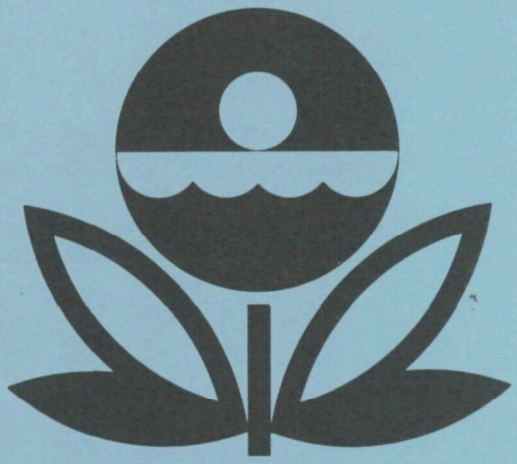
U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL EUTROPHICATION SURVEY

WORKING PAPER SERIES



REPORT

ON

HOUGHTON LAKE

ROSCOMMON COUNTY

MICHIGAN

EPA REGION V

WORKING PAPER No. 196

PACIFIC NORTHWEST ENVIRONMENTAL RESEARCH LABORATORY

An Associate Laboratory of the

NATIONAL ENVIRONMENTAL RESEARCH CENTER - CORVALLIS, OREGON

and

NATIONAL ENVIRONMENTAL RESEARCH CENTER - LAS VEGAS, NEVADA

☆GPO—697-032

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314

EPA REGION V

WORKING PAPER No. 196

WITH THE COOPERATION OF THE

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

AND THE

MICHIGAN NATIONAL GUARD

FEBRUARY, 1975

CONTENTS

	Page
Foreword	ii
List of Michigan Study Lakes	iv
Lake and Drainage Area Map	v
Sections	
I. Conclusions	1
II. Lake and Drainage Basin Characteristics	3
III. Lake Water Quality Summary	4
IV. Nutrient Loadings	7
V. Literature Reviewed	13
VI. Appendices	14

F O R E W O R D

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to fresh water lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's fresh water lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U. S. Environmental Protection Agency) expresses sincere appreciation to the Michigan Department of Natural Resources for professional involvement and to the Michigan National Guard for conducting the tributary sampling phase of the Survey.

A. Gene Gazlay, former Director, and David H. Jenkins, Acting Director, Michigan Department of Natural Resources; and Carlos Fetterolf, Chief Environmental Scientist, and Dennis Tierney, Aquatic Biologist, Bureau of Water Management, Department of Natural Resources, provided invaluable lake documentation and counsel during the course of the Survey. John Vogt, Chief of the Bureau of Environmental Health, Michigan Department of Public Health, and his staff were most helpful in identfying point sources and soliciting municipal participation in the Survey.

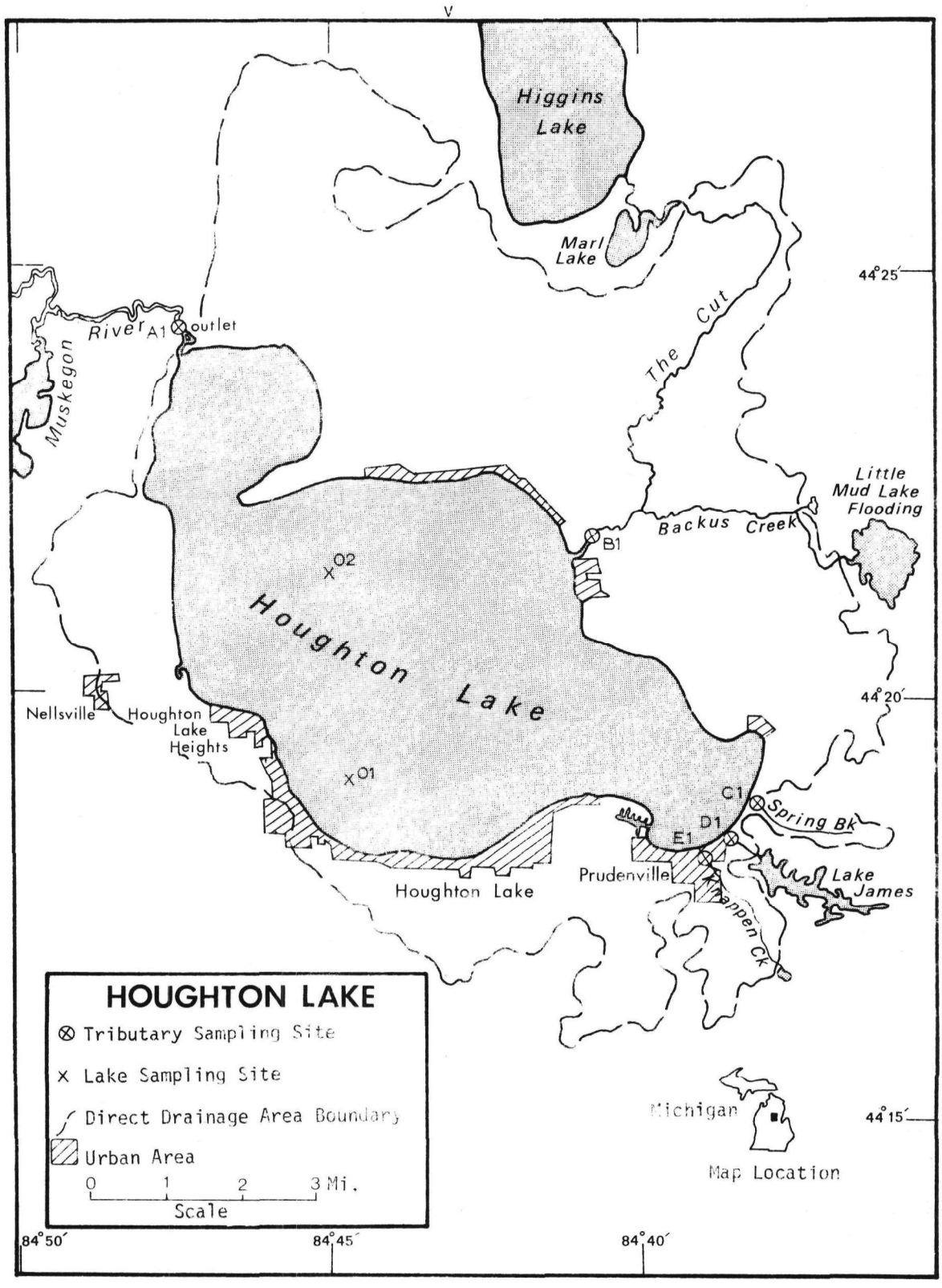
Major General Clarence A. Schnipke (Retired), then the Adjutant General of Michigan, and Project Officer Colonel Albert W. Lesky, who directed the volunteer efforts of the Michigan National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF MICHIGAN

