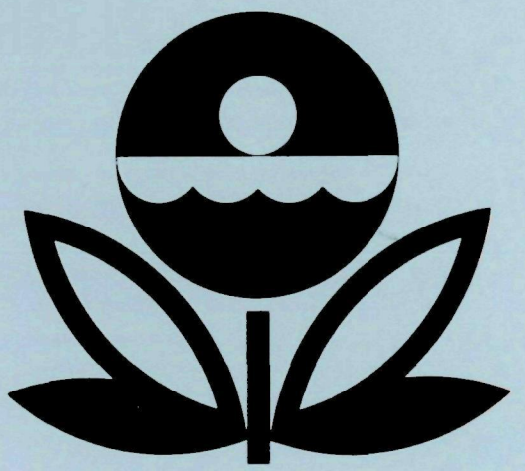
U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL EUTROPHICATION SURVEY

WORKING PAPER SERIES



REPORT

ON

RAINBOW LAKE

NAVAJO COUNTY

ARIZONA

EPA REGION IX

WORKING PAPER No. 734

CORVALLIS ENVIRONMENTAL RESEARCH LABORATORY - CORVALLIS, OREGON

and

ENVIRONMENTAL MONITORING & SUPPORT LABORATORY - LAS VEGAS, NEVADA

REPORT
ON
RAINBOW LAKE
NAVAJO COUNTY
ARIZONA
EPA REGION IX
WORKING PAPER No. 734

WITH THE COOPERATION OF THE
ARIZONA STATE DEPARTMENT OF HEALTH
AND THE
ARIZONA NATIONAL GUARD
AUGUST, 1977

REPORT ON RAINBOW LAKE

NAVAJO COUNTY, ARIZONA

EPA REGION IX

by

National Eutrophication Survey

Water and Land Quality Branch
Monitoring Operations Division
Environmental Monitoring & Support Laboratory
Las Vegas, Nevada

and

Special Studies Branch
Corvallis Environmental Research Laboratory
Corvallis, Oregon

Working Paper No. 734

OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY

August 1977

CONTENTS

FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to freshwater 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 nonpoint 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 freshwater 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 the U.S. Environmental Protection Agency and to augment plans implementation by the states.

ACKNOWLEDGMENTS

The staff of the National Eutrophication Survey (Office of Research and Development, U.S. Environmental Protection Agency) expresses sincere appreciation to the Arizona State Department of Health for professional involvement, to the Arizona National Guard for conducting the tributary sampling phase of the Survey, and to those Arizona wastewater treatment plant operators who provided effluent samples and flow data.

The staffs of the Bureau of Water Quality Control, Environmental Health Services, Arizona State Department of Health, and the Arizona Game and Fish Department, provided invaluable lake documentation and counsel during the Survey, reviewed the preliminary reports and provided critiques most useful in the preparation of this Working Paper Series.

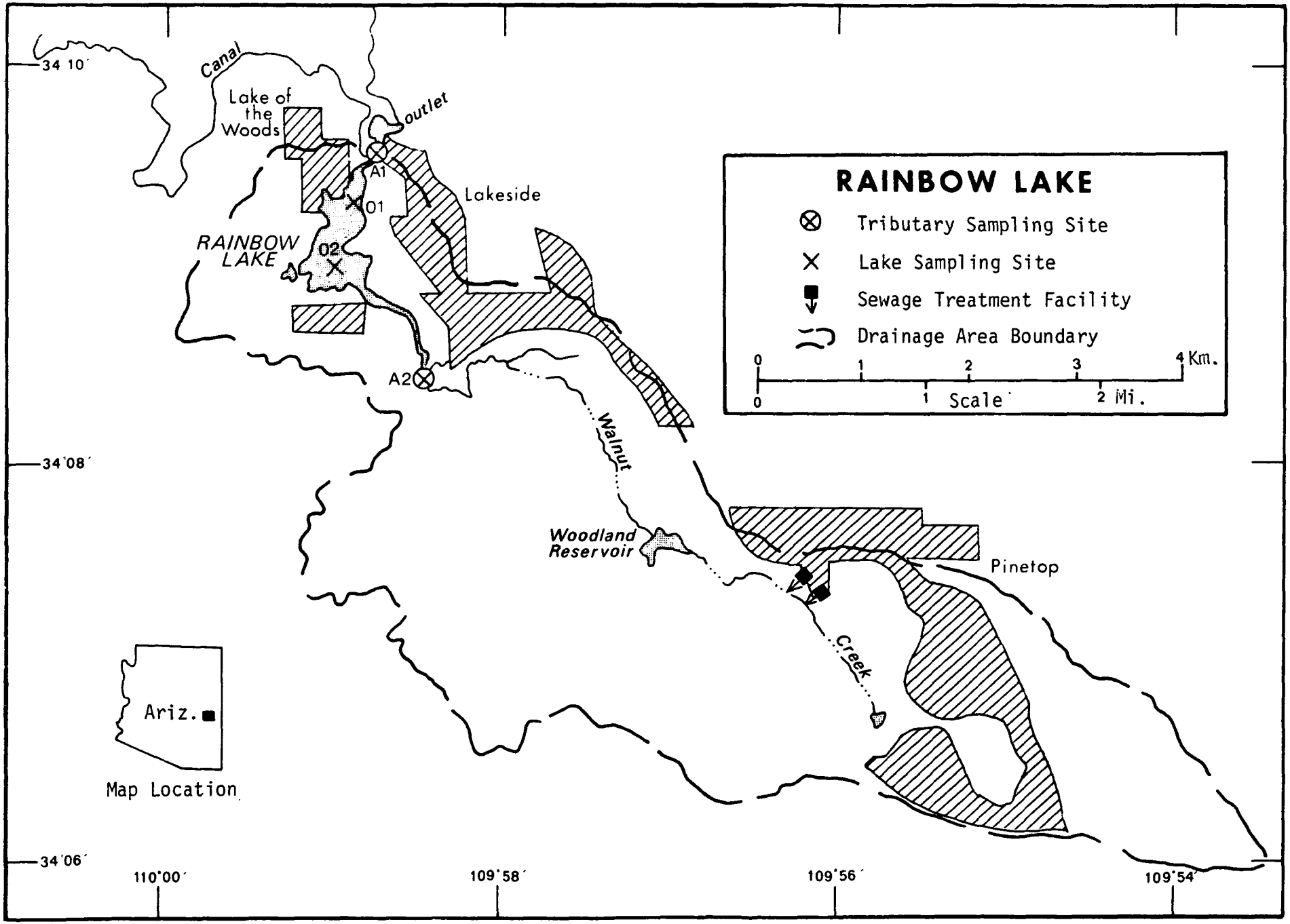
Major General John G. Smith, the Adjutant General of Arizona, and Project Officer Colonel Richard A. Colson, who directed the volunteer efforts of the Arizona National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

