U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL EUTROPHICATION SURVEY

WORKING PAPER SERIES

REPORT
ON
PENTWATER LAKE
OCEANA COUNTY
MICHIGAN
EPA REGION V
WORKING PAPER No. 204

PACIFIC NORTHWEST ENVIRONMENTAL RESEARCH LABORATORY

An Associate Laboratory of the

NATIONAL ENVIRONMENTAL RESEARCH CENTER - CORVALLIS, OREGON

and

NATIONAL ENVIRONMENTAL RESEARCH CENTER - LAS VEGAS, NEVADA

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REPORT

ON

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WORKING PAPER No. 204

WITH THE COOPERATION OF THE

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

AND THE

MICHIGAN NATIONAL GUARD

MARCH, 1975

CONTENTS

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 identifying point sources and soliciting municipal participation in the Survey.

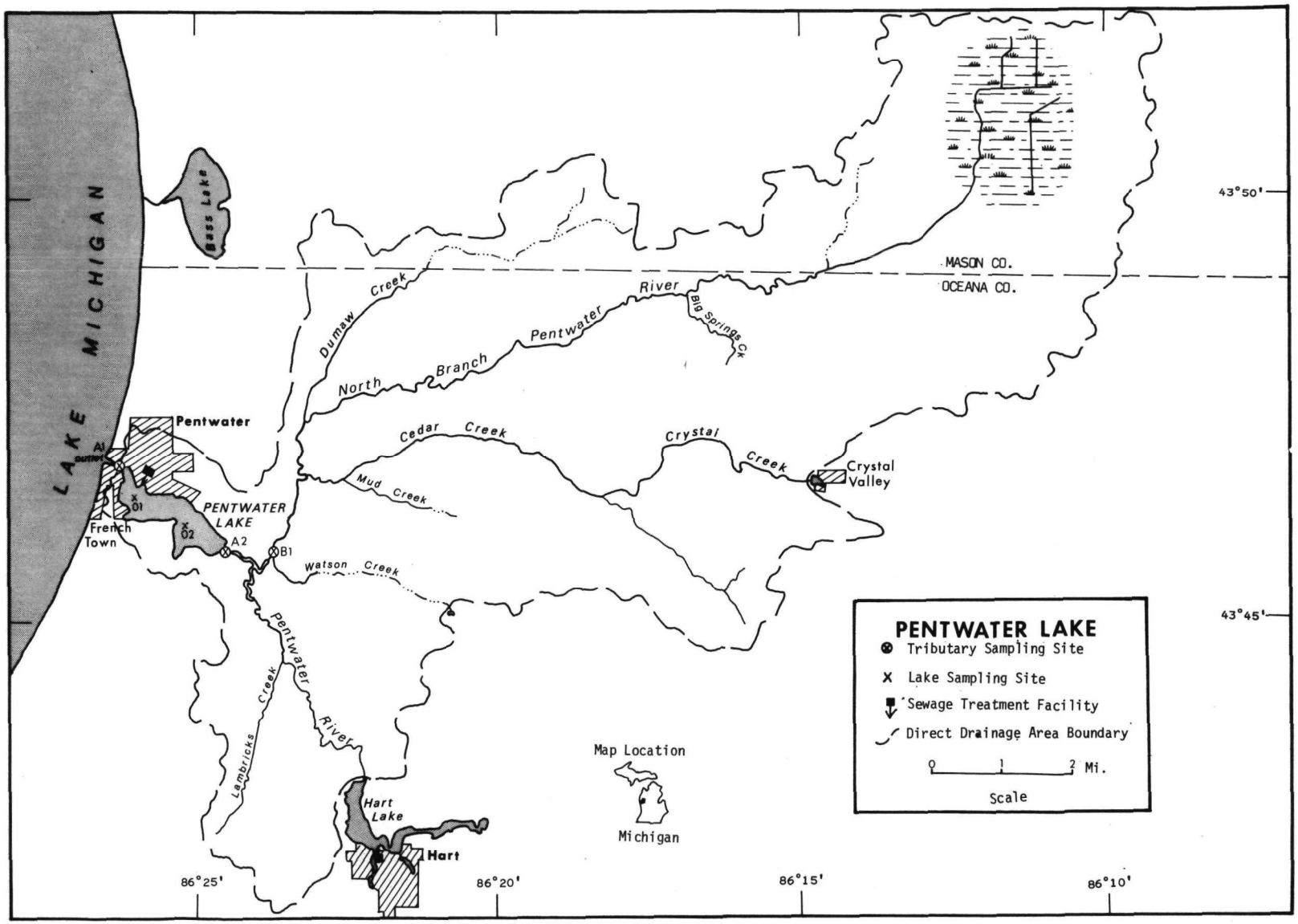
Major General Clarence A. Schnipke (Retired), then the Adjutant General of Michigan, and Project Officer Colonel Albert W. Lesky, who directed the volunteer efforts of the Michigan National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