LAKE NAME	COUNTY
Allegan Res.	Allegan
Barton	Kalamazoo
Belleville	Wayne
Betsie	Benzie
Brighton	Livingston
Caro Res.	Tuscola
Charlevoix	Charlevoix
Chemung	Livingston
Constantine Res.	St. Joseph
Crystal	Montcalm
Deer	Marquette
Ford	Washtenaw
Fremont	Newago
Higgins	Roscommon
Holloway Res.	Genesee, Lapeer
Houghton	Roscommon
Jordon	Ionia, Barry
Kent	Oakland
Long	St. Joseph
Macatawa	Ottawa
Manistee	Manistee
Mona	Muskegon
Muskegon	Muskegon
Pentwater	Oceana
Pere Marquette	Mason
Portage	Houghton
Randall	Branch
Rogers Pond	Mecosta
Ross	Gladwin
St. Louis Res.	Gratiot
Sanford	Midland
Strawberry	Livingston
Thompson	Livingston
Thornapple	Barry
Union	Branch
White	Muskegon


Higgins Lake
Marl Lake
44°25′
The Cut
Muskegon River
A1
outlet
Little Mud Lake Flooding
Backus Creek
B1
X02
Houghton Lake
44°20′
Nellsville
Houghton Lake Heights
X01
C1
Spring Bk
D1
E1
Prudenville
Houghton Lake
Lake James
Kneppen Ck
HOUGHTON LAKE
⊗ Tributary Sampling Site
× Lake Sampling Site
Direct Drainage Area Boundary
Urban Area
0 1 2 3 Mi.
Scale
Michigan
44°15′
Map Location
84°50′
84°45′
84°40′

HOUGHTON LAKE

STORET NO. 2696

I. CONCLUSIONS

A. Trophic Condition:

Considering only the Survey lake data, it could be concluded that Houghton Lake is mesotrophic; e.g., of the 35 Michigan lakes sampled in November when essentially all were well-mixed, four had less mean dissolved phosphorus, five had less mean total phosphorus, and only two had less mean inorganic nitrogen*. However, on the basis of a recently completed 2-year study, personnel of the Michigan Department of Natural Resources consider the lake to be eutrophic; although they report that the eutrophic condition is not typical in that Houghton Lake exhibits few, if any, of the adverse conditions usually associated with eutrophic water bodies (Tierney, 1974).

B. Rate-Limiting Nutrient:

There was a significant loss of inorganic nitrogen in the algal assay sample, and the results are not indicative of conditions in the lake at the time the sample was collected.

The lake data indicate phosphorus limitation in September and November but possible nitrogen limitation in June.

C. Nutrient Controllability:

1. Point sources--During the sampling year, Houghton Lake received a total phosphorus load at a rate less than one-half

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* See Appendix A.

that proposed by Vollenweider (in press) as "permissible"; i.e., at a rate less than an oligotrophic rate (see page 11).

Despite this low phosphorus loading rate, the lake is eutrophic, and contributions of phosphorus from both point and non-point sources should be minimized to prevent development of nuisance conditions in the lake.

There are no known municipal or industrial point sources impacting Houghton Lake; and, although septic tanks were estimated to have contributed about 32% of the total phosphorus load, a shoreline survey would be needed to determine the actual contribution from these sources.

2. Non-point sources (see page 11)--It is calculated that the non-point sources contributed about 67% of the total phosphorus load to Houghton Lake; however, the exports of the Houghton Lake tributaries were quite low as compared to other Michigan streams sampled.