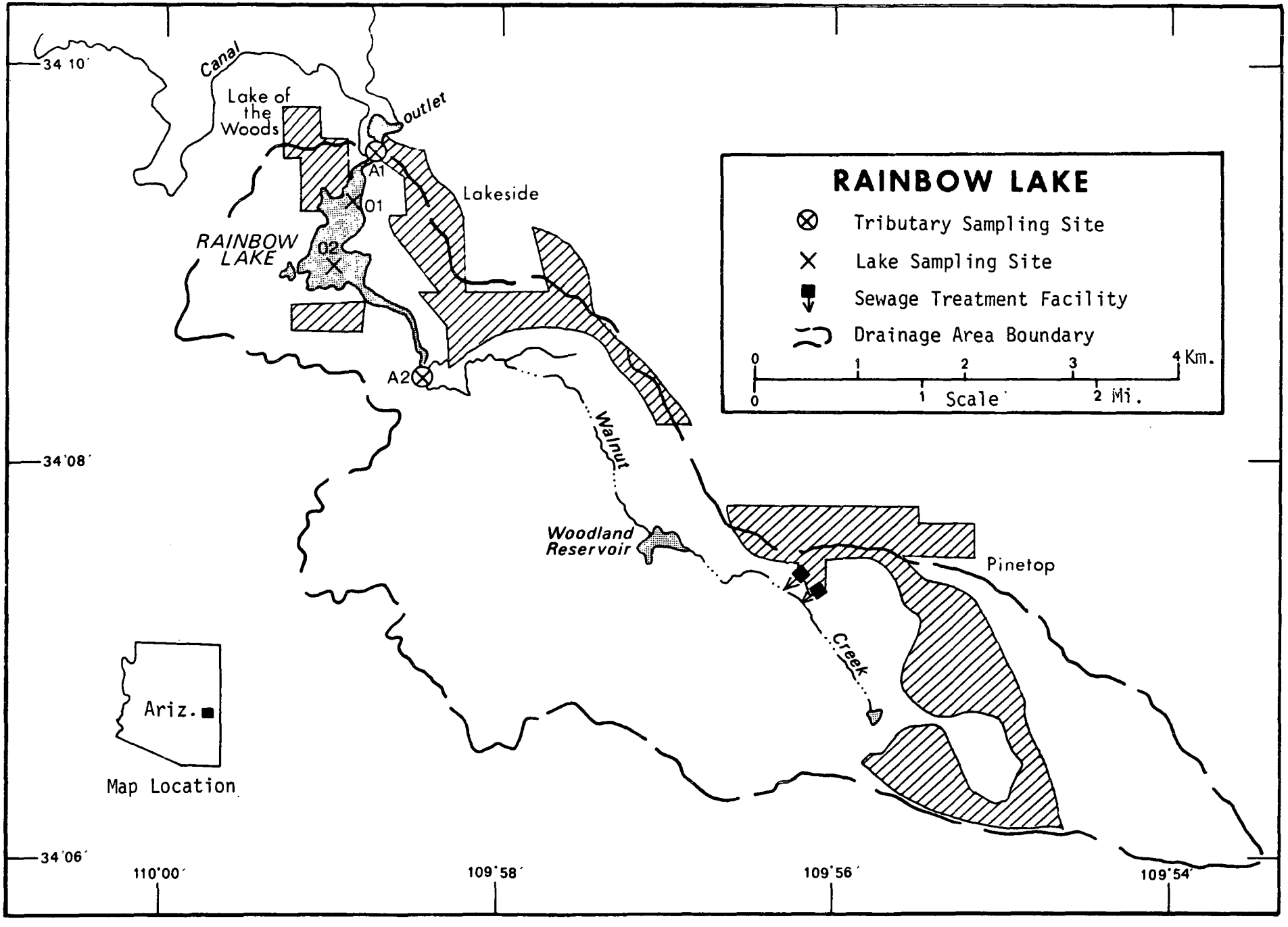
NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF ARIZONA

LAKE NAME	COUNTY
Big Lake	Apache
Fools Hollow Lake	Navajo
Lake Havasu	Mohave (San Bernadino in CA)
Luna Lake	Apache
Lyman Lake	Apache
Lake Mohave	Mohave (Clark in NV)
Lake Pleasant	Yavapai, Maricopa
Lake Powell	Coconino (Kane, Garfield, San Juan in UT)
Rainbow Lake	Navajo
Theodore Roosevelt Lake	Gila
San Carlos Reservoir	Graham, Gila, Pinal


RAINBOW LAKE
Tributary Sampling Site
Lake Sampling Site
Sewage Treatment Facility
Drainage Area Boundary
0 1 2 3 4 Km.
0 1 Scale 2 Mi.
34°10'
34°08'
34°06'
110°00'
109°58'
109°56'
109°54'
Canal
Lake of the Woods
Outlet
A1
O1
Lakeside
RAINBOW LAKE
O2
A2
Walnut
Creek
Woodland Reservoir
Pinetop
Ariz.
Map Location


RAINBOW LAKE
Tributary Sampling Site
Lake Sampling Site
Sewage Treatment Facility
Drainage Area Boundary
0 1 2 3 4 Km.
0 1 2 Mi.
Scale
34°10'
34°08'
34°06'
110°00'
109°58'
109°56'
109°54'
Canal
Lake of the Woods
Outlet
A1
O1
Lakeside
RAINBOW LAKE
O2
A2
Walnut
Creek
Woodland Reservoir
Pinetop
Ariz.
Map Location

REPORT ON RAINBOW LAKE, ARIZONA

STORET NO. 0409

I. CONCLUSIONS

A. Trophic Condition:*

On the basis of field observations and Survey data, Rainbow Lake is considered eutrophic, i.e., nutrient rich and highly productive. Whether such nutrient enrichment is to be considered beneficial or deleterious is determined by its actual or potential impact upon designated beneficial water uses of each lake.

