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Water Quality Management Strategies for Beaver Reservoir

Richard L. Meyer
University of Arkansas, Fayetteville

W. Reed Green
University of Arkansas, Fayetteville

Arkansas Water Resources Center

WATER QUALITY MANAGEMENT STRATEGIES FOR BEAVER RESERVOIR

PREPARED FOR:

ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY

PREPARED BY:

ARKANSAS WATER RESOURCES
UNIVERSITY OF ARKANSAS
112 OZARK HALL
FAYETTEVILLE, ARKANSAS 72701

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WATER QUALITY MANAGEMENT STRATEGIES FOR BEAVER RESERVOIR

PART I. THE APPLICATION OF THE ALGAL ASSAY BOTTLE TEST TO DEFINE POTENTIAL ALGAL PRODUCTION THROUGH TIME AND SPACE

PART II. A STRATEGY FOR MANAGING WATER QUALITY

FINAL REPORT

PREPARED FOR THE ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY

PREPARED BY:

ARKANSAS WATER RESOURCES RESEARCH CENTER
223 OZARK HALL, UNIVERSITY OF ARKANSAS
FAYETTEVILLE, ARKANSAS

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INTRODUCTION

The initial Arkansas Water Quality Management Plan (AWQMP) inventoried and identified nonpoint sources of pollution which adversely affect water quality while developing and recommending control strategies and the institutional arrangements and management programs to reduce or eliminate these problems. Nonpoint sources of pollution to Arkansas' streams were identified as agriculture, silviculture, mining, urban runoff, and roadway erosion. These land use activities, Best Management Practices (BMPs) and management agencies identified to implement a control program were discussed in Chapter V of the AWQMP.

The statewide nonpoint source assessments, an important part of the AWQMP, gave us our first wide angle view of the state's nonpoint source pollution problems as they relate to existing land use activities and current management practices. We now have information which shows us where the worst soil erosion problems are and the number of pounds of pesticides, herbicides, and fertilizers that were used in individual watersheds.

An important step in creating the nonpoint source data base was completed with the publication of these assessments, but many questions have yet to be answered. Though we know where erosion is the worst and where large quantities of chemicals are being utilized, we still have to prioritize problems and problem areas or qualify and quantify actual delivery to Arkansas streams and lakes.

Therefore, the objectives of this two part report are: (1) determine the degree and type of nutrients (nitrogen and phosphorus) available in time and space to Beaver Reservoir which can be used as an indicator for management decisions in the operation of the reservoir, and (2) determine what management practices or control measures are available and practical under the present laws and regulations of this area.

Beaver Reservoir is located in Northwest Arkansas on the White River. The reservoir is a 1,600,000 acre-foot impoundment which supplies water for over 100,000 users including the cities of Bentonville, Fayetteville, Rogers and Springdale. The portion of the reservoir above the water supply intake is only 5 percent of the total Beaver Reservoir Watershed. The importance of the upper White River drainage area in terms of input to the reservoir is also obvious from flow data, e.g., 90 percent of the flow at the intake is contributed by the West, Middle and Main Forks of the White River and by War Eagle Creek.

The predominant land uses in the total watershed of the reservoir are forest and agriculture which account for about 60-65 percent and 35-40 percent of the total area, respectively. Most of the agricultural activities in the watershed are related to production of chickens, cattle and hogs. Although only 680 cattle were reported in 1979 significant numbers of chickens (20 million) and hogs (22,000) were reported. Between production cycles the animal manure is typically spread as fertilizer onto fields. The fescue grass in the fields takes up nutrients and thus reduces wash-off into streams. The predominant rocks of the area are limestone, shale and sandstone. Therefore, these rocks would supply little if any phosphate, nitrate and ammonia via runoff or groundwater.

PART I

THE APPLICATION OF THE ALGAL ASSAY BOTTLE TEST TO DEFINE POTENTIAL ALGAL PRODUCTION THROUGH TIME AND SPACE IN BEAVER LAKE

for

ARKANSAS DEPARTMENT OF POLLUTION CONTROL AND ECOLOGY
Little Rock, Arkansas

and

U. S. ENVIRONMENTAL PROTECTION AGENCY
Washington, D. C.

by

Dr. Richard L. Meyer, Principal Investigator
and
W. Reed Green, Research Assistant
Department of Botany & Microbiology
University of Arkansas
Fayetteville, Arkansas