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

A. Lake Morphometry†:

1. Surface Area: 20,044 acres.
2. Mean depth: 7.6 feet.
3. Maximum depth: 21 feet.
4. Volume: 152,334 acre/feet.
5. Mean hydraulic retention time: 1.3 years.

B. Tributary and Outlet:
(See Appendix B for flow data)

1. Tributaries -

Name	Drainage area*	Mean flow*
Backus Creek	90.0 mi^2	71.5 cfs
Spring Brook	1.3 mi^2	0.4 cfs
Denton Creek	47.7 mi^2	12.9 cfs
Knappen Creek	4.6 mi^2	3.4 cfs
Minor tributaries & immediate drainage -	47.1 mi^2	68.5 cfs
Totals	190.7 mi^2	156.7 cfs

2. Outlet -

Muskegon River	222.0 mi^2**	156.7 cfs

C. Precipitation***:

1. Year of sampling: 28.3 inches.
2. Mean annual: 28.4 inches.

† MI Dept. Cons. lake inventory map (1962).
* Drainage areas are accurate within ±5%; mean daily flows for 74% of the sampling sites are accurate within ±25% and the remaining sites up to ±40%; and mean monthly flows, normalized mean monthly flows, and mean annual flows are slightly more accurate than mean daily flows.
** Includes area of lake.
*** See Working Paper No. 1, "Survey Methods, 1972".

III. LAKE WATER QUALITY SUMMARY

Houghton Lake was sampled three times during the open-water season of 1972 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from two stations on the lake and from two or more depths at each station (see map, page v). During each visit, a single depth-integrated (near bottom to surface) sample was composited from the stations for phytoplankton identification and enumeration; and during the second visit, a single five-gallon depth-integrated sample was composited for algal assays. Also each time, a depth-integrated sample was collected from each of the stations for chlorophyll a analyses. The maximum depths sampled were 16 feet at station 1 and 12 feet at station 2.

The results obtained are presented in full in Appendix C, and the data for the fall sampling period, when the lake essentially was well-mixed, are summarized below. Note, however, the Secchi disc summary is based on all values.

For differences in the various parameters at the other sampling times, refer to Appendix C.

A. Physical and chemical characteristics:

Parameter	Minimum	Mean	Median	Maximum
		FALL VALUES (11/14/72)		
Temperature (Cent.)	2.6	3.1	3.4	3.4
Dissolved oxygen (mg/l)	11.6	12.0	12.2	12.3
Conductivity (µmhos)	200	207	205	220
pH (units)	8.2	8.2	8.2	8.2
Alkalinity (mg/l)	79	82	83	84
Total P (mg/l)	0.015	0.018	0.018	0.020
Dissolved P (mg/l)	0.006	0.008	0.007	0.010
NO_2 + NO_3 (mg/l)	0.040	0.052	0.040	0.080
Ammonia (mg/l)	0.060	0.084	0.080	0.110
		ALL VALUES		
Secchi disc (inches)	48	79	79	114

B. Biological characteristics:

1. Phytoplankton* -

Sampling Date	Dominant Genera	Number per ml
09/20/72	1. Polycystis	1,401
	2. Lyngbya	708
	3. Achnanthes	557
	4. Synedra	407
	5. Flagellates	392
	Other genera	1,595
	Total	5,060
11/14/72	1. Fragilaria	1,811
	2. Flagellates	1,434
	3. Polycystis	1,245
	4. Dinobryon	905
	5. Achnanthes	868
	Other genera	2,718
	Total	8,981

* The June sample was lost in shipment.

2. Chlorophyll a -
(Because of instrumentation problems during the 1972 sampling, the following values may be in error by plus or minus 20 percent.)

Sampling Date	Station Number	Chlorophyll a (µg/l)
06/15/72	01	5.9
	02	9.8
09/20/72	01	7.2
	02	12.7
11/14/72	01	11.6
	02	8.1

C. Limiting Nutrient Study:

A 58% loss of inorganic nitrogen occurred in the assay sample between the time of collection and the beginning of the assay, and the assay results are not indicative of conditions in the lake at the time of sampling.

The lake data indicate phosphorus limitation in September (N/P ratio = 28/1) and November (N/P = 17/1) but a possible nitrogen limitation in June (N/P = 13/1). Phosphorus limitation would be expected with N/P ratios of 14/1 or greater.

IV. NUTRIENT LOADINGS
(See Appendix D for data)

For the determination of nutrient loadings, the Michigan National Guard collected monthly near-surface grab samples from each of the tributary sites indicated on the map (page v), except for the high runoff months of April and May, when two samples were collected, and in December when low flows prevented sampling at three sites. Sampling was begun in October, 1972, and was completed in September, 1973.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the Michigan District Office of the U.S. Geological Survey for the tributary sites nearest the lake.

In this report, nutrient loads for sampled tributaries were determined by using a modification of a U.S. Geological Survey computer program for calculating stream loadings*. Nutrient loadings for unsampled "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S.) were estimated by using the means of the nutrient loads, in lbs/mi^2/year, at stations B-1, C-1, D-1, and E-1 and multiplying the means by the ZZ area in mi^2.

There are no known municipal wastewater treatment plants impacting Houghton Lake. However, the communities of Houghton Lake, The Heights, and Prudenville are located on the lake shore and are served by septic tanks. Nutrient loads from these sources were estimated at 0.25 lbs P and 9.4 lbs N/capita/year*.