Chlorophyll a levels in the lake ranged from 2.0 µg/l to 47.7 µg/l with a mean of 16.4 µg/l. Secchi disc transparency was low during spring sampling and potential for primary production as measured by algal assay control yield was high in both spring and fall. Of the 11 Arizona lakes sampled in 1975, 4 had higher median total phosphorus values (0.046 mg/l), 8 had higher median inorganic nitrogen levels (0.045 mg/l) and 4 had higher median orthophosphorus values (0.009 mg/l) than Rainbow Lake.

Survey limnologists reported severe macrophyte problems in Rainbow Lake. Submerged weeds were observed over most of the lake bottom on all sampling occasions, and floating macrophytes were noted to cover 50-60% of the lake during

*See Appendix E.

June and October. Other sources report that the lake also experiences some problem algal growths as a result of septic tank seepage (A.C. Hunt, personal communication) and dissolved oxygen levels below the state standard for maintenance of a cold water fishery (Arizona Department of Health Services, 1976).

B. Rate-Limiting Nutrient:

The algal assay results indicate that Rainbow Lake was limited by available nitrogen during the spring sampling (03/04/75) and co-limited by both nitrogen and phosphorus during the October sampling (10/01/75). Lake data suggest primary limitation by nitrogen throughout the sampling year.

C. Nutrient Controllability:

1. Point sources -

During the sampling year there was one known point source impacting Rainbow Lake which participated in the Survey. This source, Charlie Clark's Restaurant, contributed an estimated 3.0% of the total phosphorus load to the lake. In addition, there are a number of small municipal and domestic plants that are located in the communities of Lakeside and Pinetop which did not participate in the 1975 Survey. The State of Arizona considers three of these plants to be significant dischargers: the Pine Shadow Mobile Home Park, the El Rancho Restaurant, and the Pinetop Country Club Village, all in the community of

Pinetop (Arizona Department of Health Services, 1976). Because data on the nutrient discharges from the plants are not available, these sources are not listed in the lake nutrient budget on pages 14-15; however, their nutrient loads are included in the tributary loadings for Walnut Creek. A sewage treatment facility is planned for the Pinetop-Lakeside area which will pump effluent to dry lake beds outside of the drainage basin of Rainbow Lake. This facility may reduce nutrient loadings to the lake from the above mentioned sources as well as from septic tanks in the area (W. H. Shafer, personal communication).

The present calculated loading of 2.17 g $P/m^2/yr$ is over three times that proposed by Vollenweider (1975) as a "eutrophic" rate for a lake with such volume and hydraulic retention time. Unless the annual phosphorus loading can be reduced, Rainbow Lake can be expected to exhibit progressive symptoms of eutrophication.

2. Nonpoint sources -

Walnut Creek contributed 82.7% of the total phosphorus load to Rainbow Lake during the sampling year and ungaged drainage areas were estimated to have contributed 15.5% of the total. It is not known at this time how much of the "nonpoint" loading attributed to Walnut Creek is actually a result of unmeasured point source contributions; however, the Arizona Department of Health Services (1976) states that discharges from package plants

in the Little Colorado River Basin often are the entire flow of their receiving waters, creating considerable health and environmental problems.

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

Lake and drainage basin characteristics are itemized below. Lake morphometry data were provided by Ned Rathbun (1974); average surface area and maximum volume at spillway are indicated. Tributary flow data were provided by the Arizona District Office of the U.S. Geological Survey (USGS). Outlet drainage area includes the lake surface area. Mean hydraulic retention time was found by dividing the lake volume by mean flow of the outlet. Precipitation values are estimated by methods as outlined in National Eutrophication Survey (NES) Working Paper No. 175. A table of metric/English conversions is included as Appendix A.

A. Lake Morphometry:

1. Surface area: 0.32 km^2.
2. Mean depth: 4.6 meters.
3. Maximum depth: 5.0 meters.
4. Volume: 1.479 x 10^6 m^3.
5. Mean hydraulic retention time: 171 days.

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

1. Tributaries -

Name	Drainage area (km^2)	Mean Flow (m^3/sec)
A-2 Walnut Creek	21.8	0.25
Minor tributaries and immediate drainage -	4.1	0.04
Totals	25.9	0.29
2. Outlets - A-1 Walnut Creek	26.2	0.10

C. Precipitation:

1. Year of sampling: 33.4 cm.
2. Mean annual: 27.9 cm.

III. LAKE WATER QUALITY SUMMARY

Rainbow Lake was sampled three times during the open-water season of 1975 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 one or more depths at each station (see map, page v). During each visit, depth-integrated samples were collected from each station for chlorophyll a analysis and phytoplankton identification and enumeration. During the first and last visits, 18.9-liter depth-integrated samples were composited for algal assays. Maximum depths sampled were 2.7 meters at Station 01 and 2.4 meters at Station 02. For a more detailed explanation of NES methods, see NES Working Paper No. 175.

The results obtained are presented in full in Appendix C and are summarized in III-A for waters at the surface and at the maximum depth for each site. Results of the phytoplankton counts and chlorophyll a determinations are included in III-B. Results of the limiting nutrient study are presented in III-C.

