Impact Of Outboard Motor Operation On Water Quality

Water Quality Protection Project
Houghton Lake, Michigan

An Inland Lake Water Quality Management Project Report

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IMPACT OF OUTBOARD MOTOR OPERATION ON WATER QUALITY

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by

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A Cooperative Study Financed by the

Upper Great Lakes Regional Commission and the

Michigan Water Resources Commission

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ABSTRACT

The impact of current outboard motor usage on Houghton Lake water quality was investigated during 1972, as part of a Water Quality Protection Demonstration Project at Houghton Lake. Boating use was determined through direct boat counts and questionnaires distributed to lake area resident and transient boaters.

Estimates of the total number of two-cycle outboard engines used on Houghton Lake by residents during the June-July and August-September periods were 3122 and 3402, respectively. A total of 4150 transient boaters used the lake during July and August. The total boating hours for the May through November period was approximately 265,000 hours.

Approximately 246,469 gallons of outboard motor fuel were consumed on Houghton Lake during May through November, 1972.

Inherent in the operation of two-cycle outboard engines are three sources of chemical pollution: (1) crankcase condensate discharge, (2) fuel vapor discharge and (3) gaseous emissions. Assuming 5 to 10% of the total fuel used by an outboard engine is discharged from the crankcase without being burned, approximately 12,000 to 25,000 gallons of raw fuel, containing short and long chained hydrocarbons, tetraethyl lead, ethylene dibromide or ethylene dichloride, elements such as zinc, sulfur, phosphorus and other unspecified additives, were discharged into Houghton Lake. Exhaust products from burned fuel contribute large quantities of oxides of carbon, nitrogen and sulfur; hydrocarbons; partial oxidation products and complexed particulate lead compounds to lake waters. These emission products are toxic to fish and aquatic life but only at concentrations generally higher than would result from normal outboard engine usage. The fuel consumption rate of 4.4 gallons fuel consumed/million gallons dilution water (lake water) for Houghton Lake was approximately 50% below values reported in the literature that resulted in fish tainting.

Dissolved lead was not detectable (<0.01 ppm) in Houghton Lake water. Lead concentrations in lake sediments were within the range found in sediments from Michigan stream background stations. Sediments near marinas did not show elevated lead concentrations as a result of high usage and accidental fuel spillage. Five macroinvertebrates and six species of warm-water fish had average lead concentrations ranging from <1.0 to 1.87 ppm (wet weight) and 0.50 to 1.33 ppm (wet weight), respectively. Lead concentrations in three species of warm-water fish from Michigan background stream stations ranged from 0.1 to 0.5 ppm wet weight. Lead levels appear to be higher in Houghton Lake fishes, but insufficient data prevented statistical analysis.

The snowmobile and car usage of Houghton Lake during the winter 1972-73 was surveyed. These surveys showed that Houghton Lake received substantial usage during the winter months and that these vehicles may contribute significant quantities of exhaust products (hydrocarbons and lead) to Houghton Lake.

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INTRODUCTION

Increased use of two-cycle outboard engines for recreational purposes in the past 10-15 years has caused concern that the exhaust products from these engines may be polluting our nation's waters. Between 1959 and 1972, the number of outboard engines in use in the United States increased from 5.8 to 7.4 million, with the average size engine sold annually also increasing from 24 to horsepower during the same period (Anonymous, 1972). The estimated average size of all outboard engines sold since 1946 and still in use today is 25 horsepower (Hare and Springer, 1973). The increased possibility of environmental degradation from greater numbers of larger engines has resulted in numerous investigations concerning the environmental effects of outboard engine exhaust products. These studies have been conducted and are presently being continued by various private consulting firms, universities, independent testing laboratories, manufacturers of outboard engines, state governments and federal agencies.

Michigan has the largest number of licensed boats in the United States and is second only to New York in the estimated number of outboard motors in use (Anonymous, 1972). Michigan and the seven other states bordering the Great Lakes account for 37.6% of the estimated number of motors in use in the entire nation. This high use of Michigan waters for recreational boating makes it imperative that definite conclusions be made concerning the effects outboard engines are having on the aquatic environment.

Houghton Lake is Michigan's largest inland lake (20,044 acres) and it receives heavy use by fishermen and pleasure boaters. Although results of existing studies are conflicting, they indicate a potential for water quality degradation from outboard motor exhaust. This potential prompted a survey of the present outboard motor usage on Houghton Lake. An attempt was also made to determine, by reviewing the literature, what effects the current level of usage could have on water quality and if these effects could be documented in Houghton Lake.

LITERATURE REVIEW

The primary cause of pollution from the operation of outboard engines is the basic design of the two-cycle gasoline engine. Unlike four-cycle engines which use separate piston strokes during fuel intake and exhaust, the two-cycle engine combines the intake and exhaust cycles into one piston stroke (Figure 1). Upon ignition of the compressed fuel vapor in the cylinder, the downward or power stroke of the piston increases the pressure on the fuel vapor in the crankcase. This pressure forces fuel vapor from the crankcase into the cylinder through the open intake port. Spent gases in the cylinder are, at the same time, forced out the open exhaust port by this inflow of the new fuel vapor (Figure 1,B). This operation is termed "crankcase scavenging" and requires an airtight crankcase to allow the vaporized fuel mixture in the crankcase to be forced into the cylinder by the downward piston stroke (Lussier, 1970).

The airtight crankcase prevents the direct application of lubricant to the internal parts of the engine. Therefore, oil is mixed with the gasoline before the fuel is fed to the engine. During the previously described cycle, a portion of the gas-oil fuel mixture condenses within the crankcase on the internal parts of the engine, providing lubrication. The condensate does not reach the combustion chamber, so it is not burned and begins to collect as a liquid in the lower portion of the crankcase. Since this process of lubricant condensation is cumulative and the crankcase is airtight, this liquid would eventually accumulate to such an extent that the piston would not operate, a condition termed "hydraulic lock". To avoid this condition, the pool of liquid is vented directly to the water through the exhaust system by means of pressure activated valves (Shuster, 1971; Lussier, 1970; Muratori, 1967).