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


LAKE MICHIGAN
Bass Lake
Pentwater
A1
outfall
PENTWATER LAKE
01
02
A2
B1
French Town
Dumaw Creek
Pentwater River
Big Springs Ck
North Branch
Cedar Creek
Crystal Creek
Crystal Valley
Mud Creek
Watson Creek
Pentwater River
Lambricks Creek
Hart Lake
Hart
MASON CO.
OCEANA CO.
43°50'
43°45'
86°25'
86°20'
86°15'
86°10'
Map Location
Michigan
PENTWATER LAKE
Tributary Sampling Site
Lake Sampling Site
Sewage Treatment Facility
Direct Drainage Area Boundary
0 1 2 Mi.
Scale

PENTWATER LAKE

STORET NO. 2665

I. CONCLUSIONS

A. Trophic Condition:

Survey data show that Pentwater Lake is eutrophic. Of the 35 lakes sampled in November when essentially all were well-mixed, nine had less mean total phosphorus, 12 had less mean dissolved phosphorus, and 16 had less mean inorganic nitrogen; of the 41 lakes sampled, 28 had less mean chlorophyll a, and 13 had greater Secchi disc transparency*.

Depression of dissolved oxygen occurred below 15 feet at both sampling stations in June, and depletion or near-depletion occurred below 30 feet at both stations in September, 1972.

B. Rate-Limiting Nutrient:

The results of the algal assay show that Pentwater Lake was phosphorus limited when the sample was collected (09/18/72). The lake data indicate phosphorus limitation in June and November as well.

C. Nutrient Controllability:

1. Point sources--During the sampling year, Pentwater Lake received a total phosphorus load at a rate nearly 2½ times that

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* See Appendix A.

proposed by Vollenweider (in press) as "dangerous"; i.e., a eutrophic rate (see page 14). However, Vollenweider's model probably is not applicable to water bodies with short hydraulic retention times, and the hydraulic retention time of Pentwater Lake is certain to be quite short. For example, the maximum depth sampled during the Survey was 40 feet; and, if the mean depth is as much as one-half of that (i.e., a mean depth of 20 feet), the lake would have a mean hydraulic retention time of only 19 days. Therefore, it is quite likely that Vollenweider's model does not apply in this case.

It is calculated that the communities of Pentwater and Hart contributed about 24% of the total phosphorus load to Pentwater Lake during the sampling year. As of November, 1973, Hart converted to a land-disposal system and no longer impacts Pentwater Lake. It is calculated that this diversion, plus 80% phosphorus removal at Pentwater, would reduce the loading to the lake from about 5 $g/m^2/yr$ to 3.9 $g/m^2/yr$. Considering the hydraulic retention time of the lake, which is certain to be quite short, it is likely that the lower loading rate would at least result in a reduction in the incidence and severity of nuisance algal blooms, as well as provide additional protection for Lake Michigan.

2. Non-point sources--During the sampling year, the Pentwater River had a relatively high phosphorus export rate of 82 pounds per square mile of drainage area (see page 14) or more than twice the mean phosphorus export rate of the tributaries to nearby Manistee Lake* (40 lbs/mi^2/yr).

It is not known whether the higher export rate is due to underestimation of the phosphorus load from the City of Hart or to cultural practices in the drainage; but, if the export can be reduced, additional enhancement of the trophic condition of Pentwater Lake would result.

* Working Paper No. 201.