RAINBOW LAKE
STORET CODE 0409

A. PHYSICAL AND CHEMICAL CHARACTERISTICS

PARAMETER	(3/ 4/74) S*** = 1 N*	RANGE	MEDIAN	MAX DEPTH RANGE (METERS)	(3/ 4/75) S*** = 2 N*	RANGE	MEDIAN	MAX DEPTH RANGE (METERS)	(6/19/75) S*** = 2 N*	RANGE	MEDIAN	MAX DEPTH RANGE (METERS)
TEMPERATURE (DEG CENT)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	5.2- 5.4	5.3	0.0- 1.5	3	15.2- 15.5	15.5	0.0- 1.5
MAX DEPTH**	0	*****-*****	*****	*****-*****	2	4.8- 5.6	5.2	2.4- 2.7	2	15.1- 15.5	15.3	1.5- 2.1
DISSOLVED OXYGEN (MG/L)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	10.0- 10.2	10.0	0.0- 1.5	3	7.4- 7.4	7.4	0.0- 1.5
MAX DEPTH**	0	*****-*****	*****	*****-*****	2	10.0- 10.2	10.1	2.4- 2.7	2	6.6- 7.4	7.0	1.5- 2.1
CONDUCTIVITY (UMHOS)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	236.- 248.	242.	0.0- 1.5	3	155.- 159.	159.	0.0- 1.5
MAX DEPTH**	0	*****-*****	*****	*****-*****	2	239.- 239.	239.	2.4- 2.7	2	159.- 168.	164.	1.5- 2.1
PH (STANDARD UNITS)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	8.6- 8.6	8.6	0.0- 1.5	2	10.1- 10.1	10.1	0.0- 0.0
MAX DEPTH**	0	*****-*****	*****	*****-*****	2	8.5- 8.6	8.6	2.4- 2.7	1	10.0- 10.0	10.0	2.1- 2.1
TOTAL ALKALINITY (MG/L)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	117.- 118.	118.	0.0- 1.5	2	82.- 97.	90.	0.0- 0.0
MAX DEPTH**	1	119.- 119.	119.	2.7- 2.7	1	116.- 116.	116.	2.4- 2.4	1	98.- 98.	98.	2.1- 2.1
TOTAL P (MG/L)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	0.023-0.052	0.027	0.0- 1.5	2	0.046-0.047	0.046	0.0- 0.0
MAX DEPTH**	1	0.033-0.033	0.033	2.7- 2.7	1	0.061-0.061	0.061	2.4- 2.4	1	0.085-0.085	0.085	2.1- 2.1
DISSOLVED ORTHO P (MG/L)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	0.005-0.007	0.006	0.0- 1.5	2	0.014-0.019	0.016	0.0- 0.0
MAX DEPTH**	1	0.014-0.014	0.014	2.7- 2.7	1	0.008-0.008	0.008	2.4- 2.4	1	0.020-0.020	0.020	2.1- 2.1
NO2+NO3 (MG/L)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	0.020-0.020	0.020	0.0- 1.5	2	0.020-0.030	0.025	0.0- 0.0
MAX DEPTH**	1	0.020-0.020	0.020	2.7- 2.7	1	0.020-0.020	0.020	2.4- 2.4	1	0.020-0.020	0.020	2.1- 2.1
AMMONIA (MG/L)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	0.020-0.030	0.025	0.0- 1.5	2	0.030-0.060	0.045	0.0- 0.0
MAX DEPTH**	1	0.020-0.020	0.020	2.7- 2.7	1	0.020-0.020	0.020	2.4- 2.4	1	0.030-0.030	0.030	2.1- 2.1
KJELDAHL N (MG/L)												
0.-1.5 M DEPTH	0	*****-*****	*****	*****-*****	4	0.400-0.700	0.550	0.0- 1.5	2	0.500-0.600	0.550	0.0- 0.0
MAX DEPTH**	1	0.500-0.500	0.500	2.7- 2.7	1	0.500-0.500	0.500	2.4- 2.4	1	0.600-0.600	0.600	2.1- 2.1
SECCHI DISC (METERS)												
	0	*****-*****	*****		2	0.7- 1.1	0.9		0	*****-*****	*****	

* N = NO. OF SAMPLES
** MAXIMUM DEPTH SAMPLED AT EACH SITE
*** S = NO. OF SITES SAMPLED ON THIS DATE

RAINBOW LAKE
STORET CODE 0409

A. PHYSICAL AND CHEMICAL CHARACTERISTICS

(10/ 1/75)

*** = 2

PARAMETER	N*	RANGE	MEDIAN	MAX DEPTH RANGE (METERS)
TEMPERATURE (DEG CENT)				
0.-1.5 M DEPTH	3	13.8- 15.7	15.6	0.0- 1.5
MAX DEPTH**	2	13.8- 15.6	14.7	0.0- 1.5
DISSOLVED OXYGEN (MG/L)				
0.-1.5 M DEPTH	3	3.0- 5.0	4.4	0.0- 1.5
MAX DEPTH**	2	3.0- 4.4	3.7	0.0- 1.5
CONDUCTIVITY (UMHOS)				
0.-1.5 M DEPTH	3	165.- 179.	178.	0.0- 1.5
MAX DEPTH**	2	165.- 179.	172.	0.0- 1.5
PH (STANDARD UNITS)				
0.-1.5 M DEPTH	3	8.6- 8.8	8.6	0.0- 1.5
MAX DEPTH**	2	8.6- 8.8	8.7	0.0- 1.5
TOTAL ALKALINITY (MG/L)				
0.-1.5 M DEPTH	3	120.- 120.	120.	0.0- 1.5
MAX DEPTH**	2	120.- 120.	120.	0.0- 1.5
TOTAL P (MG/L)				
0.-1.5 M DEPTH	3	0.043-0.118	0.062	0.0- 1.5
MAX DEPTH**	2	0.043-0.118	0.080	0.0- 1.5
DISSOLVED ORTHO P (MG/L)				
0.-1.5 M DEPTH	3	0.006-0.018	0.011	0.0- 1.5
MAX DEPTH**	2	0.006-0.018	0.012	0.0- 1.5
NO2+NO3 (MG/L)				
0.-1.5 M DEPTH	3	0.020-0.020	0.020	0.0- 1.5
MAX DEPTH**	2	0.020-0.020	0.020	0.0- 1.5
AMMONIA (MG/L)				
0.-1.5 M DEPTH	3	0.020-0.040	0.020	0.0- 1.5
MAX DEPTH**	2	0.020-0.020	0.020	0.0- 1.5
KJELDAHL N (MG/L)				
0.-1.5 M DEPTH	3	0.600-0.600	0.600	0.0- 1.5
MAX DEPTH**	2	0.600-0.600	0.600	0.0- 1.5
SECCHI DISC (METERS)				
	2	1.8- 2.4	2.1	

