsin

Peak weekend period (July 4, 1967)

1000 hours to 1800 hours

Lake Geneva

(5100 Acres of Water)
2064 hectares of Water

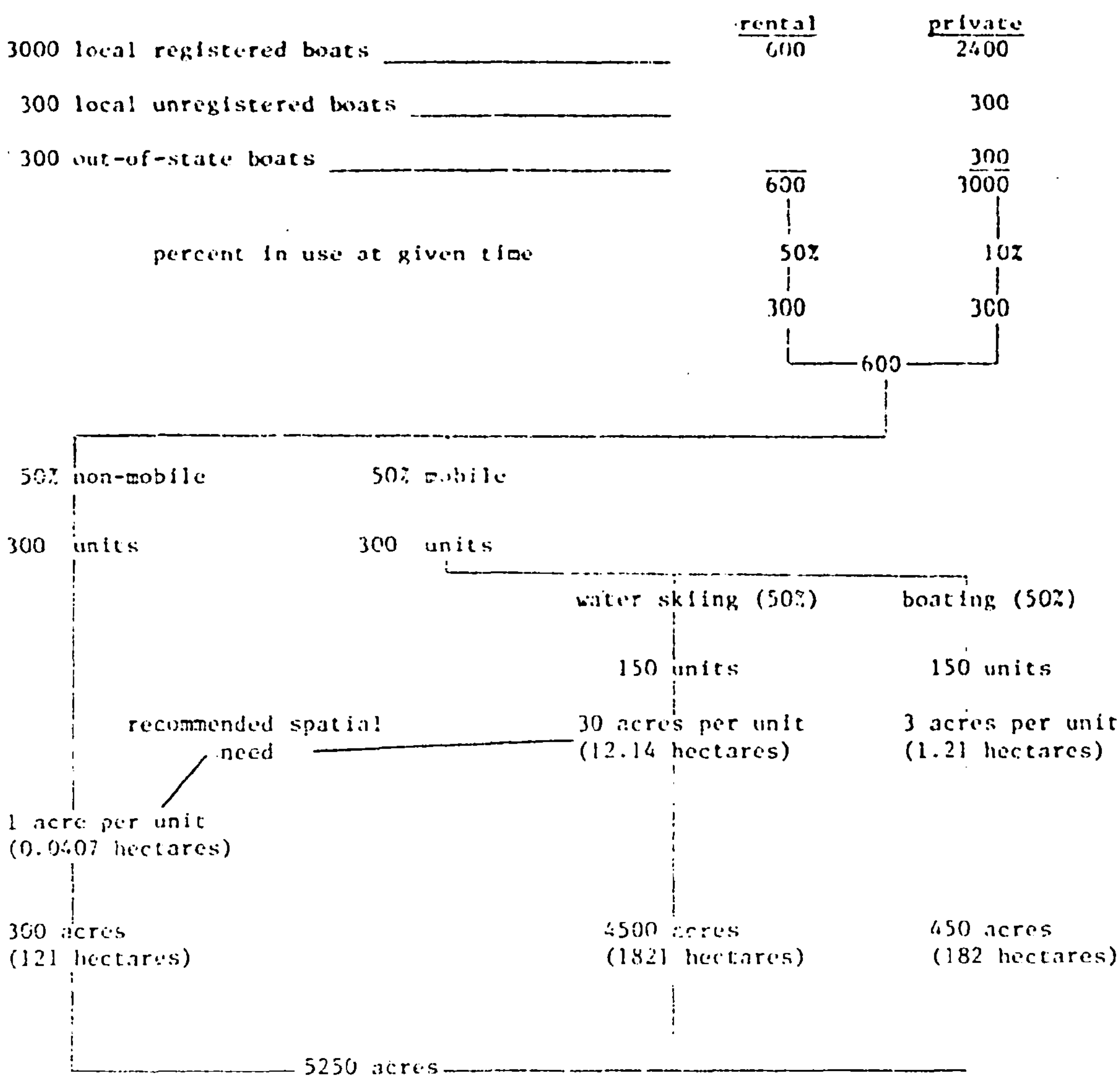


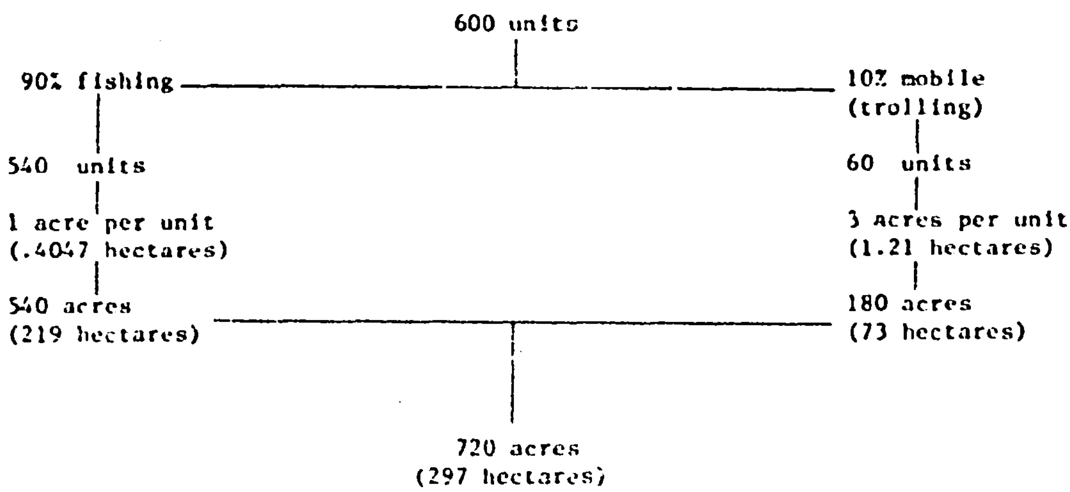
Figure 3

SIMULATED MOTORBOAT EMISSION LOADING

Spatial Consideration - Lake Geneva, Wisconsin

Peak Weekend - non-peak hours

0600 to 1000 hours and 1800 to 2000 hours



day at Lake Geneva was calculated. Since an average of one gallon (3.785 liters) of fuel is consumed for 6 bhp-hours,[2] this represents a daily fuel use of 10,300 gallons (38,986 liters), or approximately two gallons per acre per day (18.7 liters per hectare per day).

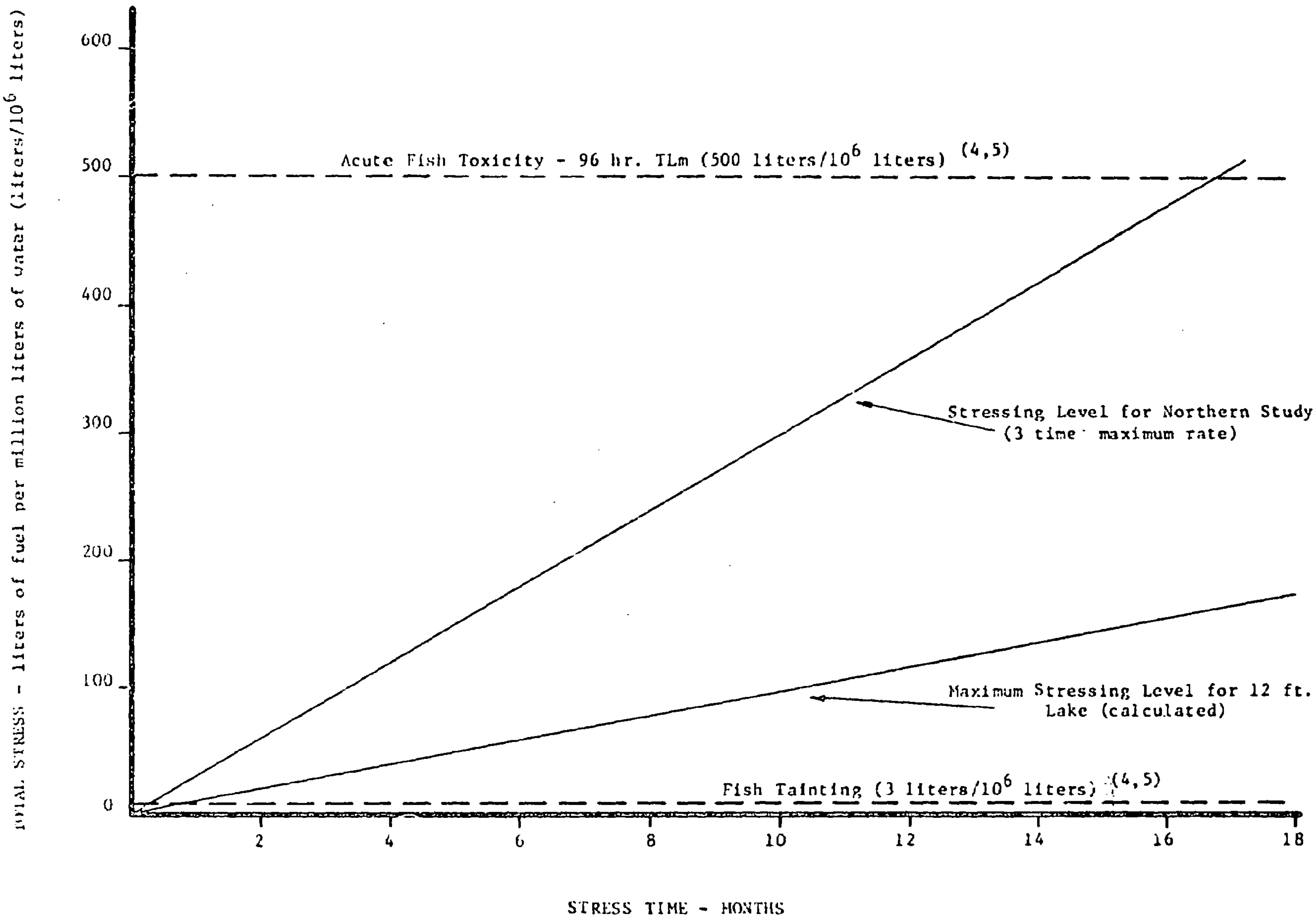
It is obvious that the vast majority of lakes do not receive such extensive boating usage on a daily basis. However, it was decided for the purpose of this study to assume that the maximum weekly stressing level of a hypothetical lake saturated by boating activity would be represented by two days of peak activity (18.7 liters per hectare per day) and five days of one-half peak activity (9.35 liters per hectare per day) of that shown for Lake Geneva. The total maximum weekly outboard motor stress, for a lake saturated by motorboat activity, was thus calculated to be nine gallons of fuel burned per acre (84.15 liters of fuel burned per hectare). Finally, for the northern study area, a boating season of eight months was assumed, while in reality the normal yearly boating season is only four to five months in duration, which represents a total yearly stress of approximately 300 gallons of fuel burned per acre (2806 liters per hectare).

These calculations (yearly stess levels of 300 gallons of fuel burned per acre), however, provides no information as to the stressing levels in terms of water volume, since no restriction has been placed on the depth of the lake. Obviously certain boating activities would be limited without sufficient water depth. A twelve foot (3.66 meters) average lake depth was assumed for purposes of placing the stressing level in terms of water volume. It was felt that this depth would be the minimum required for such non-restricted boating activity, and a lake of this depth would most likely be the first to experience stress, if any, due to two-cycle outboard motor operation. The yearly stress--based on an eight month boating period and a lake with an average depth of twelve feet (3.66 meters)-- is thus 75 liters of fuel burned per million liters of water. The daily stress over an eight month boating period would then be approximately 0.33 liters of fuel burned per day per million liters of water.

This level of stressing is shown graphically in Figure 4. Also shown in this figure are the levels reported by English, et. al.[3,4] for fish tainting and acute fish toxicity of 3 and 500 liters of fuel burned per million liters of water respectively. It is evident from the intersection of the stress line for a twelve foot (3.66 meters) lake with the reported toxicity levels[3,4] that the chances for observing effects from two-cycle outboard motor exhaust emissions would be minimal.

FIGURE 4

Design Stress Levels



Consequently, the calculated maximum stressing schedule established for this study was tripled. Thus, the stressing level used in the field studies for this project was approximately one liter of fuel burned per day per million liters of water -- see Figure 4.