Inherent in the above operation of two-cycle engines are three sources of chemical pollution: 1) crankcase condensate discharge, 2) fuel vapor

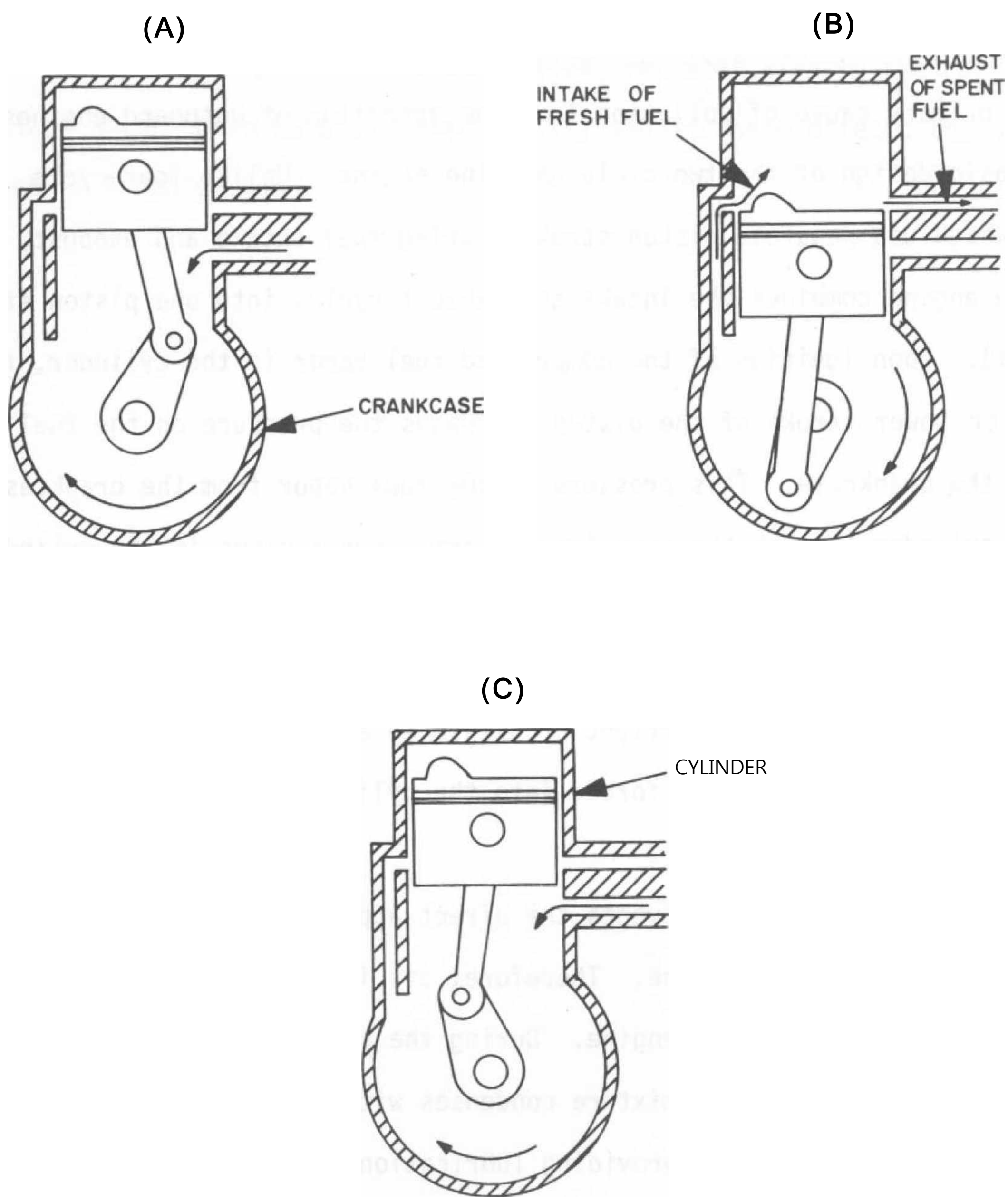

FIGURE I

SCHEMATIC OF TWO-STROKE ENGINE OPERATION

(A) – BEGINNING OF POWER (DOWNWARD PISTON STROKE)

(B) – BEGINNING OF COMPRESSION (UPWARD PISTON STROKE)

(O _ END OF COMPRESSION - BEGINNING OF POWER discharge and 3) gaseous emissions. First, the crankcase condensate is discharged directly to the water in an unburned state through the exhaust system. Several studies have been conducted to determine the amount of fuel which is discharged in this manner (Ferren, 1970; Shuster, 1971; Muratori, 1967; Stillwell and Gladding, 1969). In these studies, tests were conducted at varying engine speeds on outboard engines of different makes, ages, horsepower ratings and motor conditions. Results of all studies indicated that from 0 to 56 percent of the fuel used was not burned and was discharged directly to the water. The speed of the engine (rpm) seemed to be the single most important factor affecting the amount of fuel discharged. Shuster's (1971) tests on a 33 horsepower motor showed that the greatest quantity of unburned fuel was discharged when the engine was running at a slow speed of 1000 rpm, while the least fuel was discharged at a higher engine speed of 3000 rpm. Tests by Stillwell and Gladding (1969), as interpreted by Ferren (1970), showed that for two 1965 outboard motors (one low and one high horsepower engine), the crankcase drainage increased at slower speeds and seemed to peak around 1000 to 1250 rpm (idling and trolling speed). Muratori (1967) reported that at trolling speeds as much as 50% of the original fuel mixture could be wasted into the exhaust manifold. Lussier (1970), in a summary of previously reported works, concluded that at engine speeds of less than 1000 rpm about half of the fuel wastage results were below 10%; at engine speeds of 1000-2500 rpm, 40% of the fuel wastage figures reported exceeded 30% and at engine speeds exceeding 2500 rpm, all of the results were below 10% fuel wastage. It appears that higher engine speeds are more efficient and produce less fuel wastage.