* N = NO. OF SAMPLES
** MAXIMUM DEPTH SAMPLED AT EACH SITE
*** S = NO. OF SITES SAMPLED ON THIS DATE

B. Biological Characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Algal Units Per ml
03/04/75	1. Cyclotella	52,327
	2. Chroomonas?	706
	3. Cryptomonas	680
	4. Oocystis	419
	5. Ankistrodesmus	419
	Other genera	1,125
	Total	55,676
06/19/75	1. Fragilaria	17,976
	2. Epithemia	618
	3. Cryptomonas	353
	4. Chroomonas?	265
	5. Cocconeis	132
	Other genera	398
	Total	19,742
10/06/75	1. Fragilaria	3,821
	2. Chroomonas?	303
	3. Cryptomonas	243
	4. Epithemia	121
	5. Cocconeis	30
	Other genera	62
	Total	4,580

2. Chlorophyll *a* -

Sampling Date	Station Number	Chlorophyll *a* (µg/l)
03/04/75	01	8.1
	02	18.3
06/19/75	01	11.2
	02	47.7
10/01/75	01	10.9
	02	2.0

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

a. 03/04/75

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum Yield (mg/l-dry wt.)
Control	0.020	0.080	4.0
0.05 P	0.070	0.080	4.7
0.05 P + 1.0 N	0.070	1.080	21.9
1.00 N	0.020	1.080	8.0

b. 10/01/75

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum Yield (mg/l-dry wt.)
Control	0.020	0.115	4.8
0.05 P	0.070	0.115	6.9
0.05 P + 1.0 N	0.070	1.115	35.6
1.00 N	0.020	1.115	5.5

2. Discussion -

The control yields of the assay alga, Selenastrum capricornutum*, indicate that the potential for primary productivity in Rainbow Lake was high at both sample collection times (03/04/75, 10/01/75). In the March assay, the addition of nitrogen alone and in combination with phosphorus produced a significant increase in growth over that of the control, indicating nitrogen limitation at this time. In the October assay, a small growth response was noted with the addition of both nitrogen and phosphorus alone, and with the simultaneous addition of both nutrients, suggesting colimitation by nitrogen and phosphorus.

The mean inorganic nitrogen to orthophosphorus ratios (N/P) in the lake data were approximately 5/1 in the spring and 4/1 in the summer and fall suggesting primary limitation by nitrogen (a mean N/P ratio of 14/1 or greater generally reflects phosphorus limitation).

*For further information regarding the algal assay test procedure and selection of test organisms, see U.S. EPA (1971).

IV. NUTRIENT LOADINGS
(See Appendix D for data)

For the determination of nutrient loadings, the Arizona 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. Sampling was begun in December 1974, and was completed in November 1975.

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

In this report, nutrient loads for sampled tributaries were determined by using a modification of a USGS computer program for calculating stream loadings. Nutrient loads indicated for tributaries are those measured minus known point source loads, if any.

Nutrient loadings for unsampled "minor tributaries and immediate drainage" ("ZZ" of USGS) were estimated by using the mean annual nutrient loads, in $kg/km^2/year$, in Walnut Creek at Station A-2 and multiplying the means by the ZZ area in km^2.

The operator of the Charlie Clark's Restaurant provided several monthly effluent samples and corresponding flow data.

A. Waste Sources:

1. Known municipal -

Name	Pop.* Served	Treatment*	Mean Flow ($m^3/d \times 10^3$)	Receiving Water
Charlie Clark's Restaurant	100	Activated Sludge	0.038**	Unnamed Creek/ Walnut Creek

2. Known industrial - None

*Provided by treatment plant operator.
**Estimated at 0.3785 m^3/capita/day.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	kg P/yr	% of total
a. Tributaries (nonpoint load) -		
A-2 Walnut Creek	565	81.3
b. Minor tributaries and immediate drainage (nonpoint load) -	105	15.2
c. Known municipal STP's -		
Charlie Clark's Restaurant	10	1.4
d. Septic tanks* -	10	1.4
e. Known industrial - None		
f. Direct precipitation** -	5	0.7
Total	695	100.0%

2. Outputs - A-1 Walnut Creek 340

3. Net annual P accumulation - 355

*Estimate based on 41 lakeshore residences.
**Estimated (See NES Working Paper No. 175).

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	kg N/yr	% of total
a. Tributaries (nonpoint load) -		
A-2 Walnut Creek	8,625	75.9
b. Minor tributaries and immediate drainage (nonpoint load) -	1,625	14.3
c. Known municipal STP's -		
Charlie Clark's Restaurant	340	3.0
d.. Septic tanks* -	435	3.8
e. Known industrial - None		
f. Direct precipitation** -	345	3.0
Total	11,370	100.0%

2. Outputs - A-1 Walnut Creek 6,000

3. Net annual N accumulation - 5,370

*Estimate based on 41 lakeshore residences.
**Estimated (See NES Working Paper No. 175).