SECTION IV

LABORATORY STUDIES

ENGINE OPERATION AND TESTING

A total of 12 different engines representing a variety of two-stroke configurations, were studied. They ranged in size from 3.6 hp to 105 hp and represented a spectrum of engines from four manufacturers: Outboard Marine Corporation, Mercury, Chrysler and Tecumseh Productions. Crankcase designs included closed, recirculating, and drained types. Ignition systems represented both conventional and high-voltage capacitive-discharge (CD) system. Two engines (Chrysler 3.6 hp and Eska 7.0 hp) were air-cooled, the rest were water-cooled. Carburation varied both with manufacturer and engine size.

The engines tested (excluding two "maintenance study" engines tested after use in associated northern field studies), together with a number of pertinent specifications are shown in Table I. Each engine was instrumented and fitted with exhaust gas sample probes.

The larger engines (35 hp to 105 hp) were mounted on a special test stand and coupled to a 120 hp General Electric dynamometer. Smaller engines (3.6 hp to 18 hp) were operated in a test tank and were loaded using test propellors.

Mass flow of fuel was obtained by measuring initial and after-test fuel weight. Because each test was run at a constant speed and load, it was not necessary to continuously monitor fuel rate. Any change in engine operation was readily detected from the continuously monitored exhaust emission data. Engine speed was measured with an optical electronic tachometer on the test-tank engines.

Three engines were operated with external crankcase drainage systems installed. The engines selected were similar to three of the drainless engines tested, an 18 hp Evinrude, 35 hp Chrysler, and a 50 hp Mercury. One of the engines, the 35 hp Chrysler was an older model which was normally drained. Both the 18 hp Evinrude and 50 hp Mercury were 1972 model engines which were converted from a recirculating or drainless type engine to a drained type.

Representative and known fractions of exhaust were obtained with special sampling probes constructed of 1/4 inch O.D. stainless steel tubing and designed as static probes with a number of sample holes on the circumference and spaced longi-

TABLE I

TEST ENGINES AND SPECIFICATIONS

Brand Name	Rated hp	@ RPM	Model Number	Serial Number	No. of Cyl.	Displacement (cu. in.)	Gear Ratio	Cooling System	Crankcase Drain	Fuel/ Oil Ratio
Chrysler	105	5000	1057 HC	9994	4	96.55	15/26	Water	Recycled	50/1
Mercury	50	5300	500E	3170501	4	43.8	1/2	Water	Recycled	50/1
Chrysler	35	4750	350HD	1053	2	35.9	13/21	Water	Recycled	50/1
Chrysler	12.9	5000	122HA	3725	2	13.62	14/22	Water	Recycled	50/1
Mercury	7.5	5500	75	3196951	2	10.9	1/2	Water	Recycled	50/1
Eska	7.0	5650	1747A	153145	1	7.5	14/21	Air & Water	Closed	24/1
Chrysler	3.6	4500	32HB	6346	1	5.18	14/21	Air & Water	Closed	16/1
Evinrude	6	4500	6202DJ	03899	2	884	15/26	Water	Recycled	50/1
Evinrude	18	4500	18202R	E03098	2	22.0	12/21	Water	Recycled	50/1
Chrysler	35	4750	355HC	6336	2	35.9	13/21	Water	Drained	50/1
Evinrude	18*	4500	18202R	E03098	2	220	12/21	Water	Drained	50/1
Mercury	50*	5300	500E	3170501	4	43.8	1/2	Water	Drained	50/1

*Modified to a drained engine

tudinally along the length. Particular attention was given to the location of the probe in the engine exhaust system to insure representative sampling of the average composition from all cylinders in the multi-cylinder engines and to minimize time and spatial resolution problems. The location chosen was the position farthest down the exhaust collector before any water was added to the exhaust stream.

The sample line between the engine and condensate apparatus was maintained at 350°F. At this elevated temperature no condensation of water and only limited hydrocarbon condensation occurred on the tubing walls. This temperature was still low enough to prevent significant reaction of either hydrocarbons or CO with the oxygen present.

The exhaust sample flow and analysis system, shown schematically in Figure 5, allowed three separate modes of analytical operation, non-dispersive-infrared (NDIR) analysis of gas phase, flame ionization detector (FID) hydrocarbon analysis, of gas phase or extended condensate collection. Both the NDIR and FID analysis systems could be purged with room air and calibrated with span gas without affecting the flow through the condensate or liquid sample collection apparatus. All of the analyzers with the exception of the hydrocarbon flame ionization detector (FID) were connected in series because they are non-destructive to the sample.

A specially constructed subtractive column analyzer was used in conjunction with the FID. This device permitted separation of the gaseous hydrocarbons in the exhaust sample into principal family components: paraffins, olefins, and aromatics. Indolene 30 was used as the test fuel. All of the fuel used was from the same refinery batch, thus insuring consistent hydrocarbon family composition. Quicksilver outboard motor oil was used as the lubricant in all of the engines. It was mixed with the fuel in the ratio specified by each manufacturer. (See Table 1).

The engines were run only under steady-state conditions, after being first broken in according to the manufacturer's recommendations. A simulated boat load curve was used to establish the proper speed-horsepower relationship. Generally an outboard engine follows approximately a 2.5 order load curve on a planing hull.

GAS-PHASE EMISSIONS

Carbon Monoxide

Carbon monoxide is a moderately toxic compound with limited solubility in water. Average carbon monoxide emissions in

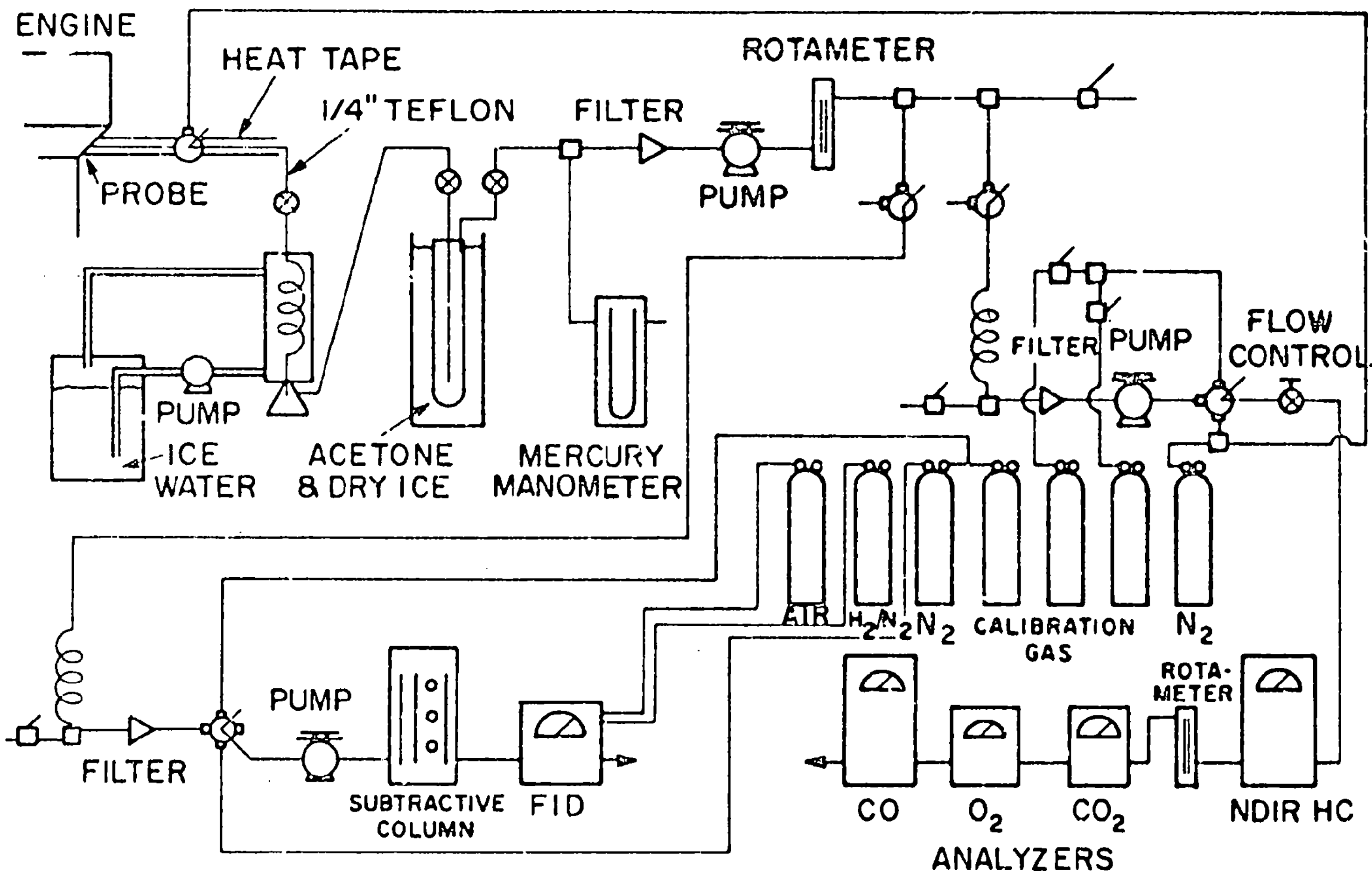


Fig. 5 Schematic Diagram of the Sample Collection and Analysis System.

percent, varied from 4-1/2 percent at 1000 rpms to a high of 6-1/2 percent at 3000 rpms. The results of percent CO emissions at 4500 and 5000 rpms have not been reported in this "average" data analysis because data at this speed were taken from only a few engines. No trend in CO emissions is evident from these results. The CO emissions are high compared to those observed from current four-cycle automotive engines.

Carbon Monoxide is basically a function of the engine air/fuel ratio. The high CO emissions of the two-cycle marine engines are attributable to a rich mixture ratio. The air/fuel ratio used on all of the test engines, generally between 10 and 13 to 1 depending on carburation requirements for the various engines, was richer than the stoichiometric ratio of approximately 14.8 to 1. This richness is necessary to assist with internal cooling and lubrication, and provide smooth operation even with substantial internal exhaust residual dilution which is a problem of all two-cycle, crankcase scavenged engines.

Another factor influencing carbon monoxide emission is the trapping efficiency of the engine, which is defined as the ratio of the mass of fuel and air trapped in the engine to that which is furnished to the engine. The lower the trapping efficiency, the greater the quantity of unburned fuel and air in the exhaust and, for a given mixture ratio, the lower the CO emissions. The unburned fuel/air in essence dilutes the exhaust products.

Carbon Dioxide

Carbon dioxide is not considered a pollutant in normal atmospheric concentrations, however it is a very significant constituent in gasoline engine exhaust. The average carbon dioxide emission results from the various test engines ranged between 5-1/4 percent at 1000 rpm to 7-1/2 percent at 4,000 rpm in an almost linear fashion. As with CO, the concentration of CO_2 is strongly a function of the air/fuel ratio used in the engine. Trapping efficiency also influences CO_2 concentration. In general, CO_2 concentration should be inversely proportional to carbon monoxide concentration, although this is not evident when comparing the average CO and CO_2 emission data for a number of engines.

Hydrocarbon Emissions

Only the flame ionization detector (FID) hydrocarbons will be discussed since this number is representative of the total hydrocarbon concentration rather than the partial hydrocarbon fraction shown by the non-dispersive infrared (NDIR) analyzer. Average total hydrocarbon concentration in the gaseous exhaust emissions data from all test engines at each speed varied from a high of 7.75 parts per thousand (ppt) at 1000 rpm to a low of 4.5 ppt at 4000 rpm. All hydrocarbon data is expressed as ppt of n-hexane, C_6H_{14}.

The total hydrocarbon emissions are higher than those observed for a typical four-cycle gasoline engine by at least a factor of 10. This is partially due to the richer ratios used in the two-cycle engine, but more significantly it is related to the trapping efficiency. If the mixture is not trapped within the engine cylinder, it is over-scavenged or in effect "dumped" into the exhaust system before it has an opportunity to burn. The concentration of hydrocarbons in the unburned mixture is extremely high, 20 ppt of C_6H_{14}. Therefore, even a small fraction of lost mixture can contribute significantly to the total hydrocarbon emission level. In general, hydrocarbon emissions tend to decrease with increasing speed. This result is consistent with both the decreasing air-fuel ratio and the improved trapping efficiency observed as the speed increases.