* See Working Paper No. 1.

A. Waste Sources:

1. Communities -

Name	Pop. Served	Treatment	Mean Flow (mgd)	Receiving Water
Houghton Lake	6,067*	septic tanks	?	Houghton Lake
The Heights	1,252*	septic tanks	?	Houghton Lake
Prudenville	1,800**	septic tanks	?	Houghton Lake

2. Known industrial - None

* 1970 Census.
** Estimated 450 homes at 4 persons each.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	lbs P/ yr	% of total
a. Tributaries (non-point load) -		
Backus Creek	2,520	23.7
Spring Brook	20	0.2
Denton Creek	440	4.1
Knappen Creek	140	1.3
b. Minor tributaries & immediate drainage (non-point load) -	970	9.1
c. Communities -		
Houghton Lake	1,520	14.3
The Heights	310	2.9
Prudenville	450	4.2
d. Septic tanks* -	1,120	10.6
e. Known industrial - None	-	-
f. Direct precipitation** -	3,130	29.6
Total	10,620	100.0

2. Outputs -

Lake outlet - Muskegon River 5,140

3. Net annual P accumulation - 5,480 pounds

* Estimated 1,800 seasonal lakeshore dwellings outside of communities; see Working Paper No. 1.
** See Working Paper No. 1.

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	lbs N/ yr	% of total
a. Tributaries (non-point load) -		
Backus Creek	159,720	28.4
Spring Brook	780	0.1
Denton Creek	22,280	4.0
Knappen Creek	7,140	1.3
b. Minor tributaries & immediate drainage (non-point load) -	51,740	9.2
c. Communities -		
Houghton Lake	57,030	10.1
The Heights	11,770	2.1
Prudenville	16,920	3.0
d. Septic tanks* -	42,300	7.5
e. Known industrial - None	-	-
f. Direct precipitation** -	193,100	34.3
Total	562,780	100.0

2. Outputs -

Lake outlet - Muskegon River 214,840

3. Net annual N accumulation - 347,940 pounds

* Estimated 1,800 seasonal lakeshore dwellings outside of communities; see Working Paper No. 1.
** See Working Paper No. 1.

D. Mean Annual Non-point Nutrient Export by Subdrainage Area:

Tributary	lbs P/mi^2/yr	lbs N/mi^2/yr
Backus Creek	28	1,775
Spring Brook	15	600
Denton Creek	9	467
Knappen Creek	30	1,552

E. Yearly Loading Rates:

In the following table, the existing phosphorus loading rates are compared to those proposed by Vollenweider (in press). Essentially, his "dangerous" rate is the rate at which the receiving waters would become eutrophic or remain eutrophic; his "permissible" rate is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic rate would be considered one between "dangerous" and "permissible".

	Total Phosphorus		Total Nitrogen	
Units	Total	Accumulated	Total	Accumulated
lbs/acre/yr	0.5	0.3	28.1	17.4
grams/m^2/yr	0.06	0.03	3.1	1.9

Vollenweider loading rates for phosphorus (g/m^2/yr) based on mean depth and mean hydraulic retention time of Houghton Lake:

"Dangerous" (eutrophic rate)	0.26
"Permissible" (oligotrophic rate)	0.13

V. LITERATURE REVIEWED

Fetterolf, Carlos, 1972. Personal communication (mean depth of Houghton Lake). MI Dept. Nat. Resources, Lansing.

Tierney, Dennis, 1974. Personal communication (review of preliminary report on Houghton Lake). MI Dept. of Nat. Resources, Lansing.

Vollenweider, Richard A. (in press). Input-output models. Schweiz. Z. Hydrol.