Arkansas Water Resources Research Center
223 Ozark Hall
University of Arkansas
Fayetteville, Arkansas
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THE APPLICATION OF THE ALGAL ASSAY BOTTLE TEST TO DEFINE POTENTIAL ALGAL PRODUCTION THROUGH TIME AND SPACE IN BEAVER LAKE

Richard L. Meyer, Ph.D., Principal Investigator
W. Reed Green, B.S., Research Assistant

INTRODUCTION

The algal assay bottle test as employed on the upper third of Beaver Lake is designed to apply a modification of Liebig's Law of the Minimum to positional and seasonal events for use in developing a basis for appropriate institutional management practices. The significant implication of the protocol is its potential to differentiate between the nutrients present, as measured by chemical analysis, from those available for algal growth and to detect the effects of certain chemical species which inhibit algal growth. With the addition of known concentrations of specified nutrients the assay can provide an indication of which nutrient or nutrients may be limiting algal production; if an imbalance of nitrogen-to-phosphorus ratio exists. The *in vitro* experimental protocol can detect the presence of an growth inhibitor when nutrients are in adequate supply and the physical conditions for growth are present. The design, including the use of a standard test organism with test water from appropriate temporal and spatial collections, will assist in determining the status and contribution of various levels of nutrients and growth inhibitors associated with these collections. The difference between the limiting or inhibiting factor at the upper margin and the lower margin of the spatial compartment can be used to estimate the processing events occuring within the compartment. The data generated from these test can assist in selecting appropriate management practices.

The protocol applied in this study is "The *Selenastrum capricornutum* Printz Algal Assay Bottle Test" authored by W. E. Miller, J. C. Greene and T. Shiroyama for the U.S. EPA (EPA-600/9-78-018). These tests are capable of identifying the limiting nutrient based upon biological response and chemical analysis with a total soluble inorganic nitrogen-to-ortho-phosphate ratio of 11:1. These tests also evaluate actual production of a maximum standing crop based upon biologically available nutrients and detect the absence of other growth requiring nutrients. With the addition of a chelating agent the influence of certain metallic growth inhibitors can be estimated. The protocol, which includes checks and balances, is structured so that unreliable chemical analysis can be recognized.

The samples were collected at four time intervals from selected locations on the upper portion of Beaver Lake. These samples were subjected to the complete test protocol and the maximum standing crop was measured for each test condition. The resulting data was cross compared with chemical analysis, calculated estimates and maximum production without and with the chelating agent Ethylene-diaminetetraacetic Acid (EDTA).

The optimal ratio of nitrogen-to-phosphorus of 11:1 for *Selenastrum* has been applied to estimate nitrogen or phosphorus limitation. Nitrogen or phosphorus are predicted as limiting if the ratio is less than or greater than 11:1, respectively, from the chemical analysis data. However, placement of a sample or water body into either a nitrogen or phosphorus limitation category without actual assay analysis is to be discouraged since only responses based upon bioavailable nutrients without or with the presence of a chelator verify limitation (Miller, et al., 1978)

This algal assay provides a standard method for measuring and calculating the growth potential of a water sample. The test employs a standard organism, *Selenastrum capricornutum* Printz which is unlikely to be present in the endemic assemblage of phytoplankters. In aquatic ecosystems numerous organisms interact with the chemical and physical parameters that influence the system and these organisms will react differently to similar parameters. In addition, the endemic phytoplankton assemblage changes in quality and quantity through the annual cycle and varies in abundance and composition along the length of the reservoir. Field response of the endemic plankters naturally selected and/or adapted to the specific environment may vary from the estimates and results derived from the laboratory analysis. The *Selenastrum* alagl assay bottle test does however provide an experimental design which can be applied to the analysis of the problems of eutrophication and toxicity within aquatic ecosystems.

MATERIAL AND METHODS

Spatial and Temporal Experimental Design

The experimental design includes spatial and temporal sampling as recommended by EPA procedures from upper Beaver Lake.

Spatial compartments.