Trapping Efficiency

Trapping efficiency is an important measure of the engine's ability to retain the fuel and air that is furnished to the engine. Ideally this should be 100 percent; however, with the dynamic scavenging used with current small two-cycle engines this goal is essentially impossible to achieve.

Trapping efficiency is particularly important from the standpoint of fuel consumption and hydrocarbon emissions, as discussed in the previous section. In general trapping efficiency increases with speed and appears to reach a maximum in the vicinity of 3,000 to 4,000 rpm. Several of the engines exhibit a trapping efficiency exceeding 80 percent, others, particularly at the low load and speed test conditions, may lose nearly half of the unburned mixture to the exhaust with a consequent high level of hydrocarbon emissions. On the average the trapping efficiencies of the engines tested varied between 60 and 75 percent at 1,000 and 4,000 rpm's respectively.

Mass Emission Results

Of ultimate concern, however, are mass rates of emissions. This quality is the product of the concentration emissions and a mass flow factor related to the flow rate of air and fuel required by the engine to satisfy a given speed and load requirement. Comparisons of the largest engine tested, a

105 hp Chrysler, and one of the smaller engines, a 6 hp Evinrude, show that the concentration emissions are similar. Thus, the major factor causing higher mass emissions from large engines is the greater air and fuel flow rate. Brake horsepower is closely related to mass flow rate. In general the mass rate increases with both speed and horsepower.

Hydrocarbon Family Analysis

The exhaust hydrocarbons were separated into their primary family constituents (paraffins, aromatics and olefins) with the aid of the subtractive column analyzer.

In general the results from testing of the two-cycle outboard engines differ significantly from those observed with the conventional four-cycle engines in that the exhaust hydrocarbons appear to be more closely related to the fuel. The major difference observed between the exhaust hydrocarbons and the fuel was the olefin concentration, which is moderately greater in the exhaust gas, averaging between 20 and 30 percent of the total hydrocarbon composition whereas in the fuel the olefin fraction was six percent. The increase in olefins is a result of "restructuring", primarily of paraffinic hydrocarbons during combustion. Most of the reaction occurs in a "quench zone" located between the hot flame and the relatively cold walls of the engine combustion chamber.

The aromatic fraction is slightly less than observed in the fuel and is generally in the range of 20-30 percent of the total hydrocarbon composition. As a class, the aromatics appear to be relatively stable.

Paraffinic hydrocarbons generally are the most prevalent of the exhaust hydrocarbons, comprising approximately 50 percent of the total. However, in some instances the paraffinic fraction, such as with the 6 hp Evinrude engine, was nearly 70 percent of the total and very similar to the fraction of paraffins observed in the test fuel. Other engines, such as the 3.6 hp Chrysler, exhibited only approximately 45 percent paraffinic hydrocarbons under several test conditions.

No discernible trend is evident with regard to the hydrocarbon family breakdown as a function of engine speed and load.

CONDENSABLE COMPONENTS

General

The purpose of this part of the study was to collect and identify condensable fractions of outboard engine exhaust emissions under controlled laboratory conditions, in a manner such that the contribution of this fraction of the exhaust could be accurately assessed. As noted previously, condensable fractions are those most likely to be transferred from submerged exhaust emission to the water column.

To this end, engines were mounted on test stands, as described in a previous section of this report. The exhaust was passed through the collection and gas-phase analysis system shown schematically in Figure 5. Collection of condensate samples required three hours of continuous engine operation at each test condition. The system was arranged so that a constant 2 cu. ft./hr. (0.56 cu.m/hr) was passed through the condensation section. It was possible to calculate condensables in the total exhaust by measuring the hydrocarbon flux with and without the collection apparatus in operation.

The condensation system consists essentially of an efficient cold water condenser and a dry-ice cold finger trap. At the end of each run both condenser systems were washed down with a fixed volume of $CHCl_3$, and the condensates and washings from the two receivers combined. Due to the large condensing surface area and the low temperatures used in collecting the condensate, it is virtually certain that this system condenses at least as much - and probably significantly more - of the exhaust than would a column of water in a lake or other water body under normal engine usage. Consequently, the amounts reported herein should represent maximum potential pollution loads rather than average values.

The composition of the condensable organic portion of the exhaust has been shown to consist of three fractions: unburned gasoline, partially oxidized hydrocarbons (i.e. phenols and carbonyl compounds) and unburned oil[3]. Further, the unburned fuel is composed of three fractions, aromatics, olefins and paraffins. Since it has been established that aromatic compounds constitute the most important of these in terms of acute toxicity to aquatic life[5], primary attention was directed to the qualitative and quantitative analysis of this fraction.

The condensates were analysed for aromatic hydrocarbons, olefins, phenols, carbonyl compounds, paraffinic hydrocarbons, and total condensable organic material. The respective analytical techniques and methods used are outlined in detail in the University's final report to the Environmental Protection Agency. Only the results and discussions of these analyses are presented in this summary report.

Aromatic Hydrocarbons

Samples of the fuel used in the engine tests were examined first by infrared spectroscopy and then by gas chromatography. Identification of the major peaks was done by mass spectral analysis and confirmed by comparing the retention times of the pure components with those of the major peaks in the exhaust chromatogram. A comparison of the ratio of toluene to other aromatics in the condensate and in the fuel showed that in most cases the ratio is lower in the condensate, suggesting that either toluene is preferentially burned or that the higher boiling aromatics are preferentially condensed, or both.

Binuclear aromatic hydrocarbons were also detected in randomly selected samples of the condensable fraction. In particular, naphthalene and its two isomeric methyl derivatives were identified by comparison of their retention times with those of the pure compounds. In six samples analyzed, the three binuclear aromatics ranged from 1 - 2 percent of the total mononuclear aromatic content of the condensate. This level is somewhat higher than that in the raw fuel (0.5 percent binuclear aromatics).

Olefins

Olefins were determined by amperometric titration using a standard ASTM Method[6]. Phenols interfered and were removed by extraction with 0.1N NaOH. Olefins are reported as cyclohexene (molecular weight 86).

Phenols

Phenols were determined on the base extract from the olefin determination by ultraviolet spectroscopy. Due to the high background absorbance however, it was necessary to take the difference in absorbance at 290 millimicrons between an acidic and basic solution[7].

Carbonyl Compounds

Carbonyl compounds were determined by direct infrared spectroscopy on the organic phase of the extracted condensate. No attempt was made to distinguish between the various types of carbonyl compounds; the peak at about 5.9 microns was measured and compared with known solutions of butyraldehyde. Base extraction lowered the absorbance in a random selection of samples by 7 - 12 percent, indicating an acid content of roughly 1/10 of the carbonyl signal.

Paraffinic Hydrocarbons

Paraffinic hydrocarbons were not determined directly; however, paraffins were estimated by obtaining the total condensable hydrocarbons, subtracting the major constituents (olefins and aromatics) and assuming the remainder to be paraffins.

Total Condensable Organic Material

Determination of the total amount of organic material condensed from the exhaust is complicated by the fact that considerable water is formed during the combustion process and condensed in the traps. For one particular engine, the normal addition of $CHCl_3$ to the condensate was eliminated. Instead, the weight of total condensate (water plus organics) was recorded. A known weight of tetrahydrofuran was added such that the two phases initially present were completely miscible. Water was determined by Karl Fischer titration and the weight of organic material determined by difference.

RESULTS

Exhaust Condensate

Results of the exhaust condensate analysis are presented in Table II. The last two columns entitled Total Condensable Mononuclear Aromatics were calculated as follows: the TCMA quantity in grams/hr was calculated by multiplying the observed condensable mononuclear aromatics in mg/cu ft. by the total exhaust in cu ft./hr and dividing by 1000 to convert mg to grams; the TCMA quantity in grams/kg was calculated by dividing the grams/hr value by the fuel consumption rate (kg/hr) to give grams of condensable mononuclear aromatic per kg. of fuel. Condensables concentration was measured in duplicate runs on the first few engines tested. The reproducibility was very good and therefore it was decided that single condensate collections would suffice thereafter.

Table II

SUMMARY OF CONDENSATE ANALYSES

Engine and speed (rpm)	Fuel Consumption Rate (kg/hr.)	Total Exhaust (cu.ft./hr.)	Concentrations of Condensable Substances: (mg/cu.ft.)				Total Condensable Mononuclear Aromatics	
			Mononuclear Aromatic	Olefin*	Phenol*	Carbonyl	(g/hr.)	(g/kg fuel)
Chrysler 3.6 hp (air-cooled)								
1000	0.322	111	98	16.0	-	-	10.9	33.9
2000	0.589	190	113	20.3	-	-	21.5	36.5
3000	0.815	281	55	15.3	-	-	15.5	19.0
4000	1.060	407	47	10.2	1.53	10.8	19.1	18.0
4500	1.287	482	55	10.3	1.26	10.2	26.5	20.6
Mercury 7.5 hp								
1000	0.5559	205	105	19.3	-	7.0	21.5	38.5
2000	1.074	383	70	14.1	-	5.8	26.8	25.0
3000	1.628	849	68	-	-	6.8	57.7	35.4
4000	2.220	905	36	-	-	7.2	32.6	14.7
Chrysler 12.9 hp								
1150	0.900	313	145	18.8	1.15	9.5	45.4	50.4
2000	1.432	495	159	19.2	1.07	14.5	78.7	55.0
3000	1.770	656	73	11.6	1.57	9.5	47.9	27.1
4000	2.952	1070	119	15.0	1.82	18.3	127	43.0
5000	4.298	1575	132	17.2	3.37	12.5	208	48.4
Evinrude 18 hp								
1500	1.821	599	217	36.0	4.70	-	130	71.4
2000	2.400	810	165	13.7	1.65	11.8	134	55.8
3000	3.740	1220	77	13.0	1.43	12.5	93.9	25.1
4000	5.249	1818	140	15.8	1.80	-	255	48.6
4900	7.398	2478	142	12.0	1.05	19.5	352	47.6
Evinrude 18 hp - drained								
1500	1.724	581	229	20.3	1.48	26.8	133	44.8
2000	1.926	692	123	17.3	2.08	30.0	85.1	44.2
3000	3.049	1064	107	17.6	1.92	14.0	114	37.4
4000	5.873	1905	165	17.3	1.08	13.3	314	53.5
5000	6.783	2347	160	16.3	0.80	9.8	376	55.4

Table II (continued)

SUMMARY OF CONDENSATE ANALYSES

Engine and Speed (rpm)	Fuel Consumption Rate (kg/hr.)	Total Exhaust (cu.ft./hr.)	Mononuclear Aromatic	Concentration of Condensable Substances: (mg/cu.ft.) Olefin*	Phenol*	Carbonyl*	Total Condensable Mononuclear Aromatics (g/hr.)	(g/kg fuel)
Mercury 50 hp								
1500	3.477	1266	104	14.2	0.53	6.7	132	38.0
2000	3.540	1370	73	9.8	0.80	7.3	100	28.2
3000	6.581	2326	88	9.3	0.52	5.2	205	31.2
4000	9.828	3643	63	7.3	0.52	6.5	230	23.4
Mercury 50 hp - drained								
1500	3.779	1376	85	-	-	5.8	117	31.0
2000	3.784	1460	70	-	-	6.8	102	27.0
3000	6.787	2404	73	-	-	5.5	175	25.8
4000	10.390	3824	78	-	-	7.7	298	28.7
Chrysler 105 hp								
1000	4.472	1550	150	20.0	-	28.6	233	52.1
1500	5.655	2094	86	19.7	-	19.0	180	31.8
2000	6.557	2513	91	19.5	2.05	62.2	188	28.7
3000	9.666	3663	76	14.5	1.85	66.0	278	28.7
4000	16.636	6369	74	16.5	-	29.3	467	28.1
Evinrude 18 hp (field engine as received)								
1000	1.460	475	123	-	-	8.8	58.4	40.0
2000	2.195	760	56	-	-	8.1	42.6	19.4
3000	3.493	1163	45	-	-	7.2	52.3	15.0
4000	5.073	1302	43	-	-	9.0	77.5	15.3
Evinrude 18 hp (field engine new plugs)								
1500	1.870	-	71	-	-	7.2	-	-
2000	2.140	736	73	-	-	10.1	53.7	25.1
3000	3.695	1247	49	-	-	7.8	61.1	16.5
4000	5.073	-	40	-	-	7.8	-	-
4500	7.000	-	45	-	-	6.4	-	-