The 10% average fuel wastage figure suggested by Muratori (1967), Ferren (1970) and Shuster (1971) is probably a high estimate of the fuel wastage for the "real population" of outboard motors. "Real population" meaning all outboard engines currently in use. The experimental motors were generally operated under controlled conditions at three or four speeds for similar periods of time. Since outboard motors are normally operated over the whole range of engine speeds for varying amounts of time, these factors would have to be taken into account in computing the average fuel wastage for the "real population" of motors. Estimations of the fuel wastage for the "real population" motors from data obtained during controlled studies can result in inaccuracies. The potential inaccuracies can be demonstrated using Shuster's (1971) data on fuel wastage for a 33 hp tuned engine (Table 1), and the data presented by Hare and Springer (1973). Hare and Springer reported the percentage of the time outboard motors of differing engine size are normally operated at various rpm ranges (Table 2). Their data was taken from a compilation of data by the Outboard Marine Corporation. Combining the Outboard Marine Corporation's 10 rpm ranges (Table 2) into three major groups (500-1500, 1500-2500 and 2500-5500 rpm) gives percent operating times of 16, 19 and 65% respectively, for the 40 hp motor (the size closest to the 33 hp engine used by Shuster). These three percentages approximate the percentage of the time Shuster's 33 hp motor should have been operated at his test speeds (Table 1) to simulate the fuel wastage of an outboard motor from the "real population". The average fuel wastage computed using these percent operating times is approximately 5.5 percent, which is substantially lower than the average fuel wastage of 11.7 percent computed solely from the data presented in Table 1. Therefore, the 5.5% average fuel wastage figure would be a more realistic number than the 11.7% figure to apply to a "real population" of outboard engines. Previous studies, however, did not take into account the cyclic operation of motors (i.e. amount of time spent in each attainable speed range) under actual use. It is probable that an

Table 1. Fuel wastage of a 33 hp untuned engine at three rpm speeds (Shuster, 1971).

Engine Speed (rpm)	Duration (mi no	Fuel Used (ml)	Fuel Wasted (ml }	Percent Wasted
1000	30	1976	515	26.06
2000	30	3000	180	6.00
3000	30	4215	125	2.97

Table 2. Percent operating time in rpm range by engine size (Hare and Springer, 1973).

	Horsepower			
Rpm Ranges	>100	50-55	40	9.5
500-1000	30	7	3	8
1000-1500	15	17	13	12
1500-2000	5	10	12	10
2000-2500	3	7	7	10
2500-3000	3	4	3	6
3000-3500	8	8	13	13
3500-4000	12	13	13	12
4000-4500	18	23	19	16
4500-5000	4	5	12	11
5000-5500	2	4	5	2
5500-6000	-	2	-	-

average figure as low as 3 to 5 percent wastage will be realistic after more research is completed. Toward this end the Federal Environmental Protection Agency (EPA) is currently sponsoring research by the Southwest Research Institute, San Antonio, Texas, to determine crankcase emissions of motors operated under normal conditions. In the discussion to follow, an average fuel wastage of from 5 to 10 percent will be considered a realistic estimate for the "real population" of outboard motors so that the potential maximum effect can be calculated.

Estimates of fuel consumed annually by outboard motors in the United States during the past four years range between 0.99 and 1.10 billion gallons {Lussier, 1970; Anonymous, 1972; Hare and Springer, 1973). Hare and Springer also reported their value of 0.99 billion gallons for 1971 was an over-estimate. Assuming 5 to 10 percent fuel wastage, the total annual amount of raw fuel discharged into receiving waters is 50 to 100 million gallons. Therefore, large quantities of long and short chained hydrocarbons, lead and other compounds associated with gasoline and oil are being released into the nations waters.

A significant advancement in eliminating the discharge of raw fuel from the crankcase was made by the Goggi Corporation in 1964 (Lussier, 1970). This company's patented device redirects usually wasted fuel from the crankcase back to the fuel system, significantly reducing the discharge of unburned fuel to the water. By 1968, most major outboard motor manufacturers had developed a modification of their engines which recycled unburned fuel condensate in the crankcase back to the fuel line for combustion. Beginning with the 1968 model line some engines were equipped to recycle unburned fuel and since 1972, all engines have been manufactured with this feature. Although this modification reduces the amount of pollutants going into the water, it doesn't completely solve the problem, since it will take approximately 10 to 15 years for the more than 7 million outboard motors presently in use to be replaced by motors with recycling devices.

The second source of pollution inherent in two-cycle engines is the discharge of raw fuel through the exhaust port as a result of fuel intake and waste exhaust occuring during the same piston stroke. Manufacturers often construct a deflector on the top of the piston to prevent the incoming fuel vapors from passing directly through the cylinder and out the open exhaust port along with the exhaust gases. There is virtually no information available on the efficiencies of different deflector designs or on the amount of fuel discharged in this manner (Jackivicz and Kuzminski, 1972a).

The third source of pollution is the emissions resulting from the combustion of fuel. These gaseous emissions consist mainly of water vapor; oxides of carbon, nitrogen and sulfur; hydrocarbons derived from rearrangement of normal fuel hydrocarbons; partial oxidation products and complexed particulate lead compounds (Jackivicz and Kuzminski, 1972a). Researchers have made no attempt to differentiate between the volume of unburned fuel vapor passing across the cylinder and out the exhaust port and the volume of burned gaseous fuel exhaust.

A minimal amount of work has been done on identifying and quantifying the substances discharged to the receiving water from combusted fuel. Hare and Springer (1973) evaluated the gaseous exhaust emission of four marine outboard motors, 4 hp (model-4R71, make-OMC), 9.5 hp (9R72, OMC), 35 hp (356HA, Chrysler) and 65 hp (650, Mercury). The engines were operated at six or seven rpm speeds from idle to maximum rpm rating and the gaseous emissions were bubbled through water to determine amounts of the various gases absorbed by the water. Table 3 shows the amounts in gm/hr of CO_2, CO, partially burned hydrocarbons and NO_x (nitrogen oxides) absorbed in water at three different rpm speeds for all four motors. Formaldehyde and aliphatic aldehydes were also detected in the water (Hare and Springer, 1973).