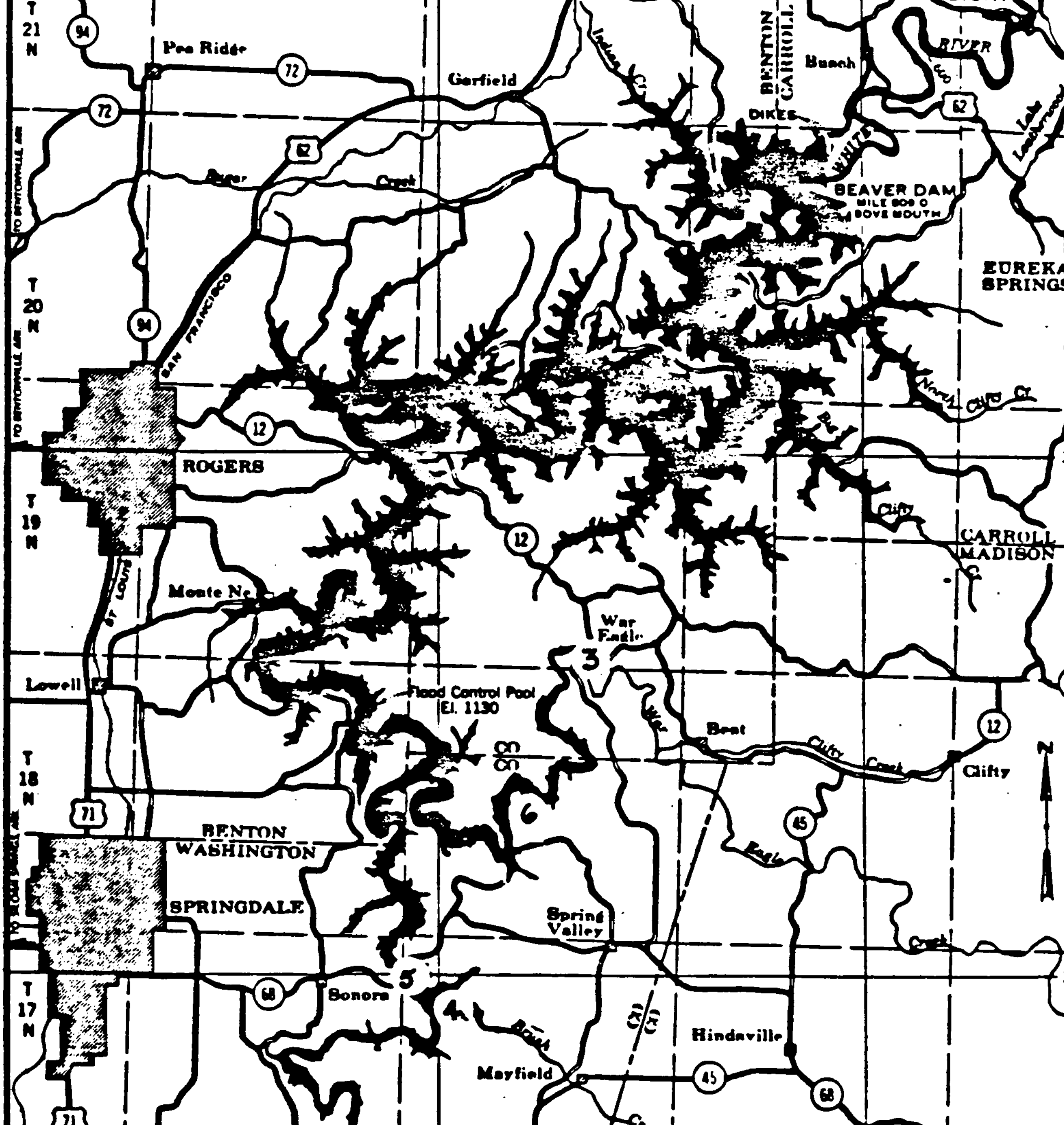
Test water samples were collected from three lake compartments with stations at the end of each compartment. The compartments were delineated by sampling sites in the 1) upper White River arm at Arkansas Highway 45 bridge, 2) the middle White River arm at U.S. Highway 68 bridge, 3) War Eagle River arm at the Hickory Creek recreational area, and 4) the lower lake at U.S. Highway 12 bridge. [See Figure 1.]

Temporal compartments.

Test water samples were collected four times during the spring through fall including two summer sample sets. The fall sample set was collected after a major runoff period and on the falling slope of the hydrograph. The inflow was great enough to produce plug flow into the upper reservoir. The conditions during collection of the other three sample sets were more stable and typical for the season involved.

In Vitro Bioassay

The field samples were collected by Arkansas Department of Pollution Control and Ecology personnel. A portion of each


T 21 N
94
Pea Ridge
72
Garfield
BENTON
CARROLL
Busch
RIVER
62
DIKES
WHITE
Lake Leatherwood
BEAVER DAM
MILE 609.0 ABOVE MOUTH
EUREKA SPRINGS
Sugar Creek
SAN FRANCISCO
T 20 N
ROGERS
12
North Clifty Cr.
T 19 N
Clifty
CARROLL
MADISON
ST LOUIS
Monte Ne
War Eagle
3
Lowell
Flood Control Pool
El. 1130
Best
Clifty Creek
Clifty
T 18 N
71
6
BENTON
WASHINGTON
45
Eagle
SPRINGDALE
Spring Valley
Creek
T 17 N
68
Sonora
5
4
Hindsville
Mayfield

sample was transferred to the University of Arkansas Phycology Laboratory for processing and testing. The remaining portion was used to conduct chemical assays by the ADPC&E.