D. Mean Annual Nonpoint Nutrient Export by Subdrainage Area:

Tributary	kg P/km^2/yr	kg N/km^2/yr
Walnut Creek	26	396

E. Mean Nutrient Concentrations in Ungaged Streams:

Tributary	Mean Total P (mg/l)	Mean Total N (mg/l)
*1-B Trout Creek	0.060	1.147
*1-C Gooseberry Creek	0.061	0.767

*Special interest stream outside the Rainbow Lake watershed.

E. Yearly Loading:

In the following table, the existing phosphorus loading is compared to the relationship proposed by Vollenweider (1975). Essentially, his "eutrophic" loading is that at which the receiving waters would become eutrophic or remain eutrophic; his "oligotrophic" loading is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A "mesotrophic" loading would be considered one between "eutrophic" and "oligotrophic".

Note that Vollenweider's model may not be applicable to water bodies with very short retention times or in which light penetration is severely restricted from high concentrations of suspended solids in the surface waters.

	Total Yearly Phosphorus Loading ($g/m^2/yr$)
Estimated loading for Rainbow Lake	2.17
Vollenweider's "eutrophic" loading	0.61
Vollenweider's "oligotrophic" loading	0.31

V. LITERATURE REVIEWED

Arizona Department of Health Services. 1976. Water Quality Management Basin Plan, Little Colorado River Basin, Arizona. Phoenix, Arizona.

Hunt, A. C. 1976. Personal Communication (septic tanks). Pinetop-Lakeside Sanitation District, Pinetop, Arizona.

Rathbun, Ned L. 1974. Personal Communication (morphometry data). Arizona Game and Fish Department, Phoenix, Arizona.

Shafer, W. H. Personal Communication (lake nutrient loadings). Arizona Department of Health Services, Phoenix, Arizona.

U.S. Environmental Protection Agency. 1971. Algal Assay Procedure Bottle Test. National Eutrophication Research Program, Corvallis, Oregon.

U.S. Environmental Protection Agency. 1975. National Eutrophication Survey Methods 1973-1976. Working Paper No. 175. National Environmental Research Center, Las Vegas, Nevada, and Pacific Northwest Environmental Research Laboratory, Corvallis, Oregon.

Vollenweider, R. A. 1975. Input-Output Models With Special Reference to the Phosphorus Loading Concept in Limnology. Schweiz. Z. Hydrol. 37:53-84.

VI. APPENDICES

APPENDIX A

CONVERSION FACTORS

CONVERSION FACTORS

Hectares x 2.471 = acres

Kilometers x 0.6214 = miles

Meters x 3.281 = feet

Cubic meters x 8.107×10^{-4} = acre/feet

Square kilometers x 0.3861 = square miles

Cubic meters/sec x 35.315 = cubic feet/sec

Centimeters x 0.3937 = inches

Kilograms x 2.205 = pounds

Kilograms/square kilometer x 5.711 = lbs/square mile

APPENDIX B

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR ARIZONA 11/26/76

LAKE CODE 0409 RAINBOW LAKE

TOTAL DRAINAGE AREA OF LAKE(SQ KM) 26.2

TRIBUTARY	SUB-DRAINAGE AREA(SQ KM)	NORMALIZED FLOWS(CMS) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
0409A1	26.2	0.198	0.340	0.198	0.028	0.014	0.0	0.014	0.028	0.028	0.085	0.085	0.198	0.100
0409A2	21.8	0.425	0.566	0.425	0.142	0.085	0.057	0.085	0.142	0.113	0.283	0.283	0.425	0.251
0409ZZ	4.4	0.057	0.085	0.057	0.028	0.028	0.014	0.028	0.042	0.028	0.057	0.057	0.057	0.045

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 26.2
SUM OF SUB-DRAINAGE AREAS = 26.2
TOTAL FLOW IN = 3.57
TOTAL FLOW OUT = 1.22

MEAN MONTHLY FLOWS AND DAILY FLOWS(CMS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
0409A1	12	74	0.0	7	0.0				
	1	75	0.0	5	0.0				
	2	75	0.028	1	0.0				
	3	75	0.340	8	0.425				
	4	75	0.425	12	0.566	29	0.048		
	5	75	0.113	11	0.042	26	0.057		
	6	75	0.085	8	0.085				
	7	75	0.085	6	0.085				
	8	75	0.085	23	0.085				
	9	75	0.028	7	0.057				
	10	75	0.085	12	0.071				
	11	75	0.028	16	0.003				
0409A2	12	74	0.085	7	0.085				
	1	75	0.113	5	0.099				
	2	75	0.425	1	0.198				
	3	75	0.566	8	0.566				
	4	75	0.425	12	0.708	29	0.076		
	5	75	0.085	11	0.071	26	0.057		
	7	75	0.071	6	0.057				
	8	75	0.085	23	0.057				
	9	75	0.085	7	0.113				
	10	75	0.085	12	0.071				
	11	75	0.085	16	0.071				
	16	75	0.057	8	0.057				
0409ZZ	12	74	0.028						
	1	75	0.028						
	2	75	0.057						
	3	75	0.057						
	4	75	0.057						
	5	75	0.028						
	6	75	0.014						
	7	75	0.028						
	8	75	0.028						
	9	75	0.028						
	10	75	0.028						
	11	75	0.028						

APPENDIX C

PHYSICAL AND CHEMICAL DATA

STORET RETRIEVAL DATE 76/11/26
NATL EUTROPHICATION SURVEY
EPA-LAS VEGAS

040901
34 09 22.0 109 58 57.0 3
RAINBOW LAKE
04017 ARIZONA

110492

11EPALES 2111202
0011 FEET DEPTH CLASS 00

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	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
74/03/04	15 35	0009						119	0.020	0.500	0.020K	0.014
75/03/04	15 35	0000	5.2	10.0	42	248	8.65	118	0.020	0.600	0.020K	0.005
	15 35	0005	5.3	10.2		241	8.65	118	0.030	0.400	0.020K	0.005
	15 35	0009	5.6	10.2		239	8.65					
75/06/19	11 20	0000	15.5	7.4		159	10.15	82	0.060	0.500	0.030	0.014
	11 20	0005	15.5	7.4		159						
75/10/01	16 45	0000	15.7	5.0	96	178	8.60	120	0.040	0.600	0.020K	0.011
	16 45	0005	15.6	4.4		179	8.60	120	0.020K	0.600	0.020K	0.018