Most of the data, therefore, was obtained in this way. As can be seen from Table II, condensable aromatics amount to from 1.5 to 7.1% of the fuel fed (15 to 71 g/kg) with most values between 2 and 5%. An estimate of the total amount of hydrocarbons which would be condensed in normal use situations can be arrived at by reference to Table III and Figure 6. Aromatics and olefins were determined and the difference between the total weight of condensable organics and the sum of olefins and aromatics was assumed to be paraffins. As can be seen from Figure 6 and Table III, over the range of speeds studied, the amounts of olefin and paraffin present in the total (gas stream) exhaust varied markedly; nevertheless, both the percent aromatics in the condensed phase and the percent of the total hydrocarbons condensed in the cold water trap varied between 20 and 25%. The range of family composition of total exhaust shown in Figure 6 for the smallest engine (a 3.6 h.p. Chrysler) encompasses almost the exact range found for the largest engine (105 h.p.) as shown in Table II. Table II indicates that the total condensable aromatics for the 3.6 h.p. engine are about average for all engines. Thus to find total condensable hydrocarbons, one can multiply the total condensable aromatics by 4 or 5. To determine how much of the total condensable hydrocarbons are found in the cold water trap one can divide the total condensable hydrocarbons by a factor of 4 or 5. It is felt that the amount condensed in the cold water trap (1-3^{o} C) best approximates the amount that would be condensed in a water column, as the temperature of condensation in this trap is much closer to that of water in a lake or pond than is that in the dry ice trap. One arrives, by means of these estimates, at a value of about 1.5-7 for that percent of fuel fed to the engine which would be condensed in the water column.

If 3000 r.p.m. is selected as the speed at which most boat usage occurs, and the values of total condensable aromatics as percent of fuel is averaged over all engines tested in this study, a figure of 2.5% condensable aromatics is obtained. Therefore, the conclusion may be reached that the "average" engine will contribute about 2.5% of its fuel to the water, exclusive of drainage, during most of the time it is in use.

Influence of Maintenance

Two engines, an 18 hp Evinrude and a 35 hp Chrysler, were investigated for the influence of maintenance on emission performance. These engines were of similar model and horsepower to two new engines tested, but were engines that had

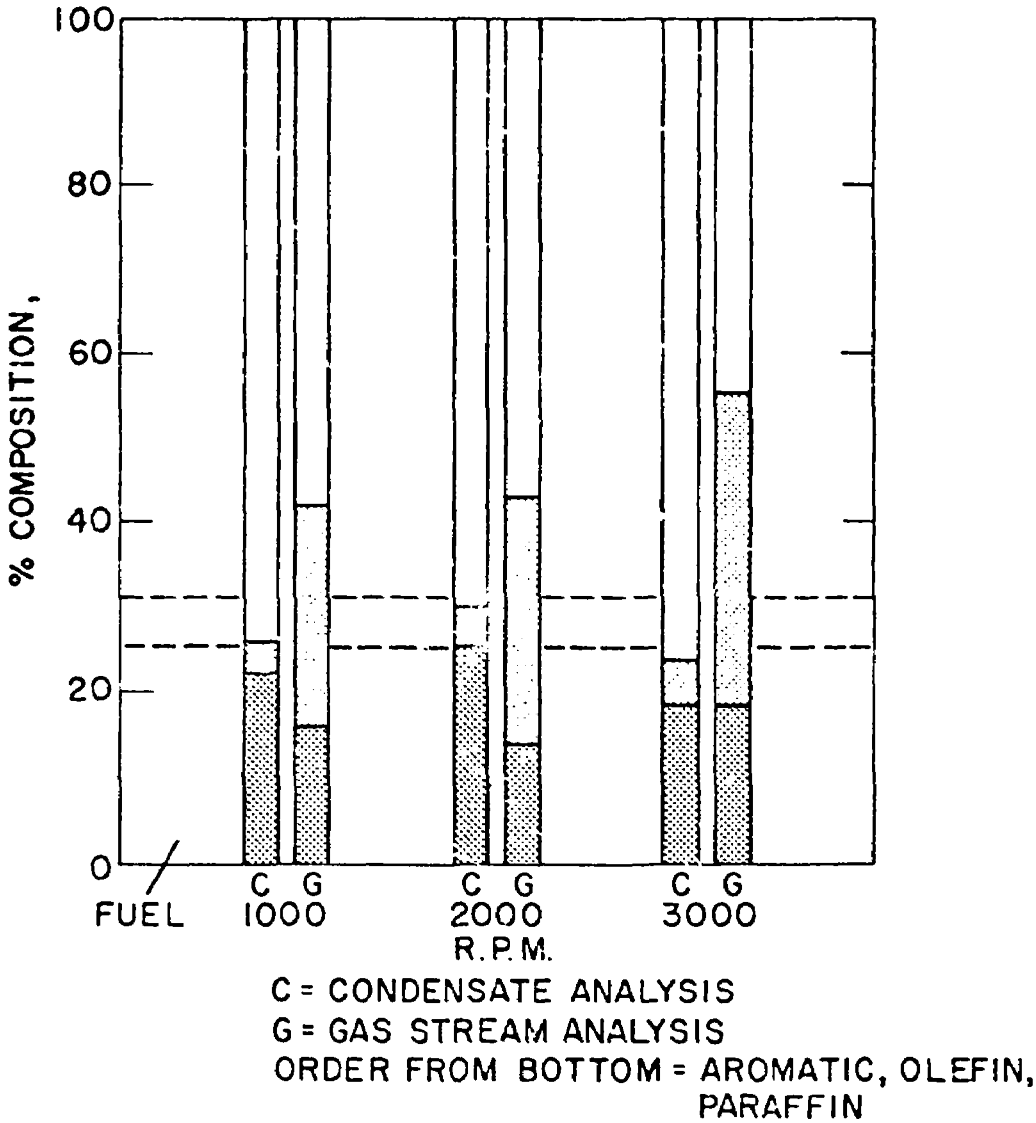


FIG. 6 COMPOSITION BY HYDROCARBON FAMILIES OF CONDENSATE AND OF EXHAUST GAS STREAM, SUPERIMPOSED OVER THAT OF RAW FUEL. ENGINE: CHRYSLER 3.6 HP

TABLE III

CONDENSABLE MATERIAL IN EACH STAGE AS WATER AND ORGANIC MATERIAL (CHRYSLER 3.6 HP ENGINE)

Sample	Total Wt. (g)	Total Organics (g)	% Organics	% of Total Condensable Organics
1000 r.p.m.				
Stage I (1-3°C)	34.52	0.47	1.4	18
Stage II (-65°C)	3.97	2.18	55.0	82
2000 r.p.m.				
Stage I (1-3°C)	15.68	0.50	3.2	19
Stage II (-65°C)	3.58	2.16	60.5	81
3000 r.p.m.				
Stage I (1-3°C)	16.12	0.43	2.6	24
Stage II (-65°C)	2.81	1.34	47.7	76

been used extensively in associated northern field studies. The 18 hp engine had been operated for 81 hrs. and the 35 hp engine for 67 hrs. in the field. The intent was to run the engines as received, perform normal maintenance and then rerun the engines again to compare emission performance. These engines were subjected to the same analyses as the new engines, including gas-phase and condensate analyses.

The maintenance procedures resulted in only very minor changes in gas phase emission performance as is shown in Table II for the 18 hp Evinrude. The maximum variation in the air/fuel ratio was only 4 percent. This is not a significant variation and supports the findings that there is little difference in emission performance.

The only trend toward a difference was exhibited by the 18 hp Evinrude engines, for which the field engine gave lower amounts of condensables than did the laboratory engine. This small difference may be accounted for by the fact that there are some differences to be expected even within a given engine model.

Crankcase Drainage

Three engines were investigated with internal crankcase drainage rather than the recycling system used on all current engines. The engines selected were the 35 hp Chrysler, 50 hp Mercury and 18 hp Evinrude.

A relatively wide variation was observed between the three test engines. The Chrysler in particular exhibited substantial drainage (11 percent) at the low-speed test conditions. However, as with all of the engines, the drainage tended to decrease with an increase in engine speed. Decreased drainage with increasing speed was expected because the greater air flow at higher speed results in more crankcase turbulence. No explanation is evident for the drainage differences observed between the engines other than it is related to particular design characteristics.

A maximum drainage rate, of approximately 300 grams per hour was observed at the 1500 rpm test condition with the Chrysler and a minimum rate of 39 grams per hour at 4000 rpm with the 18 hp Evinrude engines. In terms of the percentage of fuel used, the drainage observed ranged from a maximum of 11 percent at 1500 rpm for the Chrysler engine to less than one percent for the Mercury 50 hp engine at the 3000 rpm test condition. At low speed substantial variation was observed in the results from run to run for a given engine. For example, with the Mercury 50 hp engine at 1500 rpm a drainage rate of 197.0 gm/hr. was observed as the speed was increased to the test speed, whereas a drainage rate of 3.7 gms/hr. was observed when the speed was decreased to this test speed. This suggests that a hysteresis effect is present such that if one would approach a given speed from one side a different crankcase drainage would be expected than if one approached the speed from the other side. This is probably related to the slight differences in combinations of spark advance and throttle settings required to maintain a given performance level. This difference is amplified by the steep slope of the drainage curve evident in the low speed range of the engine.

The gaseous emission performance of the "drained" engines compared favorably with that observed from the "drainless" engines. No significant differences were noted in the 18 hp Evinrude and 50 hp Mercury "drained" or "drainless" engines as shown by the data in Table II.

The oil composition of the crankcase drainage was about 20 - 30 percent. Since the ratio of oil to gasoline in the fuel was 1:50 (2 percent) crankcase drainage represents a 10-15 fold increase in oil content over the mixture fed to the engine.

Evaporation Studies

Once the exhaust products are condensed in the water column there exist several mechanisms by which they can be removed from the system. One of the most important of these is the process of evaporation. In this particular study specific attention was paid to the evaporation of the aromatic compounds present in OME water.

Solutions containing outboard engine exhaust were prepared by running a small engine (1-1/2 hp) in a 55-gallon drum for a period such that an organic phase did not separate in the receiving water. Solutions of pure aromatic components were also prepared by dissolving these compounds in water and stirring briefly in a closed volumetric flask. Concentration of exhaust products and of pure compounds was monitored by observing ultraviolet absorbance of the test solutions at 250 millimicrons under controlled conditions of temperature, initial concentration, turbulence and surface to volume ratio. As the ultraviolet absorbance of total outboard exhaust product decayed with time to a final non-zero value (see Figure 7), the rate studies were corrected for this value so as to represent the disappearance of volatile aromatic components only.

As expected, agitation in the form of stirring or aeration markedly increases the rate of evaporation. Detailed evaluation of the evaporation kinetics of the OME water indicate that the aromatic component removal may be described by a first-order rate expression. 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. Rate of loss would of course be lowest in a quiescent water body. This condition of no turbulence would be most unusual in a natural lake situation; thus, the half-life of 11 days is highly conservative. A fairly rapid disappearance of volatile aromatics from the condensable phase can therefore be expected in the natural water systems. Half-life values of an order of magnitude (≈ 1 day) less than the quiescent value has been observed in the laboratory under aerated conditions (see Figure 7).

Fish Toxicity Studies

Fish toxicity studies were undertaken to determine the effect of OME water on the fish populations. Because of the fairly rapid evaporation of toxic components (described in the previous section), conventional static fish toxicity studies were deemed unsuitable, and a dynamic testing system[8] was devised whereby fresh solutions of the toxic components studied were continuously fed to test aquaria.

