U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL EUTROPHICATION SURVEY

WORKING PAPER SERIES

REPORT

ON

BETSIE LAKE

BENZIE COUNTY

MICHIGAN

EPA REGION V

WORKING PAPER No. 185

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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208

WITH THE COOPERATION OF THE

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

AND THE

MICHIGAN NATIONAL GUARD

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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	4
III. Lake Water Quality Summary	5
IV. Nutrient Loadings	10
V. Literature Reviewed	15
VI. Appendices	16

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; Carlos Fetterolf, Chief Environmental Scientist, Bureau of Water Management; and John Robinson, Chief, Dennis Tierney, Aquatic Biologist, and Albert Massey, Aquatic Biologist, Water Quality Appraisal Section, 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.

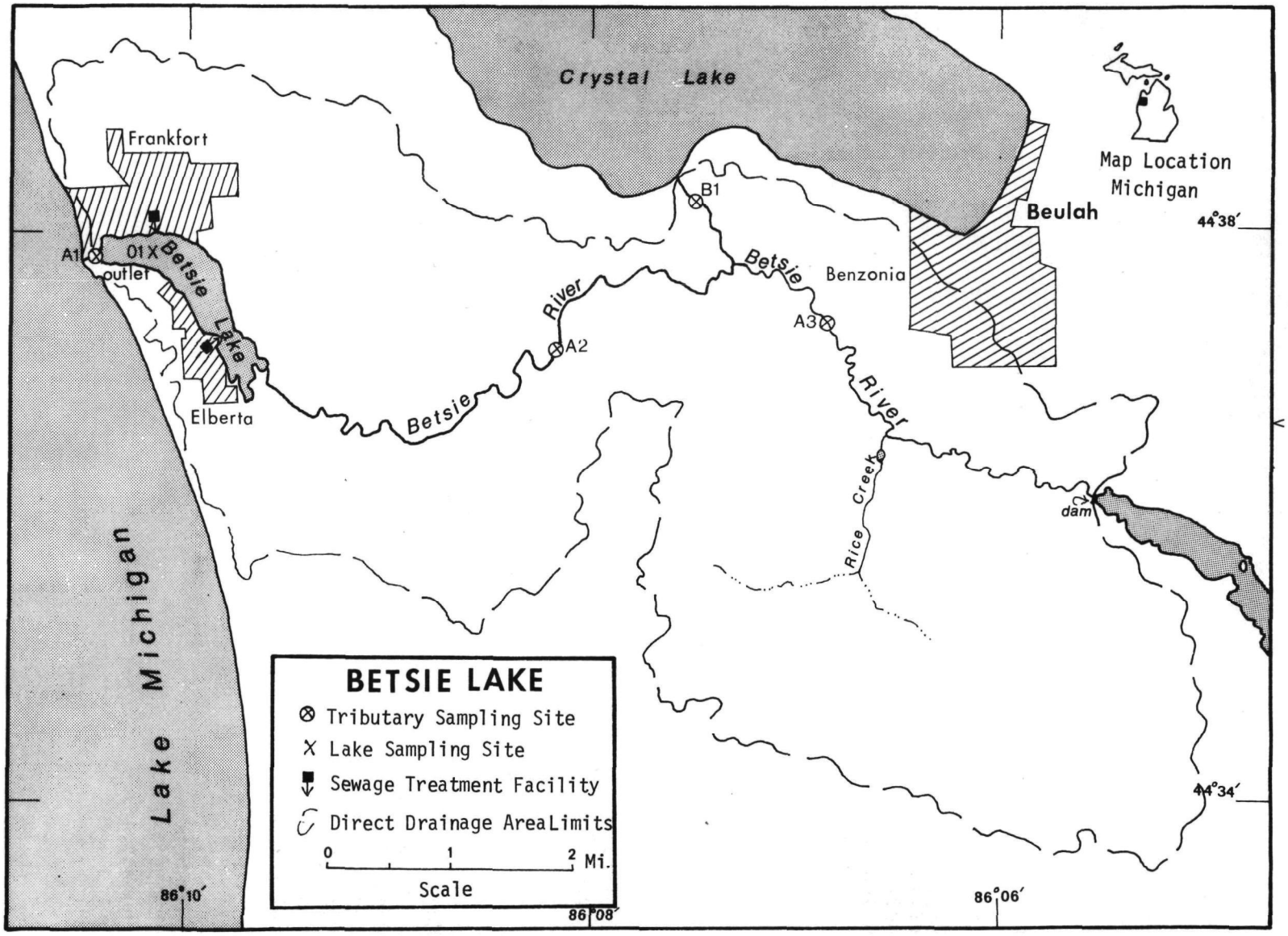
Major General Clarence A. Schnipke (Retired), then the Adjutant General of Michigan, and Project Officer Colonel Albert W. Lesky, who directed the volunteer efforts of the Michigan National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