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
74/03/04	15 35	0009	0.033		
75/03/04	15 35	0000	0.023	8.1	
	15 35	0005	0.025		
75/06/19	11 20	0000	0.047	11.2	
75/10/01	16 45	0000	0.062	10.9	
	16 45	0005	0.118		

K VALUE KNOWN TO BE LESS THAN INDICATED

STORET RETRIEVAL DATE 76/11/26
NATL EUTROPHICATION SURVEY
EPA-LAS VEGAS

040902
34 09 00.0 109 59 02.0 3
RAINBOW LAKE
04017 ARIZONA

110492

11EPALES 2111202
0012 FEET DEPTH CLASS 00

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	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
75/03/04	16 05	0000	5.4	10.0	27	242	8.65	117	0.030	0.700	0.020	0.007
	16 05	0005	5.3	10.0		236	8.60	117	0.020	0.500	0.020K	0.007
	16 05	0008	4.8	10.0		239	8.55	116	0.020	0.500	0.020K	0.006
75/06/19	11 30	0000	15.2	7.4		155	10.10	97	0.030	0.600	0.020K	0.019
	11 30	0007	15.1	6.6		168	10.05	98	0.030	0.600	0.020K	0.020
75/10/01	16 55	0000	13.8	3.0	72	165	8.75	120	0.020	0.600	0.020K	0.006

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
75/03/04	16 05	0000	0.052	18.3	
	16 05	0005	0.029		
	16 05	0008	0.061		
75/06/19	11 30	0000	0.046	47.7	
	11 30	0007	0.085		
75/10/01	16 55	0000	0.043	2.0	

K VALUE KNOWN TO BE LESS
THAN INDICATED

APPENDIX D

TRIBUTARY AND WASTEWATER TREATMENT PLANT DATA

STORET RETRIEVAL DATE 75/11/30
NATL EUTROPHICATION SURVEY
EPA- LAS VEGAS

0409A1
34 09 32.0 109 58 45.0 4
WALNUT CREEK
04 15 MCNARY
0/RAINBOW LAKE 110492
RT 173 BRDG BTWN LK OF THE WOODS/LKSIDE
11EPALES 2111204
0000 FEET DEPTH CLASS 00

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
74/12/07	10 35		2.800	1.400	0.020	0.035	0.140
75/02/01	12 20		0.016	0.600	0.040	0.008	0.050
75/03/08	09 30		0.008	1.800	0.032	0.008	0.040
75/04/12	15 40		0.005	0.700	0.015	0.010	0.080
75/04/29	14 35		0.010	1.400	0.025	0.005K	0.060
75/05/11	14 30		0.020	1.300	0.030	0.020	0.040
75/05/26	12 30		0.010	0.900	0.015	0.010	0.030
75/06/08	15 30		0.005	0.450	0.035	0.010	0.020
75/07/06	15 30		0.020	0.800	0.030	0.040	0.080
75/08/23	15 20		0.005	0.650	0.055	0.060	0.120
75/09/07	17 45		0.005	1.000	0.070	0.060	0.100
75/10/12	13 00		0.005	0.500	0.025	0.015	0.050

K VALUE KNOWN TO BE LESS THAN INDICATED

STORET RETRIEVAL DATE 76/11/30
NATL EUTROPHICATION SURVEY
EPA- LAS VEGAS

0409A2
34 08 26.0 109 58 39.0 4
WALNUT CREEK
04 15 MCNARY
T/RAINBOW LAKE 110492
HIM RD BRDG .2 M W OF WOODLAND RD JCT
11EPALES 2111204
0000 FEET DEPTH CLASS 00

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
74/12/07	10	30	0.368	1.000	0.020	0.055	0.080
75/01/05	15	35	0.368	1.200	0.024	0.060	0.090
75/02/01	14	40	0.264	1.500	0.024	0.056	0.090
75/03/08	09	10	0.176	0.750	0.040	0.028	0.070
75/04/12	13	35	0.070	1.200	0.032	0.045	0.110
75/04/29	14	50	0.175	0.800	0.025	0.025	0.070
75/05/11	14	20	0.060	2.300	0.045	0.055	0.110
75/05/26	10	15	0.150	0.300	0.015	0.025	0.040
75/06/08	15	40	0.050	0.250	0.025	0.040	0.060
75/07/06	13	45	0.175	0.400	0.025	0.045	0.070
75/08/23	12	35	0.110	0.200	0.025	0.040	0.060
75/09/07	17	20	0.220	0.400	0.020	0.040	0.080
75/10/12	13	30	0.160	0.900	0.020	0.035	0.050
75/11/16	13	00	0.220	0.400	0.010	0.040	0.060

STORET RETRIEVAL DATE 76/11/30
NATL EUTROPHICATION S. VEY
EPA- LAS VEGAS

040918
34 01 45.0 109 49 40.0 4
TROUT CREEK
04 15 MCNARY
T/RAINBOW LAKE 110492
UPPER LOG ROAD BRDG
11EPALES 2111204
0000 FEET DEPTH CLASS 00

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
74/12/07	12 30		0.008	0.900	0.010	0.030	0.060
75/01/05	13 30		0.056	1.400	0.112	0.030	0.050
75/02/01	11 00		0.048	0.500	0.016	0.032	0.032
75/03/08	10 00		0.040	2.600	0.032	0.056	
75/04/12	14 55		0.060	0.650	0.030	0.020	0.130
75/04/29	14 15		0.070	1.800	0.025	0.005K	0.100
75/05/11	15 00		0.025	0.600	0.040	0.015	0.030
75/05/26	11 00		0.015	0.750	0.025	0.010	0.025
75/06/09	15 00		0.005	0.050K	0.020	0.030	0.030
75/07/06	14 30		0.015	0.100	0.005K	0.040	0.040
75/08/23	13 25		0.005	0.100K	0.015	0.040	0.080
75/09/07	15 30		0.015	2.600	0.030	0.045	0.110
75/10/13	17 45		0.005	1.200	0.025	0.045	0.050
75/11/16			0.005	0.300	0.010	0.040	0.040