The earliest studies in the area of outboard motor pollution were conducted in 1961 (English, 1961). Since that time, a large number of studies have been reported with differing conclusions. Investigators have agreed that outboard motor exhaust products include heavy and light hydrocarbons, lead, phenol, aldehydes and oxides. These compounds, with the exception of lead, are capable of being biologically or chemically broken down in the environment (Stewart, 1967). However, the actual fate of these compounds or their byproducts in the aquatic environment has not been determined. In the majority of cases, the information obtained from experimental tank, pool or small pond test has shown that total motor emissions will produce definite water quality deterioration. In addition, English et al. (1963 b) reported tainting of fish held in a small pond and subjected to the exhaust products from outboard engines operated experimentally at a fuel consumption rate of 0.17 gal fuel per million gallons dilution water per day. To date, studies conducted under normal operating conditions have not produced conclusive evidence to support or deny the claims that outboard motors are polluting our nation's waters.

Largely because of this controversy the Outboard Marine Corporation and the Environmental Protection Agency have sponsored extensive research (MERC Project) to determine the effect of outboard motor pollution on the aquatic environment. The overall goal of this research is to determine the amount of outboard engine usage a lake can safely sustain without causing adverse environmental effects.

Table 3. The gaseous emissions of CO_2, CO, partially burned hydrocarbons and NO_X in gm/hr absorbed in water at three engine speed for four engines (Hare and Springer, 1973).

Parameters	H. P. 4	9.5	35	65
rpm(Idle)	1050	700	1100	800
CO_2	100	261	666	799
CO	22	31	74	70
HC	64	190	378	589
NO_X	0	0	0.4	0.2
rpm	3000	3000	3000	4000
CO_2	426	1520	2730	7570
CO	52	71	115	117
HC	63	365	572	977
NO_X	0	0.4	1.6	1.5
rpm(maximum)	4500	4500	5000	5200
CO_2	857	2330	5300	14300
CO	64	80	384	260
HC	148	294	1460	2220
NO_X	1.4	0.5	2.5	14.4

METHODS

Two techniques were used to estimate the total boating use of Houghton Lake: (a) estimations of boat densities by direct boat counts, and (b) a questionnaire to determine trip time and potential exhaust contamination.

A stratified sampling technique employing three strata was used to estimate boat density. Each week was divided into two strata: week-days and weekend-days with one day selected randomly from each strata for density estimates. A third strata consisted of holiday weekends. In this strata, density estimates for each holiday weekend were made from counts of two sample days, the holiday and one other randomly selected day during the holiday weekend. Two counts were made on a sample day, one before and one after noon. The hours surveyed during each count were selected randomly with starting times restricted to two hours after sunrise and two hours before sunset. Counts were made by boat and the entire lake was counted during each census. Individual censuses covered about a 1 1/2 hour time period.

Questionnaires were mailed to resident and distributed to transient (visitors launching at the lake's public access sites) boat operators using Houghton Lake. Approximately 1300 questionnaires were mailed to Houghton Lake residents. Data were collected over the period June 1 to September 30, 1972. This time period was divided into two strata (June-July and August-September). Questionnaires were mailed to Houghton Lake and vicinity residents who were selected randomly from a list compiled from taxrolls of the four townships surrounding the lake. The questionnaire included questions concerning engine size, total hours of operation, gasoline consumption and the type of boating activity engaged in. Data was gathered on a per individual per sample period basis (Figures 2 and 3).

STATE OF MICHIGAN

WILLIAM G MILLIKEN, Governor

DEPARTMENT OF NATURAL RESOURCES

STEVENS T MASON BUILDING, LANSING, MICHIGAN 48926

RALPH A. MAC MULLAN, Director

As part of a water quality study the Michigan Water Resources Commission is conducting a survey of motor boat use on Houghton Lake. You can help by taking time to complete this questionnaire.

1. Did you operate a motor driven boat on Houghton Lake during the months of June and July 1972? ________yes _______no

(If your answer to question 1 is yes complete questions 2 through 6. If your answer is no you are finished. Please return this questionnaire by using the attached, self-addressed, stamped envelope.)

2. How many days during this time period did you operate a boat on Houghton Lake?
days

3. Whet is the average length of time you were on the lake during the days you operated a boat on Houghton Lake? _________ hours

4. Approximately how many gallons of gasoline did you use in your outboard on an average day during this time period? __________gallons

5. What is the horsepower rating of your outboard engine? ___________ horsepower

6. What is your primary reason or reasons for operating a boat on Houghton Lake?
fishing _______water skiing _______ pleasure boating

Thank you for taking the time to complete this questionnaire. Please return it by mailing in the self-addressed, stamped envelope.

Figure 2. Questionnaire sent to Houghton Lake residents during June-July period.

STATE OF MICHIGAN

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ALVIN R. BALDEN
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As part of a water quality study the Michigan Water Resources Corrmission is conducting a survey of motor boat use on Houghton Lake. You can help by taking time to complete this questionnaire.

1. Did you operate a motor driven boat on Houghton Lake during the months of August and September 1972? _________yes _______no

(If your answer to question 1 is yes complete questions 2 through 6. If your answer is no you are finished. Please return this questionnaire by using the attached self-addressed, stamped envelope.)

2. How many days during this time period did you operate a boat on Houghton Lake? days

3. What is the average length of time you were on the lake during the days you operated a boat on Houghton Lake? _________ hours

4. Approximately how many gallons of gasoline did you use in your outboard on an average day during this time period? __________gallons

5. What is the horsepower rating of your outboard engine? horsepower

6. What is your primary reason or reasons for operating a boat on Houghton Lake?
fishing _______water skiing _______ pleasure boating

Thank you for taking the time to complete this questionnaire. Please return it by mailing in the self-addressed, stamped envelope.

Figure 3. Questionnaire sent to Houghton Lake residents during August-September period.