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


Crystal Lake
Frankfort
Map Location
Michigan
Beulah
44°38′
B1
A1
01 X
outlet
Betsie Lake
Betsie River
Betsie
Benzonia
A3
A2
Elberta
Rice Creek
dam
Lake Michigan
BETSIE LAKE
Tributary Sampling Site
Lake Sampling Site
Sewage Treatment Facility
Direct Drainage Area Limits
0
1
2 Mi.
Scale
44°34′
86°10′
86°08′
86°06′

BETSIE LAKE

STORET NO. 2610

I. CONCLUSIONS

A. Trophic Condition:

Survey data show that Betsie Lake is eutrophic. Of the 35 Michigan lakes sampled in November when essentially all were well-mixed, seven had less mean total phosphorus, four had less mean dissolved phosphorus, and six had less mean inorganic nitrogen (these relatively low nutrient levels are indicative of a short hydraulic retention time); of all 41 Michigan lakes sampled, 32 had greater mean Secchi disc transparency, but only six had less mean chlorophyll a*.

Depression of dissolved oxygen occurred at 12 feet in June, 1972.

B. Rate-Limiting Nutrient:

The algal assay results show that Betsie Lake was phosphorus limited at the time the assay sample was collected (09/15/72). The lake data indicate phosphorus limitation in June and November as well.

C. Nutrient Controllability:

1. Point sources--During the Survey year, Betsie Lake received a total phosphorus load at a rate nearly four times

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* See Appendix A.

the rate proposed by Vollenweider (in press) as "dangerous"; i.e., a eutrophic rate. However, Vollenweider's model probably is not applicable to water bodies with short hydraulic retention times, and the hydraulic retention time of Betsie Lake is certain to be very short. For example, if the mean depth of the lake is as much as one-half of the maximum depth of 22 feet (i.e., a mean depth of 11 feet), the mean hydraulic retention time would be a very short four days, and it is quite likely that Vollenweider's model does not apply to this lake.

It is calculated that the communities of Elberta and Frankfort collectively contributed nearly 48% of the total phosphorus load to Betsie Lake during the sampling year. Removal of 85% of the phosphorus at these two point sources would lower the loading rate from the 12.4 $g/m^2/yr$ measured during the sampling year to about 7.4 $g/m^2/yr$. Considering the very short hydraulic retention time, this sizable (41%) reduction of the phosphorus load should result in improvement of the trophic condition of Betsie Lake, as well as provide additional protection for Lake Michigan.

2. Non-point sources--Although the mean non-point phosphorus export rate of the Betsie River drainage seems a little high (59 $lbs/mi^2/yr$; see page 14), the export N/P ratio of 45/1 indicates that if point sources are present, they are minor. However, the

high drainage area to lake area ratio of 627/1 will ensure a significant non-point contribution of phosphorus; and for this reason, all phosphorus inputs to Betsie Lake should be minimized to the greatest practicable degree.