K VALUE KNOWN TO BE LESS THAN INDICATED

STORET RETRIEVAL DATE 76/11/30
NATL EUTROPHICATION SURVEY
EPA- LAS VEGAS

04091C
34 04 50.0 109 48 30.0 4
GOOSEBERRY CREEK
04 15 MCNARY
T/RAINBOW LAKE 110492
HWY 73 BRDG 2.5 MI E OF MCNARY
11EPALES 2111204
0000 FEET DEPTH CLASS 00

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
74/12/07	11	38	0.008	0.500	0.005	0.010	0.030
75/02/01	11	40	0.136	1.200	0.032	0.016	0.070
75/03/08	11	00	0.120	1.255	0.044	0.028	0.125
75/04/12	14	10	0.025	0.650	0.020	0.020	0.060
75/04/29	11	25	0.045	1.250	0.055	0.010	0.170
75/05/11	16	10	0.015	0.850	0.020	0.030	0.040
75/05/26	11	45	0.015	0.550	0.020	0.025	0.030
75/06/09	15	45	0.010	0.250	0.015	0.025	0.050
75/07/06	15	05	0.035	0.650	0.015	0.010	0.030
75/08/23	14	20	0.015	0.600	0.015	0.015	0.070
75/09/07	16	05	0.015	0.600	0.015	0.015	0.050
75/10/12	17	15	0.065	0.500	0.075	0.015	0.040
75/11/16			0.010	0.600	0.010	0.015	0.030

STORET RETRIEVAL DATE 75/11/30
NATL EUTROPHICATION SURVEY
EPA- LAS VEGAS

0409YA AS0409YA P000100
34 07 30.0 009 56 00.0 4
CHARLIE CLARKS REST.
04 15 MCNARY
T/RAINBOW LAKE
UNNAMED CREEK
11EPALES 2141204
0000 FEET DEPTH CLASS 00

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
75/03/01	11	00	1.520	44.000	0.240	3.500	4.400		0.0002
75/04/15	10	00	1.950	1.500	0.083	1.850	3.200		
75/07/20	11	00		37.000			7.500		
75/08/04	19	15		52.000			10.000		

APPENDIX E

PARAMETRIC RANKINGS OF LAKES SAMPLED BY NES IN 1975

STATE OF ARIZONA

Mean or median values for six of the key parameters evaluated in establishing the trophic conditions of Arizona lakes sampled are presented to allow direct comparison of the ranking, by parameter, of each lake relative to the others. Median total phosphorus, median inorganic nitrogen and median dissolved orthophosphorus levels are expressed in mg/l. Chlorophyll a values are expressed in µg/l. To maintain consistent rank order with the preceding parameters, the mean Secchi disc depth, in inches, is subtracted from 500. Similarly, minimum dissolved oxygen values are subtracted from 15 to create table entries.

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P
0401	BIG LAKE	0.032	0.090	386.000	2.900	9.000	0.007
0402	FOOLS HOLLOW	0.059	0.090	466.600	10.683	14.800	0.014
0403	LAKE HAVASU	0.015	0.170	420.231	3.948	10.800	0.005
0404	LUNA LAKE	0.182	0.050	396.250	3.400	12.200	0.131
0405	LYMAN LAKE	0.099	0.060	484.667	2.633	9.000	0.056
0406	LAKE MOHAVE	0.017	0.240	369.667	4.404	8.600	0.010
0407	LAKE PLEASANT	0.027	0.040	449.154	9.808	14.900	0.004
0408	LAKE POWELL	0.009	0.400	239.000	1.333	12.200	0.010
0409	RAINBOW LAKE	0.046	0.045	440.750	16.367	12.000	0.009
0410	ROOSEVELT LAKE	0.020	0.040	429.917	4.073	14.000	0.008
0411	SAN CARLOS RESERVOIR	0.056	0.060	474.500	14.750	14.600	0.009
3201	LAKE MEAD	0.020	0.505	453.600	1.150	8.000	0.007

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

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P
0401	BIG LAKE	45 (5)	41 (4)	82 (9)	73 (8)	77 (8)	73 (8)
0402	FOOLS HOLLOW	18 (2)	41 (4)	18 (2)	18 (2)	9 (1)	18 (2)
0403	LAKE HAVASU	91 (10)	27 (3)	64 (7)	55 (6)	64 (7)	91 (10)
0404	LUNA LAKE	0 (0)	73 (8)	73 (8)	64 (7)	41 (4)	0 (0)
0405	LYMAN LAKE	9 (1)	64 (7)	0 (0)	82 (9)	77 (8)	9 (1)
0406	LAKE MOHAVE	82 (9)	18 (2)	91 (10)	36 (4)	91 (10)	32 (3)
0407	LAKE PLEASANT	55 (6)	95 (10)	36 (4)	27 (3)	0 (0)	100 (11)
0408	LAKE POWELL	100 (11)	9 (1)	100 (11)	91 (10)	41 (4)	32 (3)
0409	RAINBOW LAKE	36 (4)	82 (9)	45 (5)	0 (0)	55 (6)	45 (5)
0410	ROOSEVELT LAKE	68 (7)	95 (10)	55 (6)	45 (5)	27 (3)	64 (7)
0411	SAN CARLOS RESERVOIR	27 (3)	55 (6)	9 (1)	9 (1)	18 (2)	55 (6)
3201	LAKE MEAD	68 (7)	0 (0)	27 (3)	100 (11)	100 (11)	82 (9)