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

A. Lake Morphometry:

1. Surface area: 435 acres[†].
2. Mean depth: unknown.
3. Maximum depth: unknown.
4. Volume: unknown.

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

1. Tributaries -

Name	Drainage area*	Mean flow*
Pentwater River	168.0 mi^2	218.4 cfs
Minor tributaries & immediate drainage -	8.3 mi^2	11.0 cfs
Totals	176.3 mi^2	229.4 cfs

2. Outlet -

Pentwater River	177.0 mi^2**	229.4 cfs

C. Precipitation***:

1. Year of sampling: 33.8 inches.
2. Mean annual: 31.8 inches.

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† Fetterolf, 1973.
* 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

Pentwater 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 a number of depths at each station (see map, page v). During each visit, a single depth-integrated (15 feet 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, depth-integrated samples were collected from each of the stations for chlorophyll a analysis. The maximum depths sampled were 40 feet at station 1 and 38 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:

		FALL VALUES (11/13/72)		
Parameter	Minimum	Mean	Median	Maximum
Temperature (Cent.)	7.3	7.3	7.3	7.4
Dissolved oxygen (mg/l)	8.6	9.0	9.2	9.2
Conductivity (μmhos)	385	391	390	400
pH (units)	8.0	8.1	8.0	8.2
Alkalinity (mg/l)	132	145	146	149
Total P (mg/l)	0.024	0.027	0.027	0.030
Dissolved P (mg/l)	0.016	0.017	0.017	0.018
NO_2 + NO_3 (mg/l)	0.340	0.343	0.340	0.360
Ammonia (mg/l)	0.140	0.152	0.150	0.160
		ALL VALUES		
Secchi disc (inches)	60	71	71	82

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Number per ml
06/17/72	1. Cryptomonas	1,665
	2. Anabaena	567
	3. Fragilaria	543
	4. Dinobryon	302
	5. Chroococcus	97
	Other genera	312
	Total	3,486
09/18/72	1. Melosira	784
	2. Fragilaria	494
	3. Anabaena	410
	4. Marssionella	307
	5. Synedra	175
	Other genera	880
	Total	3,050
11/13/72	1. Flagellates	1,220
	2. Cyclotella	587
	3. Melosira	407
	4. Asterionella	361
	5. Ulothrix	241
	Other genera	783
	Total	3,599

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)
06/17/72	01	16.6
	02	32.3
09/18/72	01	16.0
	02	16.5
11/13/72	01	6.0
	02	9.1

C. Limiting Nutrient Study:

1. Filtered and nutrient spiked -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)
Control	0.024	0.402	8.6
0.010 P	0.034	0.402	9.6
0.020 P	0.044	0.402	9.5
0.050 P	0.074	0.402	10.4
0.050 P + 5.0 N	0.074	5.402	31.2
0.050 P + 10.0 N	0.074	10.402	31.5
10.0 N	0.024	10.402	8.6

2. Discussion -

The control yield of the assay alga, Selenastrum capricornutum, indicates that the primary productivity of Pentwater Lake was high at the time the algal assay sample was collected (09/18/72). Also, the increased yield with the first increment of orthophosphorus indicates that the lake was limited by phosphorus. Note that when nitrogen was added there was no significant difference in yield as compared to the control yield.

The lake data indicate phosphorus limitation in June and November as well; the N/P ratios were 33/1 and 29/1, respectively, and phosphorus limitation would be expected.

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 months of April, June, and September when two samples were collected. 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 mean annual nutrient concentrations in the North Branch of the Pentwater River at station B-1 and the mean ZZ flow.

The operators of the Pentwater and Hart wastewater treatment systems did not provide sufficient samples to permit calculation of nutrient loads, and the loads attributed to these sources were estimated at 2.5 lbs P and 7.5 lbs N/capita/year.

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* See Working Paper No. 1.

During the sampling year, the Hart wastewater system discharged to Hart Lake and thence to the Pentwater River to Pentwater Lake. In this report, it is assumed that 60% of the phosphorus load and 20% of the nitrogen load from the Hart system were retained in Hart Lake. The nutrient loads attributed to the Pentwater River are those measured at station A-2 minus the estimated Hart system loads.

The Pentwater treatment system discharges to the lower third of the lake. During periods of high tributary flows, it is possible that some portion of the Pentwater nutrients are "short-circuited" through the outlet and thus have little effect on the lake. However, in this report, it is assumed that the entire lake is affected by the Pentwater loads.