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

A. Lake Morphometry†:

1. Surface area: 250 acres.

2. Mean depth: unknown.

3. Maximum depth: 22 feet.

4. Volume: unknown.

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

1. Tributaries -

Name	Drainage area*	Mean flow*
Betsie River	242.0 mi^2	344.3 cfs
Minor tributaries & immediate drainage -	2.6 mi^2	4.5 cfs
Totals	244.6 mi^2	348.8 cfs

2. Outlet -

Betsie River	245.0 mi^2**	348.8 cfs

C. Precipitation***:

1. Year of sampling: 30.4 inches.

2. Mean annual: 29.6 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

Betsie 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 a number of depths at a single station on the lake (see map, page v). During each visit, a single depth-integrated (near bottom to surface) sample was collected for phytoplankton identification and enumeration; and during the second visit, a single five-gallon depth-integrated sample was collected for algal assays. Also each time, a depth-integrated sample was taken for chlorophyll a analysis. The maximum depth sampled was 18 feet.

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 (11/12/72)		
Temperature (Cent.)	6.2	6.2	6.2	6.2
Dissolved oxygen (mg/l)	9.8	9.9	9.9	10.0
Conductivity (μmhos)	310	313	310	320
pH (units)	7.6	7.6	7.6	7.6
Alkalinity (mg/l)	127	128	127	129
Total P (mg/l)	0.022	0.025	0.022	0.031
Dissolved P (mg/)	0.007	0.008	0.007	0.011
NO_2 + NO_3 (mg/l)	0.240	0.240	0.240	0.240
Ammonia (mg/l)	0.030	0.033	0.030	0.040
		ALL VALUES		
Secchi disc (inches)	24	38	37	54

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera		Number per ml
06/17/72	1.	Navicula	624
	2.	Cocconeis	461
	3.	Achnanthes	380
	4.	Synedra	262
	5.	Cymbella	244
		Other genera	760
			2,731
09/15/72	1.	*Melosira sp.*	8,225
	2.	*Melosira granulata*	4,094
	3.	Microcystis	435
	4.	Dinobryon	326
	5.	Synedra	217
		Other genera	616
		Total	13,913
11/12/72	1.	Anabaena	11,392
	2.	Raphidiopsis	7,722
	3.	Lyngbya	1,519
	4.	Fragilaria	90
	5.	Melosira	54
		Other genera	199
		Total	20,976

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	1.3
09/15/72	01	11.3
11/12/72	01	1.1

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)	N/P Ratio
Control	0.010	0.142	3.5	14/1
0.010 P	0.020	0.142	3.7	7/1
0.020 P	0.030	0.142	4.1	
0.050 P	0.060	0.142	4.3	
0.050 P + 5.0 N	0.060	5.142	24.6	
0.050 P + 10 N	0.060	10.142	26.1	
10.0 N	0.010	10.142	3.3	

2. Discussion -

The control yield of the assay alga, *Selenastrum capricornutum*, indicates that Betsie Lake had a moderately high potential primary productivity at the time the sample was collected (09/15/72).

The N/P ratio of the control sample, and the lack of response to the nitrogen only spike, show that the lake was phosphorus limited at the time of sampling. However, the

first phosphorus spike of only 0.010 mg/l doubled the orthophosphorus concentration in the sample, and nitrogen then became limiting, so there was no marked yield response to phosphorus (note the N/P ratio after the first addition of phosphorus).

The lake data indicate phosphorus limitation at the other sampling times as well. The N/P ratios were 26/1 in June and 34/1 in November.

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 June, when two samples were collected, and in January when ice cover prevented sampling. Sampling was begun in October, 1972, and was completed in October, 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 the U.S. Geological Survey computer program for calculating stream loadings*. Nutrient loadings for "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S.) were estimated by using the nutrient loads, in $lbs/mi^2/year$, in the Betsie River at station A-2 and multiplying by the ZZ area in mi^2.