Transients were sampled by distribution of a postcard questionnaire at the major public access sites. Questionnaires were distributed twice weekly at access sites from July 1 to September 3, 1972 by placing them on parked cars which had the capability of transporting a boat. Similar information was requested on this questionnaire but it differed from the one sent to residents in that the information was collected on a daily basis rather than on a sample period basis (Figure 4).

RESULTS AND DISCUSSION

A total of 94 boat counts (44 week-day, 38 weekend and 12 holiday) were made between May 3 and September 30, 1972. The dates, times and number of boats for each census are presented in Table 4. Boat densities ranged from 690 on May 28 to 1 on September 30.

The average monthly density for each of the strata and a composite mean of all strata are given in Table 5. Boat densities during the week-day and weekend strata followed the same monthly pattern with the average daily boat densities low during May, increasing to a peak in July, and then decreasing in September. Holidays, however, did not follow the same pattern. The peak boat density was observed during the Memorial Day weekend and declined each successive holiday weekend.

A total of 650 questionnaires were sent to Houghton Lake area residents for each period surveyed. A different set of individuals was mailed questionnaires in each strata. The data collected from the questionnaires are tabulated in Table 6. The June-July and August-September surveys had returns of 64.5 and 66.0 percent, respectively, with a combined return of 65.4 percent. Unanswered questionnaires, wrong address, moved, etc., (54, June-July; 117, August-September) were not included in computing the percent return. Of

Figure 4. Questionnaire distributed at Houghton Lake major access sites.

The Michigan Water Resources Commission is conducting a survey of boating use at Houghton Lake. You can help by completing this questionnaire.

1. How long did you operate a boat on Houghton Lake today?. . hours

2. Were you fishing. water skiing or pleasure boating?
(check the appropriate answer or answers)

3. Approximately how much gasoline did you use? --------------- gallons

4. What size is your outboard engine? ____________horsepower

Thank you for taking the time to complete this questionnaire.

Table 4. Boat densities observed during boat surveys on Houghton Lake conducted between May 3 and September 30, 1972.

May 3	10:00 a.m.	2	June 3	7:00	118	July 1	12:00	288
	2:00 p.m.	3		5:50	208		3:45	202
7	8:00	2	9	7:00	51	4	9:00	286
	1:00	4		5:45	13		4:00	278
10	9:00	3	10	7:45	28	5	9:00	210
	3:00	5		3:45	98		12:45	180
13	9:30	3	15	9:00	77	8	9:30	344
	4:00	4		2:00	63		5:00	410
15	9:30	15	17	8:00	106	14	12:00	123
	2:30	28		1:00	170		2:00	156
21	7:00	99	21	11:00	33	15	10:00	184
	6:45	58		1:45	45		5:00	256
24	8:20	33	24	11:00	188	19	8:30	228
	1:30	15		1:00	208		1:00	150
28	8:30	577	27	9:00	222	22	6:45	144
	5:30	690		4:45	183		4:45	180
29	7:00	256				26	8:00	166
	6:30	94					1:00	237
31	10:30	17				29	10:30	287
	3:30	23					1:30	262
						30	9:30	208
							5:00	134
Aug. 5	10:45	265	Sept. 2	9:00	156			
	1:45	140		12:00	116			
11	8:00	13	4	11:30	293			
	4:30	44		1:15	208			
12	10:45	400	7	10:00	47			
	12:45	262		1:15	34			
16	8:00	50	10	9:00	73			
	5:00	232		4:00	48			
19	9:00	233	14	8:00	13			
	1:00	196		1:45	40			
21	11:45	96	17	7:30	30			
	3:00	149		1:00	95			
26	8:00	81	18	9:00	29			
	2:00	88		5:00	63			
28	9:00	157	23	7:50	24			
	2:00	102		2:50	40			
			29	10:00	3			
				2:00	5			
			30	8:00	1			
				5:00	13			

Table 5. The average monthly boat density for each strata and a composite monthly mean of all strata.

	Composite Mean	Strata Mean Weekday	Weekend	Holiday Weekend
May	97	14	28	404
June	113	86	141	—
July	223	179	258	263
August	157	105	208	—
September	67	29	40	193

Table 6. A compilation of the data obtained from the resident and transient questionnaires.

RESIDENT No residents operating a boat	No. of days operated	Ave. trip time (hr)	Fuel used for ave. trip (gal)	Total fuel used	Hp
		June-July			
Total 180	1856.0	542.7	567.6	6015.6	7011.6
Mean X	10.31	3.01	3.15	33.42	33.95
		August-September			
Total 173	1608.0	532.0	484.0	4954.7	7827.9
Mean X	9.29	3.07	2.80	28.64	45.24
Combined Mean X 353	9.81*	3.04	2.98	21.08*	42.04

*Per two month period.

TRANSIENT

July-August

No. Questionnaires Returned	Time boat operation (hr)	Gas Used (gal)	Hp
Total 128	662.5	444.83	3775.8
Mean	5.17	3.47	29.50

those returning answered questionnaires, 41.6 percent of June July respondents and 45.4 percent of the August- September respondents stated that they had operated a motor driven boat on Houghton Lake during the respective periods. Statistical estimates of the total number of motorboats used on Houghton Lake by residents during the June-July and August-September periods are 3122 and 3402, respectively. These estimates were computed assuming there were 7500 residences in the Houghton Lake vicinity and that 42 and 45% of the residents, as indicated by the respective questionnaires, had operated a boat on Houghton Lake. These figures appear to be realistic when compared to an actual count of 2428 motorboats moored at the lake shoreline during the last week in July, 1973. In addition, there were 900 licensed small boats without motors moored at shore. A large portion of these boats were probably used with motors that were removed and stored when not in use. The figure obtained by direct counts at the shoreline is probably somewhat of an underestimate because it did not include motor boats owned by back lot or non-riparian landlords who stored their boats away from the lake when not in use.