A. Waste Sources:

1. Known municipal† -

Name	Pop.* Served	Treatment	Mean* Flow (mgd)	Receiving Water
Pentwater	993	stab. ponds	0.099	Pentwater Lake
Hart	2,139	stab. ponds**	0.214	Hart Lake

2. Known industrial - None

† Wetzel, 1973.
* Population from 1970 Census; flows estimated at 100 gal/capita/day.
** As of November, 1973, Hart converted to a land-disposal system.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	lbs P/ yr	% of total
a. Tributaries (non-point load) -		
Pentwater River	13,830	71.6
b. Minor tributaries & immediate drainage (non-point load) -	710	3.7
c. Known municipal systems -		
Pentwater	2,480	12.9
Hart	2,140	11.1
d. Septic tanks* -	60	0.3
e. Known industrial - None	-	-
f. Direct precipitation** -	70	0.4
Total	19,290	100.0

2. Outputs -

Lake outlet - to Lake Michigan 17,060

3. Net annual P accumulation - 2,230 pounds

* Estimate based on 91 lakeshore dwellings; 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) -		
Pentwater River	654,040	92.9
b. Minor tributaries & immediate drainage (non-point load) -	23,170	3.3
c. Known municipal systems -		
Pentwater	7,450	1.1
Hart	12,830	1.8
d. Septic tanks* -	2,140	0.3
e. Known industrial - None	-	-
f. Direct precipitation** -	4,190	0.6
Total	703,820	100.0

2. Outputs -

Lake outlet - to Lake Michigan 442,490

3. Net annual N accumulation - 261,330 pounds

* Estimate based on 91 lakeshore dwellings; 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
Pentwater River	82	3,893

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 water 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".

Note that Vollenweider's model may not be applicable to water bodies with very short hydraulic retention times.

	Total Phosphorus		Total Nitrogen	
Units	Total	Accumulated	Total	Accumulated
lbs/acre/yr	44.3	5.1	1,618.0	600.8
grams/m^2/yr	4.97	0.57	181.3	67.3

Vollenweider loading rates for phosphorus (g/m^2/yr) based on surface area and mean outflow of Pentwater Lake:

"Dangerous" (eutrophic rate)	2.10
"Permissible" (oligotrophic rate)	1.05

V. LITERATURE REVIEWED

Fetterolf, Carlos, 1973. Personal communication (area of lake). MI Dept. Nat. Resources, Lansing.

_____, 1974. Personal communication (location of Pentwater system discharge; nutrient retention in Hart Lake; present Hart system). MI Dept. Nat. Resources, Lansing.

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

Wetzel, Michael, 1973. Treatment plant questionnaires (Pentwater and Hart systems). MI Dept. Nat. Resources, Lansing.

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	3.008	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

LAKE CODE 2665 PENTWATER LAKE

TOTAL DRAINAGE AREA OF LAKE(SQ MI) 177.00

TRIBUTARY	SUB-DRAINAGE AREA(SQ MI)	NORMALIZED FLOWS(CFS) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2665A1	177.00	229.00	227.00	269.00	292.00	253.00	223.00	195.00	189.00	202.00	209.00	231.00	235.00	229.44
2665A2	168.00	218.00	216.00	256.00	278.00	241.00	212.00	186.00	180.00	192.00	199.00	220.00	224.00	218.44
2665ZZ	9.00	11.00	11.00	13.00	14.00	12.00	11.00	9.00	9.00	10.00	10.00	11.00	11.00	10.99

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 177.00
SUM OF SUB-DRAINAGE AREAS = 177.00
TOTAL FLOW IN = 2754.00
TOTAL FLOW OUT = 2754.00

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
2665A1	10	72	227.00	28	356.00				
	11	72	220.00						
	12	72	219.00	3	204.00				
	1	73	388.00	7	317.00				
	2	73	286.00	4	370.00				
	3	73	345.00	4	356.00				
	4	73	258.00	1	232.00	29	216.00		
	5	73	317.00	13	375.00				
	6	73	269.00	9	296.00	23	223.00		
	7	73	208.00	7	217.00	15	202.00		
	8	73	187.00						
	9	73	166.00	9	164.00	30	168.00		
2665A2	10	72	216.00	28	339.00				
	11	72	210.00						
	12	72	209.00	3	194.00				
	1	73	370.00	7	302.00				
	2	73	272.00	4	352.00				
	3	73	329.00	4	339.00				
	4	73	246.00	1	221.00	29	206.00		
	5	73	302.00	13	357.00				
	6	73	256.00	9	282.00	23	212.00		
	7	73	198.00	7	207.00	15	192.00		
	8	73	178.00						
	9	73	158.00	9	156.00	30	160.00		
2665ZZ	10	72	11.00						
	11	72	10.00						
	12	72	10.00						
	1	73	18.00						
	2	73	14.00						
	3	73	16.00						
	4	73	12.00						
	5	73	15.00						
	6	73	13.00						
	7	73	10.00						
	8	73	9.00						
	9	73	8.00						