The operators of the Elberta and Frankfort wastewater treatment plants provided monthly effluent samples and corresponding flow data.

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* See Working Paper No. 1.

A. Waste Sources:

1. Known municipal* -

Name	Pop. Served**	Treatment	Mean Flow (mgd)	Receiving Water
Elberta	542	prim. clarifier	0.136	Betsie Lake
Frankfort	1,660	prim. clarifier	0.414	Betsie Lake

2. Industrial - Unknown; reportedly (Ketelle and Uttormark, 1971), Betsie Lake receives industrial effluents.

* Anonymous, 1972.
** 1970 Census.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	lbs P/ yr	% of total
a. Tributaries (non-point load) -		
Betsie River	14,240	51.5
b. Minor tributaries & immediate drainage (non-point load) -	150	0.5
c. Known municipal STP's -		
Elberta	2,160	7.8
Frankfort	11,040	40.0
d. Septic tanks - Unknown	?	-
e. Industrial - Unknown	?	-
f. Direct precipitation* -	40	0.2
Total	27,630	100.0

2. Outputs -

Lake outlet - to Lake Michigan 23,560

3. Net annual P accumulation - 4,070 pounds

* 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) -		
Betsie River	652,060	93.0
b. Minor tributaries & immediate drainage (non-point load) -	7,000	1.0
c. Known municipal STP's -		
Elberta	8,400	1.2
Frankfort	31,280	4.5
d. Septic tanks - Unknown	?	-
e. Industrial - Unknown	?	-
f. Direct precipitation* -	2,410	0.3
Total	701,150	100.0

2. Outputs -

Lake outlet - to Lake Michigan 588,590

3. Net annual N accumulation - 112,560 pounds

* See Working Paper No. 1.

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

Tributary	lbs $P/mi^2/yr$	lbs $N/mi^2/yr$	N/P Ratio
Betsie River	59	2,694	46/1

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	110.5	16.3	2,804.6	405.2
grams/m^2/yr	12.39	1.82	314.4	50.5

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

"Dangerous" (eutrophic rate)	3.30
"Permissible" (oligotrophic rate)	1.65

V. LITERATURE REVIEWED

Anonymous, 1972. Treatment plant questionnaires (Elberta and Frankfort STP's). MI Dept. of Publ. Health, Lansing.

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

Ketelle, Martha J., and Paul D. Uttormark, 1971. Problem lakes in the United States. EPA Water Poll. Contr. Res. Ser., Proj. #16010 EHR.

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	3.008	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	MEAN DISS P	MEAN INORG N	----------ALL VALUES---------- 500- MEAN SEC	MEAN CHLORA	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 2610 BETSIE LAKE

TOTAL DRAINAGE AREA OF LAKE(SQ MI) 245.00

TRIBUTARY	SUB-DRAINAGE AREA(SQ MI)	NORMALIZED FLOWS(CFS) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2610A1	245.00	268.00	270.00	398.00	735.00	439.00	336.00	267.00	245.00	268.00	290.00	350.00	321.00	348.76
2610A2	242.00	265.00	266.00	393.00	725.00	433.00	332.00	263.00	242.00	265.00	286.00	346.00	317.00	344.27
2610ZZ	3.00	3.00	4.00	5.00	10.00	6.00	4.00	4.00	3.00	3.00	4.00	4.00	4.00	4.50

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 245.00 TOTAL FLOW IN = 4187.00
SUM OF SUB-DRAINAGE AREAS = 245.00 TOTAL FLOW OUT = 4187.00