Outboard engine exhaust condensate was prepared by running a small outboard engine (1-1/2 hp Johnson) in a 55-gallon drum filled with water. This condensate water was then diluted with dechlorinated tap water to give a range of desired concentrations. Carbon monoxide, a product of the fuel burning process was evaluated as a potentional source of fish mortality in both the dynamic test system and in separate static tests by bubbling the pure gas through the test water. Mortality was expressed as TL_M values for various periods of exposure, TL_M being the concentration at which 50 percent mortality occurred.

TL_M's for xylene and toluene are given in Table IV. Table V gives TL_M's for outboard engine exhaust water. The TL_M values for the exhaust components is lower than that for the pure aromatic compounds but of the same order of magnitude. It should also be noted that the 96-hour TL_M value for the pure aromatics and the condensate are two to three orders

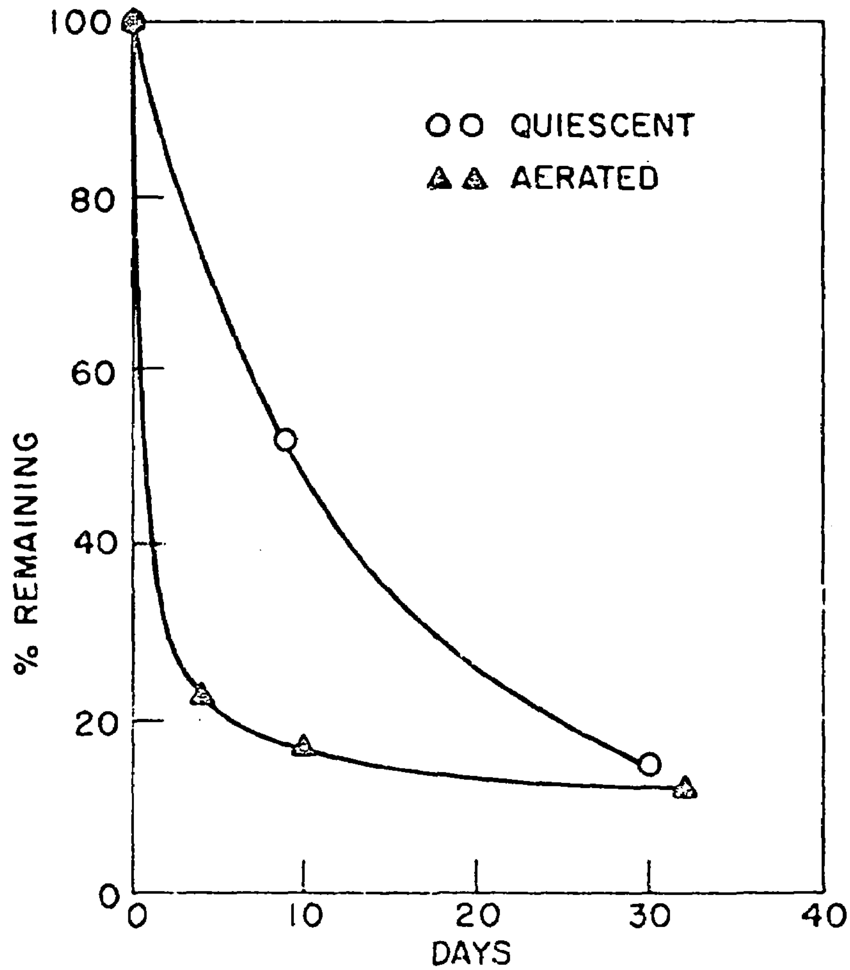


FIG. 7 DISAPPEARENCE OF OUTBOARD ENGINE EXHAUST PRODUCTS FROM AERATED AND QUIESCENT AQUEOUS SYSTEMS AT ROOM TEMPERATURE.

TABLE IV

Median Tolerance Limits for Goldfish
Exposed to Aromatic Hydrocarbons

TL_M Values (ppm)

Compound	24 hr.	48 hr.	72 hr.	96 hr.
Toluene	41.6	27.6	25.3	22.8
Xylene	30.6	25.1	20.7	16.9

TABLE V

Median Tolerance Limits for Goldfish
Exposed to Outboard Engine Exhaust Water

Exposure Time / Fuel	TL_M 24 hr.	48 hr.	72 hr.	96 hr.
Non-leaded	212* (1/4720)** [12]***	194 (1/5160) [11]***	185 (1/5410) [10]***	168 (1/5960) [8]***
Leaded	226 (1/4420)	204 (1/4920)	192 (1/5220)	171 (1/5860)

*values given in terms of gallons of fuel burned per million gallons of water

**values in parentheses given as the volume ratio of fuel to dilution water

***values in brackets express aromatic fraction of OME water in terms of ppm of toluene of magnitude higher than those aromatic levels found in a test pond used in the associated northern field studies which had been subjected to outboard usage at very high levels (Table VI). 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 under normal boating conditions.

TABLE VI

UV-Analytical Data for Saline Test Ponds (Fall 1971)
(Results calculated as ppm (Vol.) toluene)

	Oct. 5	Oct. 12	Oct. 20
Pond #1 (non-leaded)	0.27	0.24	0.08
Pond #2 (control)	0.09	-	0.07
Pond #3 (leaded)	0.19	0.20	0.12
Pond #4 (control)	0.09	0.11	0.09

SECTION V

FIELD STUDIES

NORTHERN FIELD STUDIES

Stress Levels

The engines used in the field stressing were provided by the three major two-cycle outboard engine manufacturers, Outboard Marine Corporation, Mercury Marine Corporation, and Chrysler Corporation, from standard production models (see Table VII). Before use in the field each engine was "aged" by running the engine for approximately 50 hours. This 50 hour period is equivalent to one year of normal operation [9]. The engines employed in the field studies over the three year test period ranged in size between 2 and 50 horsepower and as stated previously were a mixture from the three above mentioned manufacturers. The engines were rotated on a random basis over the three year test period. At no time during the three year period were any of the engines tuned or maintained.

In general, over a week stress period, the engines were operated at 1/4 speed (1000 to 1500 rpms) for 25 percent of the time and 3/4 speed (3000 rpms) for 75 percent of the time. The time and speed settings were agreed upon values [10] used to represent normal boating operations.

Ten weeks after the lakes were divided outboard engine stressing began. The stressing schedule for the entire test period is shown in Table VIII. This table summarizes the total fuel inputs into both the leaded and non-leaded test sections and the engines used during the study.

The fuel utilized throughout the study was Indoline 30 for the leaded test section (this gasoline contains 3.1 grams of tetraethyl lead per gallon) and Indoline clear (no lead) for the non-leaded test section. Both of these gasolines are produced by the Standard Oil Corporation to rigid specifications and are commonly used in engine testing programs where fuel characteristics are deemed necessary.

Standard two-cycle engine oil was added to the gasoline at the recommended ratio of one part to fifty parts gasoline (1:50).

Methodology

In general all chemical and biological sampling was performed by routine standard procedures. A detailed description of sampling procedures and frequency together with the chemical and biological analytical

Table VII

Engines Used During Test Period

Manufacturer	Model No.	Engine Serial No.	Engine BHP	Model Year	Motor Type
Mercury	15002	3238485	50 hp	1972	drainless
Mercury	15002	3238629	50 hp	1972	drainless
Mercury	10402	3297340	4 hp	1972	drainless
Mercury	10402	3297276	4 hp	1972	drainless
Evinrude	18202	08215	18 hp	1972	drainless
Evinrude	18202	08246	18 hp	1972	drainless
Evinrude	2202	01036	2 hp	1972	drainless
Johnson	2R72	3530006	2 hp	1972	drainless
Chrysler	354HD	21581	35 hp	1972	drainless
Chrysler	354HD	21588	35 hp	1972	drainless
Chrysler	82HB	11132	8 hp	1972	drainless
Chrysler	82HB	11152	8 hp	1972	drainless

TABLE VIII

STRESS LEVELS

A. Non-Leaded Test Section

Date	Engine	Stress Rate gallons burned per million gallons per day	Cummulative Stress Level gallons burned per million gallons
1971			
22 Sep - 4 Oct	2 Hp Evinrude	2.4	28.8
4 Oct - 18 Oct	4 Hp Mercury	2.4	62.4
18 Oct - 1 Nov	8 Hp Mercury	2.4	96.0
1 Nov - 15 Nov	4 Hp Mercury	2.4	129.6
15 Nov - 29 Nov	8 Hp Chrysler	2.4	163.2
29 Nov - 1 Dec	2 Hp Johnson	2.4	168.0
1972			
1 May - 6 May	8 Hp Chrysler	0.3	169.5
8 May - 13 May	18 Hp Evinrude	0.5	172.0
15 May - 20 May	35 Hp Chrysler	0.7	175.5
22 May - 27 May	4 Hp Mercury	1.0	180.5
27 May - 12 Jun	50 Hp Mercury	1.0	196.5
12 Jun - 26 Jun	2 Hp Johnson	1.0	210.5
26 Jun - 10 Jul	8 Hp Chrysler	1.0	224.5
10 Jul - 24 Jul	18 Hp Evinrude	1.0	238.5
24 Jul - 7 Aug	35 Hp Chrysler	1.0	252.5
7 Aug - 21 Aug	4 Hp Mercury	1.0	266.5
21 Aug - 4 Sep	50 Hp Mercury	1.0	280.5
4 Sep - 18 Sep	2 Hp Evinrude	1.0	294.5
18 Sep - 2 Oct	8 Hp Chrysler	1.0	308.5
2 Oct - 16 Oct	18 Hp Evinrude	1.0	322.5
16 Oct - 30 Oct	35 Hp Chrysler	1.0	336.5
30 Oct - 13 Nov	4 Hp Mercury	1.0	350.5
13 Nov - 27 Nov	50 Hp Mercury	1.0	364.5
27 Nov - 1 Dec	2 Hp Evinrude	1.0	368.5
1973			
15 May - 1 Jul	18 Hp Evinrude	1.0	421.0
1 Jul - 20 Aug	4 Hp Mercury	1.0	478.0

techniques employed are presented in the final report on this phase of the project to the United States Environmental Protection Agency.

Results and Discussion

Biological

Periphyton Community - Artificial substrates [11,12] were used to sample the periphyton community of the pond systems during 1972 and 1973. Standard size glass microscope slides (25 mm wide x 75 mm long x 1 mm thick) were fastened to a supporting device which held them submerged at a depth of 10 to 15 cm below water level. These slides were permitted to incubate for periods of 14 to 30 days. Slides were visually observed daily at the sampling location and were collected when growth appeared to be at a maximum before material began sloughing from the artificial substrate [13]. At the time of collection, replicate slides from each station were taken for species identification, gravimetric biomass determinations and pigment extraction.

Periphyton diatom richness and species diversity were higher in all four ponds during the 1973 collection period than during 1972. Richness and species diversity of "paired" ponds (1 versus 2 and 3 versus 4) were compared both for the shallow (4 feet - 1.22 meters) and deep (9 feet - 2.75 meters) portions. A paired t-test, 95 percent confidence level, was used to compare statistical significance. The results indicated no significant differences in richness or species diversity occurred during the study period between pond - pairs.

Ash-free dry weight (organic) biomass (g/m^2) and production ($g/m^2/day$), as well as chlorophyll a (mg/m^2) and chlorophyll a production ($mg/m^2/day$) of the periphyton community were higher in all four ponds during the 1973 test period than during the 1972 study period. On most of the collection dates, organic production was less in the stress ponds (1 and 3) than in the control ponds. Organic production in Pond 1 (non-leaded fuel stress action) was less than Pond 2 (control section) on 66.6 percent of the collections. Pond 3 (leaded fuel stress section) yielded organic production values less than Pond 4 (control section) 66.6 percent of the time. When taken as a group, the stress ponds (1 and 3) had organic productions less than controls (Ponds 2 and 4) on two of every three collections (66.6 percent). As with mean organic production, mean chlorophyll a production showed a similar pattern. Chlorophyll a production in Pond 1 was less than Pond 2 on 88.9 percent of the collection dates while 77.8 percent of the time chlorophyll a production in Pond 3 was less than in Pond 4. Regardless of these observations, no statistical significances, using a paired t-test, 95 percent confidence limit, was found between "paired" ponds (1 versus 2 and 3 versus 4).