VI. APPENDICES

APPENDIX A

LAKE RANKINGS

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	FALL VALUES: MEAN TOTAL P	FALL VALUES: MEAN DISS P	FALL VALUES: MEAN INORG N	ALL VALUES: 500- MEAN SEC	ALL VALUES: MEAN CHLORA	ALL VALUES: 15- MIN DO
26A0	HOLLOWAY RESERVOIR	0.062	0.043	1.461	439.375	10.678	9.200
26A1	CARO RESERVOIR	0.117	0.022	3.835	473.000	11.967	9.500
26A2	BOARDMAN HYDRO POND	0.006	0.005	0.358	363.500	1.267	6.600
2603	ALLEGAN LAKE	0.123	0.057	1.168	470.222	20.311	12.600
2606	BARTON LAKE	0.121	0.086	1.489	456.167	27.800	14.850
2609	BELLEVILLE LAKE	0.118	0.048	1.420	465.250	28.262	8.200
2610	BETSIE LAKE	0.025	0.008	0.273	461.667	4.567	7.400
2613	BRIGHTON LAKE	0.109	0.073	1.015	456.000	44.233	7.500
2617	LAKE CHARLEVOIX	0.007	0.006	0.230	351.250	3.038	9.240
2618	LAKE CHEMUNG	0.044	0.014	0.132	404.333	13.483	14.800
2621	CONSTANTINE RESERVOIR	0.027	0.008	0.910	456.167	39.317	7.500
2629	FORD LAKE	0.105	0.058	1.536	456.167	14.733	14.000
2631	FREMONT LAKE	0.372	0.342	1.406	441.667	28.500	14.800
2640	JORDAN LAKE	0.180	0.144	1.998	427.667	20.517	14.900
2643	KENT LAKE	0.040	0.015	0.417	455.000	33.944	13.000
2648	LAKE MACATAWA	0.197	0.120	2.358	477.600	25.600	12.200
2649	MANISTEE LAKE	0.018	0.010	0.304	451.333	6.317	11.380
2659	MUSKEGON LAKE	0.087	0.043	0.469	436.444	9.511	14.800
2665	PENTWATER LAKE	0.027	0.017	0.496	430.667	16.083	14.800
2671	RANDALL LAKE	0.246	0.183	0.818	457.333	27.217	8.020
2672	ROGERS POND	0.026	0.015	0.183	435.500	8.133	9.600
2673	ROSS RESERVOIR	0.034	0.021	0.460	465.333	10.383	8.200
2674	SANFORD LAKE	0.016	0.008	0.307	458.750	13.791	8.300
2683	THORNAPPLE LAKE	0.042	0.032	1.737	442.833	14.650	10.800
2685	UNION LAKE	0.083	0.064	1.252	455.500	15.667	8.200
2688	WHITE LAKE	0.027	0.019	0.367	417.778	9.211	13.400
2691	MONA LAKE	0.307	0.241	0.963	451.667	27.783	14.100
2692	LONG LAKE	0.163	0.148	0.749	418.400	10.067	13.600

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	FALL VALUES: MEAN TOTAL P	FALL VALUES: MEAN DISS P	FALL VALUES: MEAN INORG N	ALL VALUES: 500- MEAN SEC	ALL VALUES: MEAN CHLORA	ALL VALUES: 15- MIN DO
2693	ST LOUIS RESERVOIR	0.134	0.093	1.227	462.667	5.583	8.420
2694	CRYSTAL LAKE	0.009	0.006	0.164	380.000	2.986	13.000
2695	HIGGINS LAKE	0.007	0.005	0.058	268.500	1.043	9.400
2696	HOUGHTON LAKE	0.018	0.008	0.136	420.833	9.217	8.200
2697	THOMPSON LAKE	0.043	0.029	0.436	407.889	11.967	14.800
2698	PERE MARQUETTE LAKE	0.032	0.024	0.346	448.667	11.833	8.600
2699	STRAWBERRY LAKE	0.069	0.050	0.567	419.800	11.117	13.600

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	FALL VALUES: MEAN TOTAL P	FALL VALUES: MEAN DISS P	FALL VALUES: MEAN INORG N	ALL VALUES: 500- MEAN SEC	ALL VALUES: MEAN CHLORA	ALL VALUES: 15- MIN DO	INDEX NO
26A0	HOLLOWAY RESERVOIR	46 (16)	43 (15)	17 (6)	57 (20)	60 (21)	63 (22)	286
26A1	CARO RESERVOIR	29 (10)	54 (19)	0 (0)	3 (1)	49 (17)	54 (19)	189
26A2	BOARDMAN HYDRO POND	97 (34)	97 (34)	69 (24)	91 (32)	94 (33)	97 (34)	545
2603	ALLEGAN LAKE	20 (7)	31 (11)	31 (11)	6 (2)	29 (10)	40 (14)	157
2606	BARTON LAKE	23 (8)	20 (7)	14 (5)	29 (9)	14 (5)	3 (1)	103
2609	BELLEVILLE LAKE	26 (9)	37 (13)	20 (7)	11 (4)	11 (4)	79 (26)	184
2610	BETSIE LAKE	77 (27)	77 (27)	80 (28)	17 (6)	86 (30)	94 (33)	431
2613	BRIGHTON LAKE	31 (11)	23 (8)	34 (12)	34 (12)	0 (0)	90 (31)	212
2617	LAKE CHARLEVOIX	91 (32)	91 (32)	83 (29)	94 (33)	89 (31)	60 (21)	508
2618	LAKE CHEMUNG	49 (17)	71 (25)	94 (33)	86 (30)	46 (16)	11 (2)	357
2621	CONSTANTINE RESERVOIR	71 (25)	83 (29)	40 (14)	29 (9)	3 (1)	90 (31)	316
2629	FORD LAKE	34 (12)	29 (10)	11 (4)	29 (9)	37 (13)	23 (8)	163
2631	FREMONT LAKE	0 (0)	0 (0)	23 (8)	54 (19)	9 (3)	11 (2)	97
2640	JORDAN LAKE	11 (4)	11 (4)	6 (2)	69 (24)	26 (9)	0 (0)	123
2643	KENT LAKE	57 (20)	69 (24)	63 (22)	40 (14)	6 (2)	36 (12)	271
2648	LAKE MACATAWA	9 (3)	14 (5)	3 (1)	0 (0)	23 (8)	43 (15)	92
2649	MANISTEE LAKE	80 (28)	74 (26)	77 (27)	46 (16)	80 (28)	46 (16)	403
2659	MUSKEGON LAKE	37 (13)	40 (14)	54 (19)	60 (21)	69 (24)	11 (2)	271
2665	PENTWATER LAKE	69 (24)	63 (22)	51 (18)	66 (23)	31 (11)	11 (2)	291
2671	RANDALL LAKE	6 (2)	6 (2)	43 (15)	23 (8)	20 (7)	86 (30)	184
2672	ROGERS POND	74 (26)	66 (23)	86 (30)	63 (22)	77 (27)	51 (18)	417
2673	ROSS RESERVOIR	60 (21)	57 (20)	57 (20)	9 (3)	63 (22)	79 (26)	325
2674	SANFORD LAKE	86 (30)	80 (28)	74 (26)	20 (7)	43 (15)	71 (25)	374
2683	THORNAPPLE LAKE	54 (19)	46 (16)	9 (3)	51 (18)	40 (14)	49 (17)	249
2685	UNION LAKE	40 (14)	26 (9)	26 (9)	37 (13)	34 (12)	79 (26)	242
2688	WHITE LAKE	66 (23)	60 (21)	66 (23)	80 (28)	74 (26)	31 (11)	377
2691	MONA LAKE	3 (1)	3 (1)	37 (13)	43 (15)	17 (6)	20 (7)	123
2692	LONG LAKE	14 (5)	9 (3)	46 (16)	77 (27)	66 (23)	27 (9)	239