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
2610A1	10	72	302.00	29	322.00				
	11	72	320.00	27	335.00				
	12	72	270.00	29	260.00				
	1	73	316.00						
	2	73	275.00	3	337.00				
	3	73	470.00	3	423.00				
	4	73	634.00	8	625.00	29	577.00		
	5	73	426.00	13	438.00				
	6	73	339.00	14	318.00	26	298.00		
	7	73	259.00	14	256.00				
	8	73	236.00	12	230.00				
	9	73	251.00	8	237.00				
	10	73	275.00	3	265.00				
2610A2	10	72	298.00	29	318.00				
	11	72	316.00	27	331.00				
	12	72	267.00	29	257.00				
	1	73	312.00						
	2	73	272.00	3	333.00				
	3	73	464.00	3	418.00				
	4	73	626.00	8	618.00	29	570.00		
	5	73	421.00	13	433.00				
	6	73	335.00	14	314.00	26	294.00		
	7	73	256.00	14	253.00				
	8	73	233.00	12	227.00				
	9	73	248.00	8	234.00				
	10	73	272.00	3	262.00				

TRIBUTARY FLOW INFORMATION FOR MICHIGAN 2/3/75

LAKE CODE 2610 BETSIE LAKE

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
2610ZZ	10	72	4.00						
	11	72	4.00						
	12	72	3.00						
	1	73	4.00						
	2	73	3.00						
	3	73	6.00						
	4	73	8.00						
	5	73	5.00						
	6	73	4.00						
	7	73	3.00						
	8	73	3.00						
	9	73	3.00						
	10	73	3.00						

APPENDIX C

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 75/02/04

261001
47 37 48.0 086 14 06.0
BETSIE LAKE
26 MICHIGAN

11EPALES 2111202
3 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
72/06/17	15 14	0000	17.4	9.0	37	260	8.07	150	0.100	0.040	0.017	0.006
	15 14	0012	15.1	7.6		270	8.03	152	0.110	0.060	0.016	0.006
72/09/15	11 37	0000			24	303	7.95	145	0.130	0.030	0.036	0.014
	11 37	0004	17.4	9.0		305	7.95	145	0.140	0.040	0.046	0.014
	11 37	0015	17.4	8.8		300	7.98	144	0.130	0.030	0.031	0.013
72/11/12	15 30	0000			54	320	7.60	127	0.240	0.040	0.031	0.011
	15 30	0004	6.2	9.8		310	7.60	127	0.240	0.030	0.022	0.007
	15 30	0018	6.2	10.0		310	7.60	129	0.240	0.030	0.022	0.007

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/17	15 14	0000	1.3J
72/09/15	11 37	0000	11.3J
72/11/12	15 30	0000	1.1J

J VALUE KNOWN TO BE IN ERROR

APPENDIX D

TRIBUTARY and WASTEWATER TREATMENT PLANT DATA

STORET RETRIEVAL DATE 75/02/04

2610A1 LS2610A1
44 38 00.0 086 15 30.0
BETSIE LAKE
26163 15 FRANKFORT
0/BETSIE LAKE
2ND ST IN FRANKFORT
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
72/10/29	10 00		0.168	1.400	0.050	0.005K	0.031
72/11/27	16 40		0.280	1.050	0.046	0.014	0.035
72/12/29	10 10		0.290	0.390	0.042	0.011	0.025
73/02/03	08 11		0.270	0.610	0.026	0.011	0.022
73/03/03	07 50		0.330	0.260	0.039	0.008	0.020
73/04/08			0.210	0.370	0.050	0.009	0.025
73/04/29	12 30		0.132	1.470	0.058	0.010	0.040
73/05/13	15 25		0.154	0.420	0.079	0.011	0.045
73/06/14	09 00		0.029	0.660	0.009	0.005K	0.040
73/06/26	21 51		0.023	0.950	0.027	0.014	0.040
73/07/14	07 45		0.078	0.630	0.037	0.006	0.040
73/08/12	07 30		0.010K	0.460	0.007	0.005K	0.040
73/09/08	16 30		0.017	0.540	0.034	0.007	0.050
73/10/03	18 30		0.132	0.690	0.027	0.006	0.030