Mean autotrophic index values, $\frac{\text{ash-free weight } (g/m^2)}{\text{chlorophyll } (g/m^2)}$ calculated for the 1972 and 1973 period indicate that the test stress ponds (1 and 3) were more heterotrophic than the control ponds (2 and 4). Even though mean autotrophic index values were greater in the test ponds (1 and 3) than in the control ponds (2 and 4) in 70 percent of the collections during 1972 and 1973 these differences were statistically significant in only one case (Pond 1 greater than Pond 2). No statistical difference in autophic index levels between Ponds 1 and 2 were observed during the study period.

Phytoplankton Community - Species abundance and occurrence were studied in 1971, 1972 and 1973; samples were calculated twice weekly. Dominant species and biomass were examined in 1971 while dominant species and groups, species richness and population similarity were examined during the 1972 and 1973 test periods. During 1972, short term population variations were studied over a five day period. Throughout the study primary production was measured by ^{14}carbon fixation. During 1973 chlorophyll was measured and related to ^{14}carbon production as a productivity index. A special experiment in 1973 was undertaken to study the immediate effects of outboard engines on phytoplankton in the vicinity of the test - engine docks (refer to Figure 1). In this experiment phytoplankton cell counts, chlorophyll and ^{14}carbon production were determined before, during and after engine operation.

Shifts in phytoplankton species richness ($S/\sqrt{N}$ and $S-1/\ln N$, where S = total number of species and N = total number of individuals were quite similar in pond pairs (1 and 2, 3 and 4). Observed differences during the test period were not statistically significant based on a two-tailed paired t-test (95 percent confidence level). Comparison of mean numbers of phytoplankton individuals of Pond 1 versus Pond 2 and Pond 3 versus Pond 4 for 1972 and 1973, together with similarity coefficient analysis indicates that the initial supposition of similar populations in pond "pairs" was valid. However, during 1973 difference in species richness between Ponds 3 and 4 approached significance. These "near" differences were likely the results of a bloom of blue-green algae and shifts in the association of green algae which occurred on opposing dates. Since both ponds (3 and 4) exhibited these species pulse-phenomena (blooms), although on an asynchronous time scale, these variations must be called natural and not the result of outboard engine stressing. In summary there were not significant variations in phytoplankton species richness caused by outboard engine operation in the four test ponds under study.

Four comparisons of phytoplankton population similarity between ponds indicated a high similarity of species associations between all ponds. Pond 1 (non-leaded stress) being similar to Pond 2 (control and Pond 3 (leaded stress) being similar to its control (Pond 4). Further comparisons also showed the stress ponds (1 and 3) were similar as were the control ponds (2 and 4). The extent to which these comparisons show population similarity indicates that the stressing by two-cycle outboard engines did not affect the composition of species association in the ponds.

Analysis of the phytoplankton populations showed no significant effects due to the outboard engine operation on the abundance and occurrence of phytoplankton species associations. The population similarity coefficients and species richness indices reflect similar populations in all ponds from the onset of the study.

Phytoplankton productivity (^{14}carbon method) showed Pond 1 (non-leaded stress) to be less productive than Pond 2 (control) during 1971 to 1973. The leaded stress pond (3) likewise had less production than its control (Pond 4) during the three year collection period. A two-tailed paired t-test (95 percent confidence) showed these differences not to be significant except in 1972, when the productivity in Pond 1 was significantly less than Pond 2.

Phytoplankton chlorophyll a measurements taken during the 1973 period of study showed no significant differences between Pond 1 (non-leaded stress) and its control (Pond 2). These measurements did show a statistically significant difference however between Pond 3 (leaded stress) and Pond 4 (control). Visual observations of the ponds suggest periodic bloom conditions in Pond 4 during 1973 which would explain the increase in chlorophyll a levels in Pond 4. The variation in chlorophyll a between Ponds 3 and 4 is most probably due to the natural cyclic patterns of biological communities in isolated bodies of water.

Phytoplankton productivity index values (calculated from ^{14}carbon productivity and chlorophyll a values derived from independent subsamples of the 1973 composite collections) showed no significant difference when Pond 1 was compared with Pond 2 and 3 was compared with Pond 4. The resulting phytoplankton productivity index data of 1973 showed no inhibitory or toxic properties caused by outboard engine stressing over an extended period of time.

In midsummer of 1973 preliminary experiments were undertaken to study whether there was photosynthetic inhibition in the immediate vicinity of operating outboard engines. This study included cell counts, chlorophyll a measurements, and [14]carbon production before, during, and after short-term (one hour) engine operation. Even though phytoplankton organisms were submitted to a momentary thermal shock (T of about 10°C) preliminary results indicate no significant effects on primary production in the immediate vicinity of the engines.

Zooplankton Community - Zooplankton samples were collected on a routine basis during the 1972 and 1973 stress periods by use of a "Wisconsin" style plankton net.

The total number of net-zooplankton collected during 1973 was greater in all ponds when compared to the 1972 study period. However, the same seasonal trends and natural fluctuations were observed in both years. The two "paired" ponds (1 and 2 and 3 and 4) were approximately one month out of phase when compared on a "total individuals" recovered basis. In general, the species richness of the zooplankton community was lower in 1973 than in 1972. This effect carried through out all ponds and was concomitant with population trends.

Application of the paired "t" statistical test to the 1972 and 1973 zooplankton data showed no significant differences in zooplankton species richness (S/ N and S-1/lnN) when Pond 1 (non-leaded stress) was compared with Pond 2 (control) or when Pond 3 (leaded stress) was compared with its associated control (Pond 4).

In 1973 zooplankton species diversity between Ponds 1 and 2 again showed no significant difference. However, in 1973 a statistical difference in zooplankton species diversity was observed between Pond 3 (leaded stress section) and Pond 4 (control section). This species diversity significance occurred because Pond 3 had higher total numbers of net zooplankton than Pond 4 (7.2 percent), but more importantly, these greater numbers within Pond 4 collections were confined primarily to the Brachionid Rotifers (4.4 percent). This seems to reduce the calculated diversity of Pond 3. Further, according to Ruttner [14], variations of 10 to 20 percent have no significance in plankton statistics.

From net-zooplankton data collected during the study period it is concluded that the zooplankton community in all ponds demonstrated normal ecological dynamics throughout the study period. No effect on the zooplankton community can be attributed to two-cycle outboard motor operations in the northern test lake systems.

Benthos Community - Quantitative benthic surveys of all ponds were performed monthly during the entire study period (1971 to 1973). These surveys entailed the collection of three benthic samples from each of the four ponds once a month. Statistical sampling points were achieved by using an imaginary alphanumeric grid system over laying each pond. Sampling points were then chosen by random selection during the first study period (1971) and by directed selection the subsequent years (1972 and 1973). All four ponds had comparatively hard substrates, therefore the Ponar grab sampler was chosen for benthic collection.

The 1971 test data indicates a rather diverse (2.30, 2.04, 1.95 and 2.02 species diversity values for Ponds 1, 2, 3, and 4 respectively) benthic faunal assemblage. The subsequent years (1972 and 1973) yielded a much lower species diversity of benthic macrofauna in all four ponds (1.15, 1.24, 1.07 and 1.20 for ponds 1, 2, 3 and 4 respectively in 1972 and 0.53, 0.61, 0.61 and 0.58 for ponds 1, 2, 3, and 4 respectively in 1973). This shift in benthic populations occurred in May 1972 in all ponds.

This shift was due to normal trophic succession found in all bodies of water and accelerated here because of the size of the pond cells and the fact that the trophic nature of the ponds shifted (April through June of 1972) from Chara sp. to the free living phytoplankton species. This shift in trophic nature reduced the microhabitat availability as well as changed the type of habitat. Thus, organisms such as Odonata, Ephemeroptera and Coleoptera which lived within the Chara community gave way to substrate dwelling organisms such as: the Annelid worm and Dipterans. These organisms could survive by burrowing into the unprotected muds and feed upon the decaying Chara and other detritus. Once this shift occurred in early 1972 the benthic macrofauna were similar in all four ponds during the remainder of the study period. Paired "t" statistical testing (95 percent confidence limit) of the benthic data 1971 to 1973, indicates no significant difference between Ponds 1 and 2 and between Ponds 3 and 4. Outboard engine stressing over a three year period did not effect the benthic community.

Fish Community - In the northern field fish study fathead minnow (Pimephales promelas), Bluegills (Lepomis macrochirus), and gold fish (Carassius auratus) were stocked in the ponds (test as well as control sections) prior to stressing. In the first year (1971) the fish were allowed to roam in all ponds. During the second and third years of the study some of these fish were placed in live boxes for subsequent flesh testing studies. The fish placed in these live boxes (25 fish per box) were allowed to eat food native to their respective pond habitats rather than artificial foods.

Fish flesh taste studies were performed when the gallons of fuel burned per million gallons of water levels were 1.4, 1.5, 2.8, 4.0, 4.2, 11.2, 76.9, and 110.5 These studies were performed on fish from both the non-leaded and leaded fuel stress sections, Ponds 1 and 3, respectively. Fish handled in the same manner from Ponds 2 and 4 (control ponds) were used as control fish. On the average over the test period no "off-flavor" was noticed on 62.5 percent of the fish samples in the non-leaded test pond and 74.3 percent of the fish from the leaded test pond. At no time did the taste panel indicate an "off-flavor" due to "petroleum-like taste". The greatest response to differences in taste were directed at the texture of the fish tissue.

Chemical -

General Chemistry - In general, the level of dissolved solids in all four ponds as a group tended to increase slightly during the first study year, then leveled off and remained relatively constant during the second and third years. It should be noted that total dissolved solids were not measured directly, but rather, the majority of anions and cations which make up the dissolved solids were measured on an individual basis.

Over the three year period phosphorus levels did not vary significantly between control and stress ponds. It should be noted here that the total phosphorus levels for all ponds increased significantly during the 1973 test season. This increase is mainly in the polyphosphorus or particulate fraction. This rise in total phosphorus is most probably due to the natural process of nutrient recycling within each of the ponds.

A general review of the nitrogen data, gathered during the study, for each separate pond indicates an overall increase in organic and nitrate nitrogen when comparing 1971 levels with 1973 levels. Ammonia and nitrite nitrogen data show no such "trend" increase over the study period. Again, this chemical shifting appears to be a natural process of the ponds themselves and not related to outboard engine stressing.

Statistical analysis (paired "t" testing) of all the chemical data collected during the study showed that there was significant differences (95% confidence level) in five chemical components (pH, hardness, sulfate, conductivity and lead) when Pond 1 (non-leaded stress section) was compared to its associated control (Pond 2). Significance at the 95% confidence level was observed in nine chemical components in the water column (pH, alkalinity, hardness, calcium, magnesium, chloride, conductivity, dissolved oxygen, temperature and lead) when the leaded fuel test section (Pond 3) was compared to Pond 4 (control).

The differences reported for hardness, calcium, chloride, sulfate, and conductivity, although statistically significant were not that large when average mean values over the three year test period are compared. Variations observed in these chemical components are most probably due to normal variations in sampling and accuracy of chemical analysis. These variations could also be the result of scouring of the bottom sediments in the stressed ponds by the test propeller wash. This latter explanation is a distinct possibility as the mean values of the five above-mentioned chemical components were higher in the test section water columns (Ponds 1 and 3) than in the associated control section water columns (Ponds 2 and 4). This perturbation of the bottom sediments is more a result of physical sizing (average water depth of 6 feet) of the test facility and would be atypical of normal outboard motor operations in deeper water. Thus, it is concluded that the significant differences reported above cannot be attributable to two-cycle outboard exhaust emissions per se but rather to the physical operation of these engines in shallow water (< 6 feet).