APPENDIX C

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 75/02/04

266501
43 46 30.0 086 26 58.0
PENTWATER LAKE
26 MICHIGAN

11EPALES 2111202
3 0032 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
72/06/17	18 20	0000	17.2	10.4	76	320	8.50	143	0.700	0.040	0.027	0.010
	18 20	0015	15.1	7.2		315	8.03	140	0.130	0.040	0.019	0.008
	18 20	0020	11.2	4.6		310	7.58	140	0.220	0.110	0.045	0.006
72/09/18	13 10	0000			72	335	8.63	144	0.080	0.080	0.017	0.009
	13 10	0004	19.2	8.5		332	8.63	144	0.070	0.070	0.029	0.010
	13 10	0015	18.9	8.4		320	8.57	142	0.070	0.090	0.021	0.011
	13 10	0022	18.7	1.7		320	8.18	142	0.030	0.990	0.158	0.126
	13 10	0030	14.1	0.0		330	7.65	166	0.180	1.620	0.265	0.160
	13 10	0038	13.0	0.2		320	7.65	142	0.060	1.590	0.264	0.150
72/11/13	13 00	0000			60	390	8.00	147	0.360	0.160	0.029	0.016
	13 00	0004	7.3	8.7		385	8.00	146	0.340	0.160	0.029	0.018
	13 00	0015	7.3	8.6		390	8.00	147	0.340	0.160	0.030	0.017
	13 00	0025	7.3	9.2		385	8.00	146	0.340	0.160	0.025	0.017
	13 00	0035	7.3									
	13 00	0040	7.3	9.0		390	8.00	132	0.340	0.150	0.030	0.017

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/17	18 20	0000	16.0J
72/09/18	13 10	0000	16.0J
72/11/13	13 00	0000	6.0J

J VALUE KNOWN TO BE IN ERROR

STORET RETRIEVAL DATE 75/02/04

266502
43 46 06.0 086 25 12.0
PENTWATER LAKE
26 MICHIGAN

11EPALES 2111202
3 0026 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
72/06/17	18 45	0000	16.7	11.4	60	320	8.59	146	0.050	0.040	0.036	0.013
	18 45	0015	16.1	9.4		325	8.40	145	0.070	0.050	0.040	0.012
	18 45	0025	11.4	4.0		320	7.56	143	0.230	0.130	0.014	0.006
72/09/18	13 45	0000			60	330	8.70	137	0.080	0.060	0.018	0.013
	13 45	0004	19.6	9.8		330	8.73	136	0.080	0.050	0.020	0.009
	13 45	0015	18.7	7.6		332	8.40	136	0.090	0.080	0.017	0.007
	13 45	0022	18.1	6.2		328	8.25	134	0.090	0.140	0.016	0.008
	13 45	0028	17.2	3.4		330	7.95	132	0.080	0.280	0.028	0.010
	13 45	0034	15.1	0.7		325	7.80	132	0.040	0.580	0.068	0.029
72/11/13	13 25	0000			62	400	8.10	145	0.340	0.150	0.024	0.017
	13 25	0004	7.4	9.2		400	8.10	145	0.340	0.140	0.027	0.016
	13 25	0015	7.4	9.2		385	8.10	147	0.340	0.140	0.025	0.016
	13 25	0025	7.4									
	13 25	0035	7.4									
	13 25	0038	7.4	9.2		395	8.20	149	0.350	0.150	0.027	0.016

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/17	18 45	0000	32.3J
72/09/18	13 45	0000	16.5J
72/11/13	13 25	0000	9.1J

J VALUE KNOWN TO BE IN ERROR

APPENDIX D

TRIBUTARY and WASTEWATER TREATMENT PLANT DATA

STORET RETRIEVAL DATE 75/02/04

2665A1 LS2665A1
43 47 00.0 086 26 30.0
OUTLET CHANNEL
26 15 LUDINGTON
O/PENTWATER LAKE
BAY ST BRDG IN PENTWATER
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	17 00		0.208	0.650	0.071	0.006	0.035
72/12/03	13 15		0.350	0.400	0.073	0.012	0.035
73/01/07	09 25		0.720	0.520	0.054	0.016	0.036
73/02/04	09 45		0.790	0.480	0.046	0.012	0.025
73/03/04	10 00		0.820	0.420	0.042	0.019	0.020
73/04/01	14 15		0.520	0.580	0.019	0.009	0.030
73/04/29	10 00		0.300	1.150	0.029	0.005K	0.025
73/05/13	09 25		0.294	0.820	0.130	0.008	0.035
73/06/09	10 00		0.058	0.580	0.021	0.006	0.035
73/06/23	10 35		0.054	0.780	0.020	0.012	0.045
73/07/07	12 45		0.010K	1.050	0.014	0.018	0.055
73/07/15	10 30		0.027	0.770	0.010	0.018	0.060
73/09/09	09 15		0.132	0.420	0.038	0.022	0.042
73/09/30	16 30		0.078	0.630	0.036	0.007	0.045