A total of 412 questionnaires were distributed to transients using the major public accesses on 23 days between July 1 and September 3, 1972. A summary of this data is shown in Table 6. Thirty-three percent of the questionnaires were returned. It was assumed that during any one survey time approximately 75% of the transients using the lake received questionnaires. The number of transient boaters using the lake was calculated as follows:

$$N = [\ (412\ X\ \frac{2.7}{0.75}\ ]\ 2.8 \qquad (1)$$

where N = number of transient boaters using the lake during the survey period.

412 = total number of questionnaires distributed to transient boaters.

0.75 = estimated percentage of total transient boaters receiving a questionnaire during any survey.

2.7 = turnover factor - ratio of length of boating day (14 hrs.) to average trip time of transient boater (5.17 hrs.)

2.8 = ratio of total survey period (65 days) to survey days (23)

Using this equation about 4150 transients (boaters launching at the public accesses) operated a boat on the lake during the survey period (July-August).

The total hours of boating use on Houghton Lake were computed from the information obtained from the questionnaire as follows:

$$H = (A_1 \times B_1 \times C_1) + (A_2 \times B_2 \times C_2) + 2\,(T \times O) \qquad (2)$$

where H = total boating hours

A = total resident boats operated

B = average number of days each residents' boat was used (Table 6)

C = average resident's trip time in hours (Table 6)

T = total transient boats operated

O = average transient's trip time in hours (Table 6)

$_1$ = June-July period

$_2$ = August-September period

The transient boating hours expression (TxO) was multiplied by 2 to obtain an estimate for the four month period since the survey only covered a two month period. The total boating hours on Houghton Lake during June through September 1972 was 236,821 hours, as calculated from equation (2).

The total hours of boating use on Houghton Lake were also computed from the boat density counts as follows:

$$H_i = \sum_{i=3}^{3} \sum_{j=1}^{4} (B \times D \times O \times T) \qquad (3)$$

where Hi = total boating hours

B = average boat counts/strata/month

D = days/strata/month

0 = turnover factor $\frac{\text{14 hrs./boating day}}{\text{3.04 hrs/boat trip (Table 6)}}$

T = 3.04 hours/boat trip (Table 6)

1 = strata (weekday, weekend and holiday weekend)

j = months (June, July, August and September)

The total boating hours on Houghton Lake during June through September, 1972, was 220,850, as calculated from equation (3). The total boating hours on Houghton Lake estimated by the two equations (equations 2 and 3) utilizing different information were in close agreement. Both however, were probably underestimates because boating use during May, October and November were not taken into consideration in computing the total hours of boating use. Boat counts during May accounted for approximately 15% of the total boat counts during the five month period. October-November boats probably accounted for no more than 5% of the total boats using the lake. Increasing the figure calculated from equation (3) by 20% results in a total boating use of approximately 265,020 hours.

One portion of the boating population which was not adequately surveyed was the over 100 resorts and their guests. This is an important source of boat usage since each resort generally has from 2 to 10 low horsepower outboard motors (2-18 hp) available for their guest use. If this relatively large number of small horsepower motors had been adequatley surveyed, the average engine size of motors owned by Houghton Lake residents (42 hp, Table 6) would possibly have been lower. These small motors would probably have little effect on the other statistics compiled from the questionnaires.

The questionnaires, both resident and transient, also supplied information on the amount of time spent on the lake fishing, water skiing and pleasure boating (Table 7). Resident boaters spent 65% of their time fishing,

Table 7. Percentage of boaters time engaged in fishing, water skiing and pleasure boating.

	Motor Boat Uses {%)*		
Resident	Fishing	Water Skiing	Pleasure Boating
June-July	65	12	23
August-September	66	12	22
Transients			
July-August	75	11	14

* Resident and transient motorboat use percentages were computed from responses to question 6 of resident questionnaire {Figure 2 & 3) and question 2 of transient questionnaire (Figure 4), respectively. A check for only one activity was considered 100% of time engaged in that activity, checks for two activities resulted in a 50% split of time between the activities and checks for three activities resulted in a 33% split of time for each activity.

12% water skiing and 23% pleasure boating, while transient boaters spent 75% of their time on Houghton Lake fishing. There appeared to be no difference in the percentage of time engaged in fishing, skiing and pleasure boating between the two periods residents were surveyed.

The amount of fuel consumed by outboard motors operated on Houghton Lake during 1972 was calculated using the fuel consumption rate and the total boating hours determined from equation 3, including adjustments for May, October and November. The fuel consumption rate for resident boaters on Houghton Lake was 0.98 gal/hr (average fuel consumed per trip/average trip time, Table 6). The fuel consumption rate for transient boaters was 0.67 gal/hr (Table 6). An average fuel consumption rate weighted with respect to resident and transient total boating hours was 0.93 gal/hr. This fuel consumption rate applied to 265,020 hours boating use gave 246,469 gallons of fuel consumed between May 1 and November 30, 1972. Based on the 5 to 10 percent fuel wastage through crankcase losses proposed earlier, an estimate of raw fuel released into Houghton Lake would be 12,323 to 24,647 gallons. This amount of fuel (24.647 gal) dispersed at one time over the surface of Houghton Lake would result in a film of 4.5 X 10″ˆ inches thick. This film would be visible and have the appearance of bright to dull color bands. A film of this thickness could adversely affect the amount of oxygen available for aquatic 1 ife (Stewart, 1967). However, the fuel discharged is spread out over the whole boating season and is continuously subject to biological degradation, so that oil films would not be visible on extensive areas of the lake's surface.

Although oxygen solution is probably not effected by the raw fuel exhausted into the lake, outboard motor exhaust does contain constituents which may adversely affect lake water quality or production. Gasoline and lubricant oils contain both short (Cg to C]q) and long (C_{26} to C2g) chained hydrocarbons along with numerous additives. The most corrmon additive in gasoline is tetraethyl lead which averages 2 gms per gallon. Ethylene dibromide and ethylene dichloride are two common antiknock additives of gasoline. Oils also contain elements such as zinc, sulfur, phosphorus and other unspecified additives.