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	FALL VALUES: MEAN TOTAL P	FALL VALUES: MEAN DISS P	FALL VALUES: MEAN INORG N	ALL VALUES: 500-MEAN SEC	ALL VALUES: MEAN CHLORA	ALL VALUES: 15-MIN DO	INDEX NO
2693	ST LOUIS RESERVOIR	17 (6)	17 (6)	29 (10)	14 (5)	83 (29)	69 (24)	229
2694	CRYSTAL LAKE	89 (31)	89 (31)	89 (31)	89 (31)	91 (32)	36 (12)	483
2695	HIGGINS LAKE	94 (33)	94 (33)	97 (34)	97 (34)	97 (34)	57 (20)	536
2696	HOUGHTON LAKE	83 (29)	86 (30)	91 (32)	71 (25)	71 (25)	79 (26)	481
2697	THOMPSON LAKE	51 (18)	49 (17)	60 (21)	83 (29)	51 (18)	11 (2)	305
2698	PERE MARQUETTE LAKE	63 (22)	51 (18)	71 (25)	49 (17)	54 (19)	66 (23)	354
2699	STRAWBERRY LAKE	43 (15)	34 (12)	49 (17)	74 (26)	57 (20)	27 (9)	284

APPENDIX B

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR MICHIGAN 2/3/75

LAKE CODE 2696 HOUGHTON LAKE

TOTAL DRAINAGE AREA OF LAKE(SQ MI) 222.00

TRIBUTARY	SUB-DRAINAGE AREA(SQ MI)	NORMALIZED FLOWS(CFS) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2696A1	222.00	134.00	131.00	182.00	365.00	264.00	160.00	108.00	80.00	83.00	102.00	132.00	140.00	156.65
2696B1	90.00	59.00	58.00	80.00	165.00	137.00	71.00	51.00	34.00	36.00	46.00	58.00	63.00	71.49
2696C1	1.31	0.25	0.22	0.41	1.40	0.83	0.42	0.26	0.19	0.22	0.25	0.39	0.30	0.43
2696D1	47.70	7.60	7.40.	14.00	54.00	28.00	11.00	5.80	2.90	3.10	4.80	7.40	8.40	12.85
2696E1	4.60	2.10	2.60	5.40	12.00	5.60	2.60	1.50	1.20	1.20	1.90	2.80	1.70	3.38
2696ZZ	78.40	65.00	63.00	82.00	133.00	93.00	75.00	49.00	42.00	42.00	49.00	63.00	67.00	68.52

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 222.00
SUM OF SUB-DRAINAGE AREAS = 222.01
TOTAL FLOW IN = 1881.14
TOTAL FLOW OUT = 1881.00

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
2696A1	10	72	118.00	28	230.00				
	11	72	176.00	22	158.00				
	12	72	136.00	19	142.00				
	1	73	273.00	20	355.00				
	2	73	217.00	24	158.00				
	3	73	372.00	24	384.00				
	4	73	337.00	7	367.00	21	343.00		
	5	73	223.00	5	263.00	19	207.00		
	6	73	126.00	23	91.00				
	7	73	98.00	21	96.00				
	8	73	108.00	23	90.00				
	9	73	103.00	28	111.00				
2696B1	10	72	54.00	28	105.00				
	11	72	78.00	22	70.00				
	12	72	61.00	19	64.00				
	1	73	119.00	20	155.00				
	2	73	97.00	24	70.00				
	3	73	162.00	24	168.00				
	4	73	154.00	7	168.00	21	157.00		
	5	73	116.00	5	137.00	19	108.00		
	6	73	57.00	23	41.00				
	7	73	47.00	21	46.00				
	8	73	46.00	23	38.00				
	9	73	45.00	28	49.00				