The test water was filtered through a 0.45 um membrane filter. Following filtration the samples were divided into 50 ml aliquotes in 125 ml test flasks and autoclaved. Control and nutrient additions were added to triplicate test flasks. Triplicate repetitions were used to confidently calculate standard deviation. Nutrient additions to the triplicates were as follows:

1. Control (test water without additions)
2. Control + 0.05 mg P l^{-1} as K_2HPO_4
3. Control + 1.00 mg N l^{-1} as $NaNO_3$
4. Control + 0.05 mg P l^{-1} + 1.00 mg N l^{-1}
5. Control + 1.00 mg Na_2EDTA l^{-1}
6. Control + 0.05 mg P l^{-1} + 1.00 mg Na_2EDTA l^{-1}
7. Control + 1.00 mg N l^{-1} + 1.00 mg Na_2EDTA l^{-1}
8. Control + 0.05 mg P l^{-1} + 1.00 mg N l^{-1} + 1.00 mg Na_2EDTA mg l^{-1}

The test alga Selenastrum capricornutum Printz was obtained from Carolina Biological Supply Co. (Cat. # 15-2520). The test organism was grown as stock cultures maintained in log growth phase using Miller, et al. (1978) culture media. Weekly transfers were made in order to maintain log growth. An inoculum equivalent to 1,000 cell per milliliter was added to each test flask.

The test flasks were maintained under constant temperature (24±0.5°) and continuous 400 ft-c fluorescent light. The flasks were shaken twice daily for fourteen days.

The cells were harvested by filtering the test samples through 0.60 um membrane filters on day fourteen. The filters were dried and weighed with a Mettler H-18 analytical balance. The resultant data are reported in the Appendix.

DATA ANALYSIS.

Interpretation of the assay results are reported following the protocol set forth by Miller et al. (1978). Maximum standing crop (MSC) was determined by averaging the triplicate measured milligrams of dry weight obtained after the fourteen day test period and factoring this weight to milligrams per liter. Maximum standing crop by sampling site and date are reported in Table 1.

The values listed under "C" or control reflect the growth potential of the ambient water without an increase in nitrogen ("N") or phosphorus ("P") or the removal of heavy metals with EDTA ("E"). The data produced from single or combined nutrient additions without or with the chelator are used for further calculations; ie., growth potential, biological available nutrients, and

TABLE 1

GROWTH RESPONSE - MAXIMUM STANDING CROP (MSC)
BY SAMPLING DATE AND SITE
(Milligrams per Liter)

SITE	C	N	P	E	N+E	P+E	N+P	N+P+E
May 24, 1984								
Hwy 45	4	10	14	26	36	24	20	106
Hwy 68	28	14	32	26	42	40	22	86
Hick Ck	30	10	30	10	10	48	32	70
Hwy 12	12	14	24	8	8	44	32	58
June 19, 1984								
Hwy 45	128	182	134	156	290	160	168	302
Hwy 68	98	104	106	94	94	114	108	126
Hick Ck	ND	102	128	104	104	126	130	140
Hwy 12	106	104	128	98	104	126	134	152
July 31, 1984								
Hwy 45	146	90	146	102	198	172	50	101
Hwy 68	10	6	12	6	2	26	14	32
Hick Ck	2	4	10	2	2	20	12	30
Hwy 12	4	4	14	6	0	14	22	16
October 30, 1984								
Hwy 45	18	14	26	14	12	10	10	12
Hwy 68	10	16	16	26	16	50	22	48
Hick Ck	14	24	24	24	4	42	30	32
Hwy 12	2	2	2	6	0	8	4	6

uppermost site, Hwy 45, than at the other sites. With the addition of EDTA the value was approximately the same as those at Hwy 68 and Hickory Creek. This higher production with the addition of EDTA suggest that inhibitory heavy metals may be present.

The data from Hickory Creek reflects the inflowing waters of War Eagle Creek. Only in late summer are the growth responses of Hwy 68 and Hickory Creek significantly different. This difference is probably related to the distribution and contribution of storms in the respective drainage basins.