Along with the crankcase drainage of raw fuel, there are also the following fuel combustion products exhausted: water vapor; oxides of carbon, nitrogen and sulfur; complexed particulate lead; hydrocarbons derived from rearrangement and partial oxidation products. English, et al_. (1963a), using a 5.4 and a 10 hp engine and a 1:17 oil-gasoline mixture, found that outboard motor exhaust water (OME water) contained an average of 106 grams non-volatile oil (long-chain hydrocarbons), 57 grams volatile oil (short-chain hydrocarbons), 0.53 grams lead and 0.61 grams phenols per gallon of fuel consumed. Kemf et al_. (1967), as reported by Jackivicz and Kuzminski (1972a) found a range of 9.5 to 13.3 grams non-volatile oil, 7.6 to 11.3 grams volatile oil, (oil:gas mixture of 1:50; 6, 18 and 40 hp engines) per gallon of fuel consumed in OME water. Hare and Springer (1973) found that operation of outboard motors added an average of 299 grams of partially burned hydrocarbons, 1570 grams CO_2, 76.9 grams CO, 0.54 grams NO_X and 0.16 grams SO_X to the water per gallon of fuel consumed. Hare and Springer's values apply to a population of motors with an average horsepower of 24.6 and a lake system which has the same adsorptive properties as the laboratory water which the tests were run in.

Of the compounds discharged by outboard motors, lead is one of the most serious because it is highly toxic in all its forms to humans, mammals, fish and other aquatic organisms. Although both English et al.(1963a) and Kemf et ah (1967) found considerable quantities of lead in laboratory OME water, English et ah (1963b) and Environmental Engineering (1970) indicated lead contributions to natural waters from outboard motors was insignificant. Dissolved lead was not detectable (<0.01 ppm) in Houghton Lake water collected from four locations on six sample dates during 1972.

Sediment samples, fish and invertebrates were collected from Houghton Lake and analyzed for heavy metals, including lead (Pecor et al. ,1973). Only seven of twenty sediment samples analyzed had detectable lead concentrations (£2.0 ppm) ranging from 2 to 6 ppm wet weight and 8.1 to 93.0 ppm dry weight. Generally, sediment samples with high organic fractions had detectable concentrations of lead. All lead values from Houghton Lake were within the range found at background stream water quality stations throughout Michigan. These background levels averaged 34 ppm lead dry weight, and ranged from 1.0 to 96.0 ppm (MWRC, 1972).

In addition, sediment samples were collected near two marinas where it was suspected lead concentrations would be high because of boat densities in the area and fuel spillage from refueling operations. Sediments from these two areas differed in type, one sandy and the other with a moderate organic content. Lead concentrations of 5.9 and 65.0 ppm dry weight, respectively, were found. These results did not support the theory of high lead concentrations near marinas because higher concentrations were found in the organic sediments of offshore areas in the lake.

Lead was detectable* in a majority of macroinvertebrates and fish analysed. Mayflies (Ephemera simulans), midges (Pseudochironomus sp.) crayfish (Orconectes sp.), clams (Elliptio dilatatus) and leeches (Nephalopsis obscura) had average lead concentrations of 1.87 (7 samples), 1.80 (1 sample), 0.55 (4 samples), 0.14 (7 samples) and <1.0 (1 sample)ppm wet weight, respectively. Lead was below the detectable limit of 1.0 ppm in madtoms (3 samples) and darters (4 samples). Average lead content ranged from 0.50 to 1.33 ppm wet weight in six species of panfish and gamefish collected from Houghton Lake. Lead concentrations in northern pike, smallmouth bass and rockbass ranged from 0.1 to 0.5 ppm wet weight at a number of background water quality stations throughout Michigan

(MWRC 1972). Lead levels appear to be higher in Houghton Lake fishes, but insufficient data prevented statistical analysis.

Lead is contributed from a variety of sources (atmospheric fallout, surface drainage, snowmobiles, etc.) besides outboards. Because of their diffuse origins no attempt was made to measure the input from these sources. There was a potential for 1087 pounds of lead to be added to the lake from outboard motors alone during the 1972 boating season. This figure was based on 246,469 gallons of gas consumed and 2 grams of lead per gallon.

The effects outboard motors are having on Houghton Lake can only be speculative. Although there is ample information in the literature on the qualitative and quantitative make-up of outboard motor exhaust, the literature on the effects of outboard motor operation and exhaust on the aquatic environment is sparse. English et al. (1963b) reported fish tainting occurred in a small lake at a combined fuel consumption rate of >8 gallons of fuel (gasoline: oil, 17:1) per million gallons dilution water per season and a daily rate of 0.17 gallon fuel per million gallons dilution water. The current fuel consumption rate at Houghton Lake is 4.4 gallons fuel per million gallons dilution water per season based on 246,469 gallons of fuel consumed, a volume of 55,517 x 10^6 gallons for Houghton Lake (dilution water) and a boating season 150 days long. The total fuel consumed would have to double before reaching English's (1963b) fish tainting level.

Outboard motor exhaust (OME) waters are toxic to fish and aquatic life but only at concentrations far beyond what would result from the normal use of marine engines (Environmental Engineering Inc., 1970). English et al. (1961) reported a 96 hr TLm (Median tolerance limit) of 1:1900 (gallons of fuel consumed in gallons of dilution water), for fish, and a safe level of 1:19000, which is ten times the 96 hr TLm.

Lagler etˆ al. (1950), as reported by Jackivicz and Kuzminski (1972b), found that the operation of outboard engines did not affect the production of bluegills and largemouth bass in a small pond. Hardness, pH, alkalinity and dissolved oxygen also were not affected by motor use.

It appears, based on the literature, that the current level of outboard motor use on Houghton Lake is not adversely affecting water quality. However, it should be noted that the atypical nature of Houghton Lake makes it very difficult to apply data presented in the literature. Houghton Lake is Michigan's largest inland lake with a surface area of 20,044 acreas and an average depth of approximately 8.5 feet. The large size of the lake results in a motor population with a high average horsepower, and in certain portions of the lake being used far more extensively than others. These factors make it difficult to say that the Houghton Lake water quality is not affected by the operation of .outboard motors when some high use areas may be affected.