Significant differences in dissolved oxygen was also observed during 1972 when the non-leaded fuel stress section (Pond 1) was compared to its associated control (Pond 2). On the other hand, Pond 4 (control) showed higher dissolved oxygen levels than its associated stress test section (Pond 3). A review of the phytoplankton results for these ponds during 1972 indicates larger phytoplankton populations in Ponds 1 and 4 than in Ponds 2 and 3. This leads one to conclude that the significant differences observed in dissolved oxygen in 1972 between Ponds 1 and 2 and Ponds 3 and 4 is probably due to natural biological activity rather than an effect due to outboard engine stressing. A temperature significance was noted between Ponds 3 and 4. The mean difference in temperature (ΔT) was 0.5°C over the three year period. It is felt that this significance can be explained by the methods used to measure temperature in the field. No effect on water temperature can be attributed to the stressing by outboard engines except in the immediate vicinity of the engines. Occasional statistical significance was also observed in pH and alkalinity when stress sections were compared to control sections. These shifts in pH and alkalinities can be related to algal activities which leads to preferential consumption of carbonates by the biological communities with a resulting decrease in carbonate alkalinity[15]

Lead - Lead concentrations in the water column were significantly higher in both stressed ponds (1 and 3) than in their respective control ponds (2 and 4). The significant differences in lead levels between Ponds 1 and 2 can possibly be explained by sediment bottom scouring due to the propeller wash in the test section (Pond 1). The bottom sediments of the test ponds (1 and 3) contain between 10 and 40 mg of lead per Kg. The resuspension and subsequent resolution of this sediment material would tend to raise the total lead content observed in the water column of the test section. As suspected lead levels in the water column of Pond 3 (leaded fuel stress section) were higher than in any other pond.

Because of this possible bottom sediment scouring situation it was found desirable, from a statistical point of view to compare the leaded levels in the water column of Pond 3 with the lead levels in Pond 1. Both of these ponds were affected by possible scouring due to outboard engine operations. However, only Pond 3 was exposed to stressing with leaded fuel. Hence, Ponds 1 and 3 (non-leaded and leaded stress sections, respectively) were evaluated using a one-tailed paired "t" analysis. A significant difference in lead levels was observed between Ponds 1 and 3. There is a 34 percent increase in lead concentration in Pond 3 as compared to Pond 1. This increase in lead levels is directly attributable to the use of outboard engines operating on leaded fuel.

During the three seasons of stressing, a total of 1.48 Kg of lead was introduced to Pond 3 through the combustion of fuel containing 3.1 grams of lead per gallon. Analysis of lead content in the pond sediments and statistical evaluation of the data does not show a significant increase in lead in the sediments of Pond 3 (leaded fuel stress section). The mean lead concentration in the bottom sediments of Ponds 1, 2, 3, and 4 were 23.7, 17.9, 29.5 and 26.4 mg/kg respectively. Paired statistical comparisons between Ponds 1 and 3, does not indicate a significant difference in lead content of the sediments between the two ponds. It should be noted here that the small sample size and the high standard error of difference due to the standard deviation of the differences in the sample population may be the reason no significant differences were observed in the lead content of the sediments.

Hydrocarbon - Data from the 1973 stressing season on saturated hydrocarbon levels in the water column is presented in Table IV. These data indicate saturated hydrocarbons in the 175-300°C boiling point range (corresponding to, in molecular weight C_{10} to C_{16} n-paraffins present in the ponds) in the range of 0.35 to 0.48 mg/l. Saturated hydrocarbons in the 300-400°C boiling point range (corresponding in molecular weight to C_{17} to C_{24} n-paraffins) are present at the 0.11 to 0.21 mg/l level. It should be noted that both emulsified and adsorbed hydrocarbon material is included in the analysis of these water column samples by the analytical procedure employed. Statistical analysis of this data by a two-tailed paired "t" test shows that no significant differences exist between stressed and control ponds during the period of testing.

TABLE IX

HYDROCARBONS* (Boiling Point Range 175-300°C) (mg/l)

Date	Pond 1	Pond 2	Pond 3	Pond 4
15 May 73	0.45	0.40	0.41	0.38
1 Jun 73	0.39	0.40	0.43	0.39
26 Jun 73	0.48	0.42	0.36	0.35
2 Jul 73	0.35	0.35	0.35	0.38
23 Jul 73	0.37	0.37	0.37	0.36

HYDROCARBONS* (Boiling Point Range 300-400°C) (mg/l)

Date	Pond 1	Pond 2	Pond 3	Pond 4
15 May 73	0.13	0.11	0.12	0.11
1 Jun 73	0.11	0.12	0.13	0.12
26 Jun 73	0.15	0.14	0.17	0.19
2 Jul 73	0.18	0.16	0.19	0.20
23 Jul 73	0.21	0.16	0.16	0.17

*Samples are composites of individual samples taken at surface and middle at stations A and B and surface, middle and depth at station C.

Table X

Saturated Hydrocarbons in Sediments (mg/kg)
(boiling point range 175-300°C)

Date	Station	Pond 1	Pond 2	Pond 3	Pond 4
15 May 73	A	<0.1	3.2	12.8	11.1
15 May 73	B	6.0	15.3	3.8	<0.1
15 May 73	C	3.4	4.7	<0.1	2.8
18 Jun 73	A	3.4	3.8	10.5	9.1
18 Jun 73	B	0.8	2.7	4.0	3.6
18 Jun 73	C	5.4	5.0	25.8	6.7
23 Jul 73	A	7.5	2.1	4.6	1.8
23 Jul 73	B	5.9	8.7	<0.1	4.3
23 Jul 73	C	4.7	12.9	19.5	0.3

Saturated Hydrocarbons in Sediments (mg/kg)
(boiling point range 300-400°C)

Date	Station	Pond 1	Pond 2	Pond 3	Pond 4
15 May 73	A	4.7	2.9	19.2	7.9
15 May 73	B	11.0	6.4	4.5	3.7
15 May 73	C	5.1	4.0	6.7	3.7
18 Jun 73	A	9.9	1.7	4.6	7.3
18 Jun 73	B	3.1	3.4	6.5	4.2
18 Jun 73	C	16.0	2.3	22.5	6.1
23 Jul 73	A	22.3	1.1	1.6	7.8
23 Jul 73	B	12.3	15.9	0.2	4.6
23 Jul 73	C	8.4	7.6	8.8	5.1

Saturated hydrocarbon levels of the sediments from all four ponds are shown in Table X. Hydrocarbon levels in the 175-300° boiling point range varied from 0.1 to 25.8 mg/Kg dry weight of sediment. The overall mean concentration of hydrocarbons in the 175-300°C boiling point range in the sediments of Pond 1 is about the same as that of Pond 2 (4.1 mg/Kg versus 6.5 mg/Kg, respectively). The overall mean concentration of hydrocarbons of this range (175-300°C) in the sediments of Ponds 3 and 4 were 9.0 and 8.9 mg/Kg, respectively. In the 300-400°C boiling point range, the saturated hydrocarbon levels in the sediments were 10.3, 5.0, 8.3, and 5.6 mg/Kg for Ponds 1, 2, 3, and 4, respectively. Statistical analysis of this data indicates no significant difference between Ponds 1 and 2 and Ponds 3 and 4. Visual observations of the data seems to indicate a "trend" with an apparent increase of saturated hydrocarbons in the 300-400°C boiling point range when Pond 1 is compared to Pond 2 and Pond 3 is compared to Pond 4. However, this is negated statistically by the small sample size and the high standard error of difference due to the standard deviation of the differences in the sample population.

SOUTHERN FIELD STUDIES

Treatment Levels

Motor operations of both test systems was on a continuous basis for an 18-month period. On a cumulative basis both the drained and drainless engine test ponds were exposed to a treatment of approximately 400 liters of fuel burned per million liters of water over the first 12 months and 700 liters of fuel burned per million liters of water over the total 18-month period. It should be noted that the optimal treatment level of three times (3X) the maximum boating usage was not attained until the twelfth month of the 18 month study as the water level receded. Treatment levels continued at values of three times maximum boating usage or greater for the remainder of the project.

Methodology

All chemical and biological sampling was performed by routine standard procedures. A detailed description of sampling procedures together with the chemical and biological analytical techniques employed is presented in the final report to the Environmental Protection Agency.

Results

Biological

Benthic Macroinvertebrates - Benthic samples were collected with a 36 square inch (0.02 square meter) Ekman dredge from August, 1971 to March,

1973. The control and drained engine test ponds were sampled at five locations each month, the drainless engine test pond was sampled at four locations per month throughout the study period.

A complete list of the total macroinvertebrate taxa collected throughout the study is included in the final report. In general, the benthic community structure illustrated taxanomic similarity throughout all three test ponds; each being dominated by insect larvae primarily within the Order Diptera. Other organisms collected during the study period were: Tubificids, Amphipods, Odonates, Ephemeropterans, Nematodes, Trichopterans, Turbellarians, Hirudineans, Coleopterans, Cladocerans and Hydracarina.

The number of families of macroinvertebrates was lowest in the drainless engine test pond. However, calculated indices on community diversity indicate the drained engine test pond to be the lowest in diversity with the control pond the highest.

A one way analysis of variance (ANOVA), when applied to species composition and density, indicates no discernable difference in the macroinvertebrate populations of the three ponds after 18 months stressing. The ANOVA analysis was performed at the 95 percent level of confidence.

A multiple regression analyais was also performed on benthic invertebrate diversity to determine seasonality or differences between ponds due to engine stressing. There was a significant difference between ponds with respect to their mean diversity indices. The control pond had the highest species diversity index, the drained engine pond next, and the drainless engine pond the lowest index. The control pond was significantly higher than the drainless engine pond, but was not significantly higher than the drained engine pond. The drained engine pond was not significantly higher than the drainless engine pond. For a given pond there was no statistical difference between the mean species diversity indices over the full 1972 annual cycle, although the spring season had the highest indices and the winter season had the lowest indices.

Periphyton - Periphyton productivity as dry weight and ashfree dry weight ($g/m^2/day$) was measured throughout the study (August 19, 1971 - March 27, 1973). Glass microscope slides provided artificial substrates for periphyton colonization. Artificial substrates such as glass slides are somewhat selective but this provides a technique for sampling similar populations between ponds. Natural substrates, i.e., macrophytes, were more abundant in the drained engine and drainless engine ponds than in the control pond. Measurements of the periphyton community were based on the assumption that natural substrate surface area, grazing, predation, death, and decomposition were on the same order of magnitude in all three study ponds. Therefore, the calculated organic productivities reflected actual differences related to the natural and experimental stresses in each pond. Periphyton daily growth rates, expressed as grams of carbon fixed per square meter per day, ranged from 0.01 to 0.12 during the course of the study. The highest single daily growth rate occurred in September in the drained engine ponds (0.12 g/m²). The general, periphyton growth rates were highest during the summer months and lowest during the winter.

A one way analysis of variance test was used to determine significance of variations in the data. This test compared productivity values from the combinations of control and drained ponds, control and drainless ponds, drained and drainless ponds, and control, drained, and drainless ponds. Although the drained engine pond showed higher daily growth rates and a higher yearly average, the variations in periphyton productivity between the three study ponds was not significant at the 95 percent level of confidence. Hence, assuming substrate surface area was equal in all three ponds, the operation of two-cycle outboard engines (drained and drainless) had no apparent effect on the periphyton community over the course of the study.

Phytoplankton - The phytoplankton community was studied throughout the course of this project using species diversity, productivity and biomass analyses. Identification and counts of composite surface and bottom samples were made monthly. Comparisons between ponds were made with the Shannon-Weaver species diversity index where environmental stresses are reflected by a decrease in diversity. Biomass was estimated through chlorophyll *a* measurements which were taken on composite surface and bottom samples by *in vivo* fluorometry once each month in 1973. Phytoplankton primary productivity was measured using the ^{14}carbon technique during 1971 and an oxygen method during 1972 and 1973.

Plankton cell diversity, recorded as cells/ml, indicated that the Cyanophyceae (blue-green algae) were most abundant in all three ponds. *Anacystis marina* was described as the dominant organism as it occurred in 46 percent of all samples from the drainless engine ponds, 35 percent of all samples in the drained engine ponds, and 33 percent of all samples in the control pond. The Chlorophyceae (green algae) was the most diverse group but also occurred with the lowest abundance. "Blooms (500 cells/ml) of green algae did not occur. The Chrysophyceae (golden-brown algae), were often rare in abundance (rare = 1-5 cells/ml and uncommon = 6-19 cells/ml). Likewise the Dinoflagellates, also characteristic of most Florida lakes, occurred in the "rare-uncommon" range of abundance. The

Bacillariophyceae (diatoms) were exceedingly rare. Several other major groups were represented by a few taxa, but were "rare-uncommon" in abundance.