Total soluble inorganic nitrogen (TSIN) and ortho-phosphorus (O-P) concentrations in the test water were obtained from ADPC&E and used in calculating the predicted MSC for each test water sample. TSIN and O-P yield factors of 38 and 430, respectively, were used to determine the expected yields [cf. Miller, et al., 1978]. Under nitrogen limitation an addition of 1.0 mg of nitrogen will support an additional 38 mg of dry weight of *S. capricornutum*, and under phosphorus limitation an addition of 1.0 mg of phosphorus will support an additional 430 mg of dry wt.

To determine the limiting nutrient, the indigenous TSIN and O-P concentrations of the test water were multiplied by their corresponding yield factor to calculate the possible MSC supported under these conditions. The smaller calculated MSC value and the ratio of TSIN to O-P indicate which nutrient is growth limiting. The nutrient analysis, nitrogen-to-phosphorus ratio, the predicted limiting factor and the calculated MSC for each test water sample are reported in Table 2.

Based upon the chemical analysis and the comparison of the nitrogen-to-phosphorus concentrations a distincitve pattern of spatial distribution emerges for the spring through late summer. The upper two sites (Hwys 45 & 68) are nitrogen limited but become phosphorus during the fall. However, the lower site (Hwy 12) is consistantly phosphorus limited. War Eagle Creek (Hick Ck), in contrast to the upper White River, was limited by phosphorus.

The chemical data were used to calculate a probable maximum standing crop (CALC MSC). These data can be compared with the maximum standing crop measured (MEAS MSC) by the algal assay bottle test. The differences between the two data sets are related to analytical error, difference in chemical and biologically available nutrients, and the presence of growth inhibitors.

Bioavailable phosphorus and nitrogen concentrations were calculated by dividing the measured MSC of the test by either the TSIN or O-P yield factors. The MSC resulting from the phosphorus or phosphorus plus EDTA additions were divided by the nitrogen yield factor (38) to calculate bioavailable nitrogen and the MSC resulting from the nitrogen or nitrogen plus EDTA additions were divided by the phosphorus yield factor (430) to calculate bioavailable phosphorus. Bioavailable nutrient data and calculated results without and with EDTA additions are reported in Table 3 and 4. These data are used to estimate the presence and impact of

TABLE 2

NUTRIENT DATA - LABORATORY ANALYSIS*
NITROGEN TO PHOSPHORUS RATIO, PREDICTED LIMITING FACTOR, CALCULATED MAXIMUM STANDING CROP, AND MEASURED MAXIMUM STANDING CROP
(Milligrams per Liter)

SITE	CHEM ANA		N:P	PRED LIM	CALC MSC			MEAS MSC		
	TSIN	O-P	RATIO	FACTOR	C	N	P	C	N	P
May 24, 1984										
Hwy 45	0.62	0.06	9.7:1	Nitrogen	24	62	24	4	10	14
Hwy 68	0.77	0.09	11.7:1	Nitrogen	29	67	29	28	14	32
Hick Ck	0.99	0.02	45.9:1	Phosphorus	9	9	30	30	10	30
Hwy 12	1.07	0.02	53.5:1	Phosphorus	9	9	30	12	14	24
June 19, 1984										
Hwy 45	0.92	0.46	2.0:1	Nitrogen	35	73	35	128	182	134
Hwy 68	0.12	0.03	4.0:1	Nitrogen	5	43	5	98	104	106
Hick Ck	0.39	0.02	19.5:1	Phosphorus	9	9	32	nd	102	128
Hwy 12	0.24	0.02	12.0:1	Phosphorus	9	9	30	106	104	128
July 31, 1984										
Hwy 45	4.93	1.65	3.0:1	Nitrogen	187	225	187	146	90	146
Hwy 68	0.09	0.06	1.5:1	Nitrogen	3	41	3	10	6	12
Hick Ck	0.99	0.02	49.5:1	Phosphorus	9	9	30	2	4	10
Hwy 12	1.07	0.02	53.5:1	Phosphorus	9	9	30	4	4	14
October 30, 1984										
Hwy 45	1.41	0.08	17.6:1	Phosphorus	34	34	56	18	14	26
Hwy 68	1.47	0.08	29.4:1	Phosphorus	22	22	43	10	16	16
Hick Ck	0.87	0.04	21.8:1	Phosphorus	17	17	39	14	8	24
Hwy 12	0.14	<0.01	14.0:1	Phosphorus	4	4	26	2	0	2

* Nitrogen and phosphorus analysis conducted by Arkansas Department of Pollution Control and Ecology.