In 1970, the outboard motor industry (OMC-Johnson and Evinrude Motors, Keikhaefer-Mercury, Marine Division of the Chrysler Corporation and Boating Industry Association) and the U.S. Environmental Protection Agency organized and sponsored the Marine Exhaust Research Council (MERC Project) to undertake extensive research encompassing all aspects of outboard motor pollution and its effects on the aquatic environment. The overall goal of this project is to obtain sufficient field and laboratory data to be able to predict the number of outboard engines which can be operated on a particular body of water without causing adverse effects to the aquatic environment.

The completion of the MERC Project and the establishment of outboard motor carrying capacities for lakes by the EPA will afford a better means of assessing the environmental significance of the present level of use of Houghton Lake by outboards.

Winter Use of Houghton Lake by Snowmobiles and Cars

The increased use of inland lakes by snowmobiles is putting an additional stress on Michigan lakes. In the past, lakes received exhaust pollution only during the summer months, however, with the advent of snowmobiles, the length of time exhaust producing vehicles can use the lake is considerably extended.

The snowmobile engine is also a two-cycle engine and has the same inherent inefficiencies as the two-cycle outboard engine. The major difference between the two is that the outboard motor discharges its exhaust below the waters surface and the snowmobile discharges its exhaust into the atmosphere. However, many exhaust products, including lead, settle out on the surface of the snow to accumulate during the winter. The cold temperatures inhibit biological degradation so that the exhaust products remain basically unchanged during the winter period.

The four-cycle automotive engine also contributes quantities of hydrocarbons, partially oxidized hydrocarbons (phenols, aldehydes, etc.) and lead. Automotive exhausts vary from 0.22 to 3.2 mg of lead per gram of gasoline consumed (Jackivicz and Kuzminski, 1972a). Portions of the gaseous exhausts condense in the cold air and settle on the ice to be buried by accumulations of snow.

Analyses of surface ice collected from two high use areas along the south shore of Houghton Lake on March 9, 1973 showed lead at concentrations of 0.08 and 0.03 ppm and oil at concentrations of 2.0 ppm. The accumulated exhaust products are literally dumped into the lake at one time during spring ice-out when water temperatures are still cold enouqh to inhibit bioloaical decomposition.

Snowmobile density estimates were made on Houghton Lake during the winter of 1973 to estimate the level of use. Originally the design called for snowmobile counts throughout the winter and a direct estimate of exhaust by-products left on the ice at the end of the winter. The snowmobiles mobility and unrestricted access to the lake, however, hampered direct estimates. However, density estimates were made throughout the winter using a stratified sampling technique. Weekdays and weekend days were the two strata selected with dates and times of sampling randomly selected.

A total of 42 snowmobile and car counts (27 weekday and 15 weekend day) were made between December 27, 1972 and March 12, 1973 at Houghton Lake. Data collected are summarized in Tables 8 and 9. Maximum snowmobile and car densities were observed during the Tip-up Town U.S.A. festival, January 21, 1973, when 1,683 snowmobiles and 850 cars were counted during one census (Table 8). The average monthly counts of snowmobiles and cars for each strata showed that Houghton Lake receives substantial usage during the winter months (Table 9). The combined snowmobile and car average monthly counts were very similar to the average monthly boat counts during the summer. However, the lack of information concerning trip-time, days of use and gasoline consumption for the snowmobiles and cars prevented the estimation of total hours of use.

A direct estimate of hydrocarbon and lead contamination from existing snowmobile and car use was attempted. The plan called for sampling the ice in late winter after a thaw and subsequent refreeze had concentrated the exhaust residues in the upper portions of the ice mass. Unfavorable weather and ice conditions prevented this sampling program from being conducted. However, preliminary work showed that hydrocarbons and lead residues were present in surface ice at measurable concentrations.

Table 8. Snowmobile and car densities observed during the winter use survey conducted between December 27, 1972 and March 12, 1973 at Houghton Lake.

Date	Time	Counts Snowmobile	Cai
Dec. 27	9:30 a.m.	67	0
Jan. 1	10:00 a.m.	36	0
Jan. 3	12:00 a.m.	59	0
	1:00 a.m.	57	0
Jan. 5	10:30	22	3
	2:00	47	7
7	8:00	63	11
	2:00	162	33
10	10:45	13	26
	3:00	26	23
11	8:00	7	11
	3:15	48	36
13	11:00	220	142
	4:00	309	181
15	8:00	49	47
	1:00	113	89
18	9:00	22	23
	1:00	61	45
21*	11:00	1683	831
	1:00	1440	850
22	9:00	55	48
	1:00	22	6
28	9:00	94	41
	2:00	71	42
Feb. 1	8:00	11	23
	2:00	61	75
4	10:00	97	82
	1:00	196	145
6	9:00 a.m.	46	47
8	1:30 p.m.	52	39
10	11:30 a.m.	176	104
13	3:30 p.m.	97	121
14	4:00 p.m.	38	70
20	10:00 a.m.	40	38
	1:00 p.m.	65	61
24	9:00	133	113
	1:00	201	141
26	11:00	47	22
	1:00	55	25
Mar. 4	2:00 p.m.	47	39
8	8:00 a.m.	8	0
12	2:00 p.m.	7	0

*Tip-up Town U.S.A. festival

Table 9. Average monthly counts of snowmobiles and car on Houghton Lake for each strata during the winter 1972-73.

	Weekday		Weekend	
Month	Snowmobiles	Cars	Snowmobiles	Cars
Dec.	67	0	0	0
Jan.	71	30	136*	75*
Feb.	51	52	161	117
Mar.	7	0	47	39

*Tip-up Town dates excluded

Although no estimate of snomobile exhaust contamination was determined as a result of this survey, the snowmobile counts obtained show that substantial numbers use the lake. There is therefore, a potential for additional exhaust contamination that must be taken into consideration when setting carrying capacities for lakes.

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