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

2610A2 LS2610A2
44 37 00.0 086 10 00.0
BETSIE RIVER
26 15 FRANKFORT
I/BETSIE LAKE
.25 MI BELO LEWIS BRDG BELOBENZONIA STP
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
72/10/29	10	25	0.870	0.500	0.120	0.005K	0.016
72/11/27	16	54	0.280	0.420	0.015	0.005K	0.011
72/12/29	10	25	0.273	1.760	0.260	0.005K	0.017
73/02/03	08	25	0.252	0.500	0.049	0.006	0.010
73/03/03	08	10	0.300	0.250	0.036	0.005K	0.015
73/04/08	12	00	0.210	0.490	0.056	0.007	0.020
73/04/29	12	34	0.126	2.100	0.065	0.007	0.020
73/05/13	15	00	0.130	0.480	0.022	0.005K	0.025
73/06/14	09	12	0.094	0.785	0.035	0.005K	0.035
73/06/26	22	05	0.120	0.580	0.020	0.010	0.035
73/07/14	08	00	0.120	0.520	0.065	0.005K	0.025
73/08/12	07	45	0.126	0.370	0.020	0.005K	0.025
73/09/08	16	25	0.200	0.660	0.052	0.005K	0.020

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

2610A3 LS2610A3
44 37 00.0 086 07 30.0
BETSIE RIVER
26 15 FRANKFORT
T/BETSIE LAKE
BRDG 1.25 W ST HWY 115 ABOVBENZONIA STP
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
72/11/27	17	05	0.280	0.380	0.009	0.005K	0.012
72/12/29	10	50	0.280	0.390	0.040	0.005K	0.005K
73/02/03	08	35	0.252	0.540	0.033	0.005K	0.010
73/03/03	08	20	0.300	0.240	0.034	0.005K	0.015
73/04/08	12	15	0.210	0.420	0.056	0.007	0.015
73/04/29	12	45	0.138	0.980	0.052	0.007	0.020
73/05/13	15	05	0.132	0.400	0.042	0.006	0.025
73/06/14	09	20	0.110	0.780	0.042	0.005K	0.032
73/06/26	22	16	0.147	1.680	0.030	0.011	0.030
73/07/14	08	10	0.126	0.460	0.052	0.005K	0.025
73/08/12	08	00	0.132	0.520	0.027	0.030	0.060
73/09/08	16	15	0.132	0.540	0.046	0.005K	0.030
73/10/03	18	55	0.140	0.820	0.027	0.005K	0.020

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

261081 LS261081
44 39 00.0 086 08 30.0
UNNAMED OUTLET CRYSTAL LAKE
26 15 FRANKFORT
T/BETSIE LAKE
ST HWY 115 BRDG 1.75 MI W BENZONIA
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
72/11/27	16 30		0.048	0.390	0.014	0.005K	0.008
72/12/29	09 50		0.070	1.540	0.025	0.005K	0.005K
73/02/03	08 00		0.075	0.520	0.020	0.005K	0.005K
73/03/03	07 45		0.069	0.120	0.017	0.005K	0.005K
73/04/08	11 15		0.062	0.140	0.018	0.005K	0.005K
73/04/29	12 35		0.048	0.850	0.028	0.005K	
73/05/13	15 35		0.054	1.050	0.082	0.005K	0.010
73/06/14	08 50		0.013	0.630	0.037	0.005K	0.010
73/06/26	21 38		0.017	0.540	0.027	0.006	0.006
73/07/14	07 30		0.016	0.260	0.038	0.005K	0.005K
73/08/12	07 20		0.010K	0.420	0.016	0.005K	0.010
73/09/08	16 50		0.014	1.200	0.077	0.007	0.010
73/10/03	18 00		0.020	1.150	0.020	0.005K	0.005K