TABLE 3

BIOASSAY DATA - [WITHOUT EDTA]
CALCULATED BIOAVAILABLE NITROGEN AND PHOSPHORUS, CALCULATED NITROGEN-TO-PHOSPHORUS RATIO, CALCULATED LIMITING FACTOR, CALCULATED MAXIMUM STANDING CROP, AND MEASURED STANDING CROP
(Milligrams per Liter)

SITE	BIOAVAIL N	BIOAVAIL P	N:P RATIO	CALC LIM FACTOR	CALC MSC C	CALC MSC N	CALC MSC P	MEAS MSC C	MEAS MSC N	MEAS MSC P
May 24, 1984										
Hwy 45	0.37	0.02	18.5:1	Phosphorus	9	9	30	4	10	14
Hwy 68	0.84	0.03	28.0:1	Phosphorus	13	13	34	28	14	32
Hick Ck	0.79	0.02	39.5:1	Phosphorus	9	9	30	30	10	30
Hwy 12	0.63	0.03	21.0:1	Phosphorus	13	13	34	12	14	24
June 19, 1984										
Hwy 45	3.53	0.42	8.0:1	Nitrogen	134	172	134	128	182	134
Hwy 68	2.79	0.24	11.6:1	Equalib.	103	144	125	98	104	106
Hick Ck	3.37	0.24	14.0:1	Phosphorus	103	103	125	nd	102	128
Hwy 12	3.37	0.24	14.0:1	Phosphorus	103	103	125	106	104	128
July 31, 1984										
Hwy 45	3.84	0.21	18.3:1	Phosphorus	90	90	112	146	90	146
Hwy 68	0.32	0.01	32.0:1	Phosphorus	4	4	26	10	6	12
Hick Ck	0.26	0.01	26.0:1	Phosphorus	4	4	26	2	4	10
Hwy 12	0.37	0.01	37.0:1	Phosphorus	4	4	26	4	4	14
October 30, 1984										
Hwy 45	0.68	0.03	22.7:1	Phosphorus	13	13	34	18	14	26

TABLE 4

BIOASSAY DATA - [WITH EDTA]
CALCULATED BIOAVAILABLE NITROGEN AND PHOSPHORUS, CALCULATED NITROGEN-TO-PHOSPHORUS RATIO, CALCULATED LIMITING FACTOR, CALCULATED MAXIMUM STANDING CROP, AND MEASURED STANDING CROP
(Milligrams per Liter)

SITE	BIOAVAIL N	BIOAVAIL P	N:P RATIO	CALC LIM FACTOR	CALC MSC C	CALC MSC N	CALC MSC P	MEAS MSC C	MEAS MSC N	MEAS MSC P
May 24, 1984										
Hwy 45	0.63	0.08	7.9:1	Nitrogen	24	62	24	26	36	24
Hwy 68	1.05	0.10	10.5:1	Nitrogen	40	78	65	26	42	40
Hick Ck	1.26	0.02	63.0:1	Phosphorus	9	9	30	10	10	48
Hwy 12	1.16	0.02	58.0:1	Phosphorus	9	9	30	8	8	44
June 19, 1984										
Hwy 45	4.21	0.67	6.3:1	Nitrogen	160	198	160	156	290	160
Hwy 68	3.00	0.22	13.6:1	Phosphorus	95	95	116	94	94	114
Hick Ck	3.32	0.24	13.8:1	Phosphorus	103	103	125	104	104	126
Hwy 12	3.32	0.24	13.8:1	Phosphorus	103	103	125	98	104	126
July 31, 1984										
Hwy 45	4.53	0.46	9.8:1	Nitrogen	172	210	172	102	198	172
Hwy 68	0.68	0.01	68.0:1	Phosphorus	4	4	26	6	2	26
Hick Ck	0.53	0.00	<53.0:1	Phosphorus	-	-	-	2	0	20
Hwy 12	0.37	0.00	<37.0:1	Phosphorus	-	-	-	6	0	14
October 30, 1984										
Hwy 45	0.26	0.03	8.7:1	Nitrogen	13	13	34	14	12	10
Hwy 68	1.32	0.04	34.0:1	Phosphorus	17	17	39	26	16	50
Hick Ck	1.11	0.01	111.0:1	Phosphorus	4	4	26	24	4	42
Hwy 12	0.21	0.00	<21.0:1	Phosphorus	-	-	-	6	0	8

heavy metal inhibitors.