LAKE CODE 2696 HOUGHTON LAKE

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
2696C1	10	72	0.31	28	0.34				
	11	72	0.41	22	0.39				
	12	72	0.32	19	0.32				
	1	73	0.35	20	0.47				
	2	73	0.29	24	0.27				
	3	73	0.57	24	0.51				
	4	73	1.20	7	1.30	21	1.20		
	5	73	0.86	5	0.84	19	0.79		
	6	73	0.46	23	0.39				
	7	73	0.27	21	0.23				
	8	73	0.20	23	0.19				
	9	73	0.22	28	0.22				
2696D1	10	72	5.50	28	11.00				
	11	72	9.80	22	8.80				
	12	72	8.30	19	8.60				
	1	73	15.00	20	20.00				
	2	73	12.00	24	8.80				
	3	73	29.00	24	30.00				
	4	73	48.00	7	52.00	21	49.00		
	5	73	24.00	5	28.00	19	22.00		
	6	73	8.70	23	6.30				
	7	73	5.30	21	5.10				
	8	73	4.00	23	3.30				
	9	73	3.80	28	4.10				
2696E1	10	72	2.40	28	3.20				
	11	72	3.20	22	2.80				
	12	72	1.80	19	1.80				
	1	73	3.60	20	5.00				
	2	73	3.60	24	3.00				
	3	73	9.00	24	8.00				
	4	73	10.00	7	11.00	21	10.00		
	5	73	6.00	5	5.90	19	5.40		
	6	73	2.80	23	2.20				
	7	73	1.50	21	1.30				
	8	73	1.40	23	1.20				
	9	73	1.20	28	1.30				
2696Z2	10	72	56.00						
	11	72	85.00						
	12	72	65.00						
	1	73	135.00						
	2	73	104.00						
	3	73	171.00						
	4	73	124.00						
	5	73	76.00						
	6	73	57.00						
	7	73	44.00						
	8	73	56.00						
	9	73	53.00						

APPENDIX C

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 75/02/04

269601
44 19 00.0 084 45 00.0
HOUGHTON LAKE
26 MICHIGAN

11EPALES 2111202
5 0018 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/15	09 30	0000	18.7	7.7	114	205	7.70	98	0.030	0.020	0.009	0.004
	09 30	0016	18.0	7.6		210	7.68	100	0.030	0.020	0.010	0.005
72/09/20	07 05	0000			91	290	7.75	89	0.130	0.180	0.016	0.008
	07 05	0004	18.1	6.9		285	7.80	83	0.080	0.110	0.025	0.010
	07 05	0008	18.0	7.8		250	7.85	83	0.100	0.140	0.014	0.010
72/11/14	11 25	0000			48	210	8.20	83	0.040	0.080	0.018	0.008
	11 25	0004	3.4	12.3		205	8.20	84	0.040	0.080	0.018	0.007
	11 25	0011	3.4	11.6		200	8.20	83	0.060	0.110	0.020	0.007

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/15	09 30	0000	5.9J
72/09/20	07 05	0000	7.2J
72/11/14	11 25	0000	11.6J

J VALUE KNOWN TO BE IN ERROR

STORET RETRIEVAL DATE 75/02/04

269602
44 21 30.0 084 45 00.0
HOUGHTON LAKE
26 MICHIGAN

11EPALES 2111202
5 0015 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/15	09 56	0000	18.5	8.1	108	210	8.27	98	0.030	0.040	0.011	0.009
	09 56	0012	18.1	6.8		205	8.28	98	0.030	0.060	0.009	0.004
72/09/20	07 30	0000			66	285	7.85	83	0.150	0.180	0.016	0.008
	07 30	0004	17.7	7.8		280	7.85	84	0.150	0.190	0.017	0.010
	07 30	0008	17.6	7.8		280	7.90	83	0.140	0.160	0.017	0.012
72/11/14	11 40	0000			48	220	8.20	79	0.040	0.060	0.015	0.006
	11 40	0004	2.6	12.2		200	8.20	79	0.080	0.090		0.010

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/15	09 56	0000	9.8J
72/09/20	07 30	0000	12.7J
72/11/14	11 40	0000	8.1J

J VALUE KNOWN TO BE [illegible]

APPENDIX D

TRIBUTARY DATA

STORET RETRIEVAL DATE 75/02/04

2696A1 LS2696A1
44 24 30.0 084 47 30.0
MUSKEGON RIVER
26143 15 HOUGHTON LAKE
O/HOUGHTON LAKE
US 27 BRDG E OF MEADS LANDING
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	09 00		0.038	0.550	0.057	0.005K	0.017
72/11/22	09 25		0.010K	0.940	0.018	0.005K	0.012
72/12/19	09 30		0.010K	0.580	0.019	0.005K	0.010
73/01/20	09 30		0.030	0.520	0.032	0.005K	0.005K
73/02/24	08 55		0.027	1.680	0.060	0.005K	0.010
73/03/24	08 30		0.027	0.310	0.009	0.005K	0.010
73/04/07	09 20		0.023	2.940	0.064	0.005K	0.020
73/04/21	09 00		0.010K	0.740	0.016	0.005	0.020
73/05/05	09 20		0.023	0.750	0.011	0.005K	0.020
73/05/19	08 40		0.010K	0.520	0.006	0.005K	0.020
73/06/23	14 00		0.010K	0.750	0.033	0.006	0.027
73/07/21	09 35		0.046	0.520	0.005K	0.005K	0.020
73/08/23	14 00		0.010K	0.460	0.017	0.008	0.025
73/09/28	13 45		0.010K	0.400	0.030	0.006	0.015