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

261050 PR261050 P000545
44 37 00.0 086 10 00.0
ELBERTA
26163 15 FRANKFORT
D/BETSIE LAKE
BETSIE 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
73/01/29	08	10	1.500	15.000	1.370	2.100	4.200	0.147	0.132
73/02/28	08	00							
CP(T)-			1.000	24.000	5.200	2.800	5.100	0.129	0.139
73/02/28	17	00							
73/04/05	08	00							
CP(T)-			1.500	22.000	4.100	3.200	6.800	0.140	0.139
73/04/05	13	00							
73/05/14	08	00							
CP(T)-			0.990	14.400	0.150	2.300	5.700	0.132	0.139
73/05/14	17	00							
73/06/04	08	00							
CP(T)-			1.570	20.000	3.760	3.060	5.700	0.155	0.141
73/06/04	17	00							
73/07/12	07	00							
CP(T)-			1.540	16.800	1.760	2.100	3.450	0.165	0.160
73/07/12	17	00							
73/09/19	08	00							
CP(T)-			5.400	16.300	3.320	2.400	6.500	0.110	0.125
73/09/19	17	00							
73/10/18	08	00							
CP(T)-			0.010K	21.000	8.600	3.300	4.400	0.110	0.155
73/10/18	17	00							
73/11/26	09	00							
CP(T)-			0.660	19.500	2.770	2.970	5.600	0.112	0.116
73/11/26	12	00							
74/03/12	09	00							
CP(T)-			2.000	11.000	0.240	2.000	5.900	0.124	0.130
74/03/12	16	00							
74/04/21	09	00							
CP(T)-			1.480	26.000	0.630	2.200	4.400	0.121	0.123
74/04/21	16	00							
74/05/28	14	30	1.240	22.000	4.000	3.300	8.100	0.207	0.158
74/06/24	15	00	1.600	9.400	0.015	1.480	4.500	0.248	0.236

STORET RETRIEVAL DATE 75/02/04

261051 PR261051 P001750
44 38 00.0 086 10 00.0
FRANKFORT
26 15 FRANKFORT
D/BETSIE LAKE
BETSIE 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
73/01/25	08 00								
CP(T)-			1.500	19.900	2.100	3.100	6.860	0.513	0.420
73/01/25	17 00								
63/02/12	08 00								
CP(T)-			1.700	24.000	3.700	3.100	7.500	0.394	0.464
73/02/12	05 00								
73/03/06	08 00								
CP(T)-			1.500	20.000	1.470	2.900	8.300	0.472	0.406
73/03/06	17 00								
73/04/16	08 30								
CP(T)-			0.980	17.000	1.160	2.600	5.900	0.488	0.474
73/04/16	16 15								
73/05/21	08 00								
CP(T)-			1.000	31.000	2.400	4.300	10.080	0.510	0.460
73/05/21	16 30								
73/06/29	08 30								
CP(T)-			1.000	24.000	6.100	3.400	6.800	0.437	0.474
73/06/29	16 30								
73/07/10	08 00								
CP(T)-			0.018	32.600	3.040	7.500	13.500	0.328	0.368
73/07/10	16 30								
73/08/08	08 30								
CP(T)-			0.130	22.000	3.400	3.620	7.000	0.492	0.431
73/08/08	16 00								
73/09/10	08 15								
CP(T)-			0.110	26.000	4.800	5.100	9.700	0.368	0.438
73/09/10	16 30								
73/10/08	08 30								
CP(T)-			0.280	26.000	9.550	6.400	10.000	0.367	0.336
73/10/08	16 45								
73/11/05	08 15								
CP(T)-			0.130	27.000	7.400	5.100	9.900	0.388	0.351
73/11/05	16 40								
73/12/07	08 20								
CP(T)-			1.260	25.000	3.000	5.800	10.500	0.400	0.377
73/12/07	16 40								

STORET RETRIEVAL DATE 75/02/04

261051 PR261051 P001750
44 38 00.0 086 10 00.0
FRANKFORT
26 15 FRANKFORT
D/BETSIE LAKE
BETSIE 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
74/01/10	08 30								
CP(T)-			0.440	21.000	1.400	5.800	10.500	0.351	0.379
74/01/10	16 45								