Percent growth inhibition ($\%I_{14}$) was calculated by subtracting the measured MSC of the treatments without EDTA from those with EDTA and dividing by the MSC with EDTA, then multiplying by 100. Percent inhibition calculated from measured maximum standing crop is reported in Table 5.

The directly measured reduction in growth data clearly indicates the presence of heavy metal inhibitors. These inhibitors tend to be concentrated at the Hwy 45 (11-85%) site with a rapid decline to undetectable inhibition down lake. This gradient is disturbed as flow is increased to some critical level. The October 30 sample was collected following heavy rainfall and increased streamflow. These events diluted the concentration of inhibitors at Hwy 45 below a detectable level or replaced the ambient water with uncontaminated water. The inhibitors were pushed further down lake in front of or with the plug flow. The storm related impact resulted in growth reduction of 62% and 68% at Hwys 68 and 12, respectively. The affect extended beyond Hwy 12 and encroached into War Eagle Creek (42% inhibition).

It should be noted that the inhibitors have the greatest impact on phosphorus related growth response whenever inhibition occurs and when nitrogen is available in adequate amounts. The inhibition associated with nitrogen limitation is most evident in the upper two sites (Hwys 45 & 68). These data suggest that certain of the heavy metals inhibiting algal growth are indepen-

Table 5

PERCENT INHIBITON CALCULATED FROM MEASURED MAXIMUM STANDING CROP WITH AND WITHOUT EDTA

(%I_{14})

DATE	SITE	C+E vs C	P+E vs P	N+E vs N	P+N+E vs P+N
May 24, 1984					
	Hwy 45	85	42	72	81
	Hwy 68	0	20	67	74
	Hick Ck	0	38	0	54
	Hwy 12	0	45	0	45
July 19, 1984					
	Hwy 45	18	16	37	44
	Hwy 68	0	8	0	14
	Hick Ck	0	0	2	7
	Hwy 12	0	0	0	12
July 31, 1984					
	Hwy 45	11	15	55	50
	Hwy 68	0	54	0	56
	Hick Ck	0	50	0	60
	Hwy 12	0	0	0	0
October 30, 1984					
	Hwy 45	0	0	0	0
	Hwy 68	62	68	0	54
	Hick Ck	42	23	0	6
	Hwy 12	66	75	0	33

dently distributed along the lake length and selectively effect the availability of phosphorus and nitrogen.

Percent reduction in bioavailable nutrients due to inhibition was calculated by subtracting the bioavailable amount of the nutrient without EDTA by that with EDTA and dividing by the later, then multiplying by 100. Percent reduction in bioavailable nutrients due to inhibition is reported in Table 6.

Inhibition may interfer with several biological processes or may reduce the availability of nutrients. The amount of reduced growth which can be accounted for by reduction in bioavailable nutrients varies temporally and spatially.

The reduction of available phosphorus is restricted to the upper sites of Hwy 45 (75%) and Hwy 68 (70%) during the spring and Hwy 45 (37 & 54%) throughout the summer. Interference in nitrogen availability tends to be more widely distributed than phosphorus. All sites show nitrogen inhibition (20-46%) during the spring with the upper sites in the summer (16-70%). Only the down lake sites are effected during the fall rapid flow period (68-76%); the Hwy 45 site shows no detectable inhibition. War Eagle Creek (Hick Ck site) has nitrogen inhibition during the spring, late summer and fall but none during mid-summer (37, 51, 43, & 0, respectively). The specific heavy metal inhibitors remain to be determined.

Table 6

PERCENT REDUCTION IN BIOAVAILABLE NUTRIENTS DUE TO INHIBITION
$(\%I_{14})$

DATE	SITE	PHOSPHORUS	NITROGEN
May 24, 1984			
	Hwy 45	75	41
	Hwy 68	70	20
	Hick Ck	0	37
	Hwy 68	0	46
July 19, 1984			
	Hwy 45	37	16
	Hwy 68	0	70
	Hick Ck	0	0
	Hwy 12	0	0
July 31, 1984			
	Hwy 45	54	16
	Hwy 68	0	53
	Hick CK	0	51
	Hwy 12	0	0
October 30, 1984			
	Hwy 45	0	0
	Hwy 68	0	68
	Hick Ck	0	43
	Hwy 12	0	76

RESULTS

Nitrogen Limitation

In those test water samples in which it has been determined that nitrogen is the primary limiting nutrient (Table 7), phosphorus influences growth as the secondary limiting nutrient. In all cases, the addition of nitrogen changes the nitrogen-to-phosphorus ratio resulting in a transition from nitrogen limitation to that of phosphorus as indicated by the measured maximum standing crop results.