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

259681 LS259681
44 22 00.0 084 41 00.0
BACKUS CREEK
26 7.5 PRUDENVILLE
1/HOUGHTON LAKE
NORTH SHORE DR BRDG NE SIDE HOUGHTON LK
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	10 40		0.015	0.500	0.044	0.008	0.013
72/11/22	11 00		0.020	2.000	0.060	0.005K	0.009
73/01/20	09 00		0.060	0.645	0.026	0.005K	0.015
	13 00		0.067	1.050	0.040	0.007	0.015
73/02/24	10 20		0.028	2.000	0.084	0.014	0.015
73/03/24	10 15		0.016	0.390	0.044	0.005K	0.010
73/04/07	11 00		0.030	2.700	0.132	0.028	0.050
73/04/21	11 00		0.021	0.980	0.056	0.006	0.030
73/05/05	11 35		0.033	1.750	0.046	0.005K	0.015
73/05/19	10 40		0.012	0.480	0.017	0.005K	0.010
73/06/23	11 30		0.021	1.700	0.075	0.007	0.020
73/07/21	10 20		0.010K	0.330	0.011	0.005K	0.015
73/08/23	15 20		0.016	0.440	0.050	0.009	0.020
73/09/28	15 00		0.013	0.370	0.040	0.006	0.010

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

2696C1 LS2696C1
44 18 30.0 084 38 00.0
SPRING BROOK
26 7.5 PRUDENVILLE
T/HOUGHTON LAKE
ST HWY 18 BRDG NE OF PRUDENVILLE
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	10 15		0.024	0.450	0.037	0.005K	0.014
72/11/22	10 40		0.074	0.290	0.026	0.005K	0.011
73/01/20	11 00		0.095	0.330	0.016	0.005K	0.005K
73/02/24	09 45		0.154	0.720	0.048	0.008	0.030
73/03/24	09 35		0.065	0.290	0.011	0.005K	0.005K
73/04/07	10 45		0.066	3.360	0.105	0.037	0.080
73/04/21	10 40		0.039	0.690	0.033	0.006	0.020
73/05/05	11 00		0.046	0.220	0.018	0.005K	0.010
73/05/19	10 20		0.027	0.400	0.011	0.005K	0.010
73/06/23	11 00		0.096	1.260	0.080	0.014	0.050
73/07/21	10 10		0.098	0.330	0.058	0.017	0.045
73/08/23	15 00		0.039	2.100	0.231	0.058	
73/09/28	14 30		0.046	0.800	0.060	0.024	0.077

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

269601 LS269601
44 16 00.0 084 38 30.0
DENTON CREEK/LK JAMES/HOUGHTON C
CO 7.5 PRUDENVILLE
1/HOUGHTON LAKE
ST HWY 55 BRDG IN PRUDENVILLE
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	10	10	0.143	0.750	0.115	0.005K	0.015
72/11/22	10	30	0.027	0.970	0.046	0.005K	0.012
72/12/19	10	40	0.030	1.380	0.078	0.005K	0.012
73/01/20	10	20	0.048	0.500	0.072	0.005K	0.010
73/02/24	09	35	0.039	0.540	0.068	0.005K	0.015
73/03/24	09	30	0.037	0.310	0.016	0.005K	0.010
73/04/07	10	35	0.046	4.500	0.138	0.005K	0.015
73/04/21	10	00	0.027	0.680	0.064	0.005K	0.025
73/05/05	10	40	0.027	0.580	0.026	0.005K	0.015
73/05/19	09	45	0.010K	0.800	0.019	0.007	0.020
73/06/23	10	45	0.012	0.860	0.054	0.005K	0.020
73/07/21	10	05	0.021	0.860	0.200	0.008	0.030
73/08/23	14	45	0.147	1.800	0.176	0.010	0.030
73/09/28	14	15	0.176	0.920	0.170	0.008	0.025

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

2696E1 LS2696E1
44 18 00.0 084 39 00.0
KNAPPEN CREEK
26 7.5 PRUDENVILLE
T/HOUGHTON LAKE
ST HWY 55 BRDG IN PRUDENVILLE
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	10 00		0.117	0.550	0.105	0.005K	0.013
72/11/22	10 30		0.023	1.400	0.042	0.005K	0.007
73/01/20	10 00		0.084	0.440	0.018	0.005K	0.010
73/02/24	09 25		0.054	0.840	0.076	0.005K	0.025
73/03/24	09 25		0.033	0.810	0.033	0.005K	0.010
73/04/07	10 30		0.037	2.310	0.092	0.036	0.060
73/04/21	09 50		0.034	1.990	0.070	0.010	0.020
73/05/05	10 30		0.034	0.500	0.026	0.005K	0.010
73/05/19	09 35		0.016	0.560	0.016	0.005K	0.015
73/06/23	10 30		0.066	1.200	0.138	0.006	0.030
73/07/21	10 00		0.154	0.940	0.073	0.006	0.025
73/08/23	14 30		0.210	0.900	0.138	0.017	
73/09/28	14 00		0.168	0.600	0.064	0.006	0.020

K VALUE KNOWN TO BE
LESS THAN INDICATED