Seasonal species diversity indices were variable, although differences in mean diversity values (28 June 1971 - 2 April 1973) were not that great. A one way analysis of variance test (ANOVA) indicated no significant difference between diversity in the three test ponds during the 1971 baseline study. Furthermore, no significant variations in diversity were found during 1972. However, ANOVA calculations did show significant variations (99 percent confidence level) in species diversity during 1973 with the drainless engine pond exhibiting the lowest diversity and the control pond yielding the highest diversity. Diversity values seem to be closely related to the blue-green algae, Anacystis marina, which often occurred in "bloom" conditions. There are, however, no studies available which relate this species to environmental stress factors.

Phytoplankton cell density was quite variable although mean and standard deviation values are reported as being similar to earlier studies in acid-soft water lakes. Cell diversity was lowest during summer months and it is felt that phosphate was a limiting factor at < 0.001 mg/l orthophosphate. The one way analysis of variance test showed no significant difference between cell density of the three test ponds during the 1971 baseline study or during the 1972 test period. The ANOVA test showed significant variations between cell density of the test ponds during 1973 at the 99 percent confidence level. Greater numbers of cells/ml were found in the stressed ponds compared to the control.

Estimates of standing crop by pigment analysis indicated higher values in the control pond as opposed to the drained engine and drainless engine ponds. Biomass values were quite variable between the test ponds during the 1971-1973 study period. The one way analysis of variance test, at the 95 percent confidence level, indicated significantly higher chlorophyll a levels in the control pond than in the two stressed ponds. In applying the linear regression test to the control pond data, there was a high correlation between cell density and chlorophyll a. There was no such functional relationship found in either test pond. It should be noted however that the correlation between cell numbers and chlorophyll a may be influenced by cell size. As for example, Anacystis marina which was found in higher abundance in the stress ponds, has an extremely small cell size and most probably a small amount of chlorophyll a.

The 1971 baseline data showed greater phytoplankton productivity in the control pond than in the treated ponds. Although the control pond did not vary significantly from the drainless engine pond, the variation between the control and drained engine pond was significant at the 95 percent confidence level (ANOVA test). Significant differences between the control and the two stress ponds (95 percent confidence level) were seen in phytoplankton productivity during 1972-1973. In studying the annual trends of the three test ponds, it is noted that productivity in the control pond varied greatly from approximately 0.01 gCm^{-3} to a high of 1.1 gCm^{-3}. The stress ponds ranged approximately from 0.01 gCm^{-3} day^{-1} to 0.7 gCm^{-3} day^{-1} and essentially paralleled each other during most of the study period.

In conclusion, there were temporal changes in species composition, standing crop, species diversity, chlorophyll a, and primary productivity. These changes were most probably due to variations in nutrients including carbon dioxide, temperature, and light, and cannot be conclusively correlated to outboard engine emissions or operations.

Macrophyte associations - Evaluation of the macrophyte community include species composition and standing crop analysis together with grass bed productivity and carbonate enrichment experiments. Grass bed collections were made by random quadrat sampling and removing all vegetative structures.

The eulittoral and sublittoral zones of the drained engine pond had greater plant biomass than the other test ponds. Sampling frequency was not sufficient to examine the data statistically.

The vegetational changes in all three test ponds have followed a normal qualitative pattern as is evidenced by species composition, frequency and distribution. The control pond was dominated by Bladderwort (Utricularia floridans) and Carpet Rush (Juncus repens), while the drainless engine pond was dominated by a population of Bladderwort throughout the study period. The drained engine test pond initially supported a mixed community consisting primarily of Bladderwort and Water Mint (Hydrotrida caroliniana), however, during the summer of 1972 Water Mint began dominating all but the deepest areas of the pond. In May 1973 Bladderwort was reestablishing itself within the drained engine test system.

Grass bed productivity was measured in clear plastic domes (0.5m diameter x 0.5m high) which was placed over selected areas of the plant bed. Oxygen was measured at dawn, dusk, and at the following dawn. Productivity was calculated in terms of the difference in oxygen levels between daylight and dark periods. No statistical difference (ANOVA at 95 percent confidence) in gross productivity of the grass bed was observed between the control and the drainless engine pond. There was significant difference in productivity between the control and drained engine ponds and between the drained engine and drainless engine ponds.

During five of the seven months for which grass bed productivity data were obtained, specifically, January, April, June, July, and September, the drained engine pond had the highest productivity, the next highest was the drainless engine pond except during the month of June when it was the lowest. The control pond had the lowest productivity except for the month of June when it was higher than the drainless engine pond. Averaged over all the months, the highest productivity was in the drained engine pond, next was the drainless engine pond, and the control pond had the lowest productivity.

Enrichment experiments were conducted in the control and drained engine ponds to assay the grass bed community for carbon as a limiting factor. As pH was low (less than the carbonate-biocarbonate equivalence point) and there was the probability of a non-carbonate buffer system, carbon was suspected to be a limiting factor in the grass beds. A control and five levels of carbonate solution (0.5 - 10 ppm) were added to individual domes by capillary tubes. Oxygen production was measured before and during the addition of carbonates and compared to the control. No significant differences in productivity were noted by adding carbonates to the control pond. Most likely because of the sparse vegetation that occurred during November when the experiment was conducted. However, carbonate enrichment did significantly increase productivity in the drained engine pond. When compared, the drained engine pond had a much greater initial biomass than the control pond.

There are indications from these studies that carbon dioxide (CO_2), a component of the gaseous exhaust emissions, may cause, at the treatment levels employed in this study, an increase in productivity in soft-acid water lakes. This "treatment effect" has not been fully substantiated because only one of the test systems (drained engine pond) showed this response. In addition as a result of mixing and stirring, transport of carbon dioxide as well as other nutrients into the grass beds may cause an increase in productivity. Water circulation was observed in the ponds during the operation of the motors. Some scouring of the bottom sediments was noted in the vicinity of the motors.

Fish tainting - Samples of sunfish (Lepomis sp.) and large mouth bass (Micropterus salmoides) were collected periodically from each pond and tested by a panel of eleven judges at the University of Florida Food Sciences Laboratories. A triangular testing method was employed in which the judges were given three samples, two of which were identical. They were asked to identify like samples, and to rate than on a scale from one (very bad taste) to seven (very good taste) and to comment as to whether any traces of "tainting" by petroleum products could be detected.

The taste of bass and sunfish was found to range from four (neither like or dislike) to six (like moderately) in each of the three test ponds throughout the entire study period. No significant evidence of fish tainting was observed during the study.

Chemical -

General chemistry - To evaluate the effect of outboard marine engine operation on the chemical system of the southern lakes, a relatively broad chemical characterization study of the aquatic system was undertaken. A detailed description of the chemical methods employed is given in the final report. Baseline data on the chemical systems in the three ponds was collected during the months of July through October, 1971.

The southern "lakes" are chemically similar to many freshwater Florida lakes in that they contain low amounts of dissolved solids, are acidic, and have clear water and exhibit a dense grass bed zone. Biological activity and storm water runoff generally determines the nutrient levels, and seasonal variation in this activity can account for relatively large variations in the levels and molecular forms of carbon, nitrogen and phosphorous.

Of twenty-five chemical parameters measured, no effects were observed in total dissolved solids, total suspended solids, hardness, conductivity, turbidity, pH, dissolved oxygen, chloride, fluoride, sulfate, magnesium and iron. Excessive variations in the natural background of biochemical oxygen demand (1 to 5 mg/l) and chemical oxygen demand (9 to 85 mg/l) precluded isolating the contributions made by the outboard marine engines. Similarly, there were seasonal variations in total phosphorus, orthophosphorus, ammonia, nitrite, nitrate, particulate organic carbon, and organic nitrogen but no relationship with outboard engine operation could be found.

Inorganic carbon - Two chemical components showed a statistically significant variation as a result of outboard engine stressing. Mean total inorganic carbon concentrations in the stressed pond were 50 to 66 percent higher than in the control pond. Levels observed in all the ponds fell within the 0.2 to 1.4 mg/l range which approach the limit of detection of the analytical method employed. The increase in inorganic carbon in the stressed ponds is attributed to the CO_2 emissions of the engines, the CO_2 resulting from oxidation of unburned or partially burned hydrocarbon emissions, mixing of the bottom waters with the surface waters in the limnetic zone and the increased diffusion of CO_2 between the atmosphere and the lake waters due to engine operation.

Organic carbon - Total organic carbon levels were significantly higher in the drained engine pond than in either the drainless engine or control ponds. A mean concentration of 7.4 mg/l in the drained engine pond and 28 percent higher than that of the drainless engine pond and 17 percent higher than the control pond. This may be attributed to the crankcase drainage of dissolved organics (hydrocarbons) associated with the use of drain-type engines as well as decomposition of vegetation.

Motor operation in the southern lakes increase the concentration of dissolved aromatic hydrocarbons and also mixed and circulated the lake water. Therefore, the hydrocarbon emissions, as well as, other exhaust emissions were distributed throughout the lakes. The concentration of aromatic hydrocarbon (as measured by U-V analysis) increased from background levels of less than 0.1 mg/l (measured as toluene) to levels of 1.0 mg/l during motor operation. When the motors were not operated for two days, the hydrocarbon levels declined to less than 0.1 mg/l.

Although the leaded fuel was used in this study, the environmental impact of lead emissions were not studied because of the large background levels of lead (8 to 90 mg Pb/Kg of dried plant tissue) observed in the rooted vegetation of the lakes. No known sources of leaded pollutants were found to have entered the three southern lakes prior to the study.

SECTION VI

REFERENCES

1. Threinen, C., "Conflicts in the Boating Scene and Their Bearing on Access Sites", Proceedings of the 5th National Conference on Access to Recreational Waters - Boston, Mass. (1967)

2. Private Communication, Dr. David Cole, Department of Mechanical Engineering, University of Michigan, Ann Arbor, Mi.

3. English, J.N., McDermott, G.N., and Henderson, C., "Pollution Effects of Outboard Motor Exhaust - Laboratory Studies", Journal Water Pollution Control Fed., 35, 7, ^23 (1963).

4. English, J.N., Surber, E.W. and McDermott, G.N. "Pollution Effects of Outboard Motor Exhaust - Field Studies", Journal Water Pollution Control Federation, 35, 9, 1121 (1963).

5. Blumer, M., "Oil contamination and the Living Resources of the Sea", FAO Tech. Conf. on Marine Pollution, Rome, Italy, Dec. 9-18, 1970.

6. A.S.T.M. (1968) Manual of Hydrocarbon Analysis, 2nd Ed. Philadelphia, Pa.

7. Martin, J.M. Jr., et al, "Ultraviolet Determination of Total Phenol,"p. 21, Journal Water Pollution Control Federation, 30 (1), 1967.

8. Schenk, N.K. et al, "The Effect of Long-Term Exposure to Outboard Engine Exhaust Emission on the Fathead Minnow," University of Michigan (ORA Project 34856), August 1970.

9. Boating Industry Association, Chicago, Illinois, personal communication.

10. Project 15020 GPG. Review Meeting between EPA and BIA Consultants, Gainesville, Florida. October 1971.

11. Cooke, W.B. Colonization of artificial bare areas by microorganisms. Botanical Review. 22:613-638, 1956.

12. Vollenweider, R.A. A manual on the methods of measuring primary production in aquatic environments, IBP Handbook No. 12. Oxford and Edinburgh, Blackwell Scientific Publication, 1969. 213 p.

13 Weber, Cornelius I. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. U.S. Environmental Protection Agency. Cincinnati, Ohio. EPA-670/4-73-001. National Environmental Research Center, Office of Research and Development. July 1973. Plankton 17 p. Periphyton 6 p.

14. Ruttner, F. Fundamentals of Limnology, Third edition. Toronto, University of Toronto Press, 1963. p. 105-219.

15. King, D.L. The Role of Carbon in Eutrophication. J. Water Pollution Control Federation. 42: 2035-2051, December 1970.