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

2665A2 L52665A2
43 46 00.0 086 24 30.0
PENTWATER RIVER
26 15 LUDINGTON
I/PENTWATER LAKE
BRD 1.5 MI SE OF PENTWTER
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	16 35		0.440	0.550	0.096	0.014	0.036
72/12/03	13 05		0.650	1.980	0.160	0.023	0.037
73/01/07	09 10		0.730	1.470	0.033	0.011	0.034
73/02/04	09 32		0.820	1.380	0.076	0.012	0.030
73/03/04	09 45		0.730	0.720	0.120	0.023	0.055
73/04/01	14 05		0.540	0.520	0.027	0.005K	0.020
73/04/29	09 50		0.430	2.310	0.105	0.008	0.022
73/05/13	09 15		0.290	0.800	0.024	0.008	0.030
73/06/09	09 35		0.190	0.570	0.054	0.013	0.045
73/06/23	10 25		0.154	0.950	0.063	0.034	0.060
73/07/07	12 30		0.170	0.480	0.040	0.020	0.035
73/07/15	10 00		0.140	0.440	0.046	0.028	0.050
73/09/09	08 45		2.080	1.150	0.075	0.025	0.025
73/09/30	16 45		0.231	0.630	0.069	0.010	0.035

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

266581 L5266581
43 46 00.0 086 23 30.0
N BRANCH PENTWATER RIVER
26 15 LUDINGTON
T/PENT WATER LAKE
US ALT 31 BRDG
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	16 25		0.340	0.550	0.044	0.008	0.020
72/12/03	12 50		0.530	0.460	0.044	0.013	0.020
73/01/07	08 45		0.500	0.830	0.036	0.009	0.018
73/02/04	09 26		0.490	0.500	0.028	0.012	0.030
73/03/04	09 30		0.610	1.150	0.170	0.033	0.090
73/04/01	14 00		0.450	0.760	0.034	0.006	0.020
73/04/29	09 45		0.380	1.470	0.082	0.009	0.010
73/05/13	09 15		0.315	0.710	0.035	0.010	0.035
73/06/09	09 15		0.320	0.520	0.034	0.013	0.040
73/06/23	10 15		0.380	0.330	0.035	0.016	0.035
73/07/07	12 20		0.340	0.400	0.033	0.015	0.032
73/07/15	09 30		0.360	0.310	0.028	0.015	0.035
73/09/09	08 15		0.460	0.770	0.020	0.015	0.050
73/09/30	17 00		0.430	0.310	0.035	0.023	0.025

STORET RETRIEVAL DATE 75/02/04

266550 PD266550 P001815
43 42 30.0 086 22 00.0
HART
26 15 HART
T/PENTWATER LAKE
HART LAKE
11EPALES 2141204
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	50051 FLOW RATE INST MGD	50053 CONDUIT FLOW-MGD MONTHLY
73/05/02	15 00								
CP(T)-			0.043	17.000		5.050	6.000		
73/05/02	23 00								

STORET RETRIEVAL DATE 75/02/04

266551 P0266551 P001384
43 47 00.0 086 26 30.0
PENTWATER
26 15 LUDINGTON
D/PENTWATER LAKE
PENTWATER LAKE
11EPALES 2141204
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	50051 FLOW RATE INST MGD	50053 CONDUIT FLOW-MGD MONTHLY
73/04/12	08 00								
CP(T)-			0.230	3.200	0.290	1.800	2.100	0.172	
73/04/12	17 00								
73/04/19	09 00		0.240	3.000	0.145	1.800	2.000	0.172	
73/04/27	08 00								
CP(T)-			0.125	2.800	0.320	1.790	2.100	0.172	0.172
73/04/27	16 00								
73/05/04	08 00								
CP(T)-			0.119	6.000	0.360	1.895	2.400	0.172	0.172
73/05/04	16 00								