Phosphorus Limitation

In those samples which are phosphorus limited (Table 7) the samples remain phosphorus limited even with the addition of more phosphorus. This is due to the high nitrogen-to-phosphorus ratio and is confirmed by the measured maximum standing crop results.

Growth Inhibition

Substantial levels of growth inhibition occur in a number of test water samples (Table 5). Removal of the inhibitory effect with the addition of EDTA results in greater measured maximum standing crops. Growth inhibition influences the calculated bioavailability of both phosphorus and nitrogen (Table 6). The data from the test water treatments with the addition of EDTA are more responsive to nutrient additions than those in which inhibition occurs and as a result are more sensitive as a measure of the influence of nutrients within these samples. The increased growth with the addition of EDTA suggests that adequate trace

Table 7

LIMITING NUTRIENT AT EACH SITE BY SEASON

DATE	SITE	LIMITING NUTRIENT
May 24, 1984	Hwy 45	Nitrogen
	Hwy 68	Nitrogen
	Hick Ck	Phosphorus
	Hwy 12	Phosphorus
July 19, 1984	Hwy 45	Nitrogen
	Hwy 68	Phosphorus
	Hick Ck	Phosphorus
	Hwy 12	Phosphorus
July 31, 1984	Hwy 45	Nitrogen
	Hwy 68	Phosphorus
	Hick CK	Phosphorus
	Hwy 12	Phosphorus
October 30, 1984	Hwy 45	Phosphorus
	Hwy 68	Phosphorus
	Hick Ck	Phosphorus
	Hwy 12	Phosphorus

elements required for growth are present and that the reduction in measured MSC is associated with an inhibitor.

Spatial and Temporal Compartments

A correlation exists between the compartment sample sites, growth inhibition, nutrient concentration, and nutrient limitation. The upper two sample sites (Hwy 45 & 68), show relatively greater growth inhibitory affects. With the removal of the inhibitor the higher nutrient concentrations result in higher production. These two sites are nitrogen limited with a secondary phosphorus limitation. However, Highway 68 is phosphorus limited in early summer (June 19), as are both Hwy 45 and 68 in the fall (October 30). In the fall Hwy 45 shows no inhibitory effects; however, inhibition was noted at the other sites. This displacement down lake may be associated with heavy runoff and plug flow prior to sample collection. Hickory Creek and Hwy 12 show little if any inhibitory effect during the spring and summer, with the exception of Hickory Creek (July 31). In all cases these two sites are phosphorus limited and contain lower concentrations of nutrients and lower production potential.

Seasonal inhibition is highest in the spring, but all seasons experience some level of inhibition especially at the upper stations. However, the eaffects of inhibition may be displaced down lake by increased inflows. Nutrient levels are highest in the summer, June 19 and July 31; with the greatest concentrations at the Hwy 45 site. Nitrogen levels tend to vary more between seasons than do phosphorus levels. Nutrient limitation remains relatively stable within the spatial compartments during the seasons except in the fall where high rainfall produced dilution and a plug flow of nutrients through the system.

SUMMARY

These algal assay bottle tests clearly indicate that phosphorus is not the single limiting nutrient in Beaver Lake. In the up-lake compartments nitrogen may be limiting. The limiting factor and its distribution down-lake may be influenced by season and by physical and chemical factors.

The presence of chemical parameters which limit maximum standing crop must be considered in understanding the events occurring in the upper reaches of Beaver Lake. The assays indicate the presence of an inhibitor but the present test protocol cannot determine either the specificity or origin of the inhibitor.

The results of this research program have more clearly defined the spatial and temporal variation in factors which influence production in Beaver Lake and have identified the probable presence of an unknown inhibitor or inhibitors. More precise information on the affects of these limiting nutrients and inhibitors would be beneficial in developing appropriate management strategies.

RECOMMENDATIONS

The upper portion of Beaver Lake receives ca. 80% of the drainage basin runoff as well as the outflow of the City of Fayettevilles' sewage treatment plant. From the research results it is obvious that the activities on the drainage basin and any modifications to the sewage outfall will have a direct impact upon algal growth. At the present time the drainage basin is being modified by expansion of farmland, foresting activities and urban development. In response to this development, the City of Fayetteville is expanding and modifying it sewage treatment facilities. This growth and development will result in continuing changes in the inflowing quality of water into Beaver Lake.

The present study marks a starting point from which future changes can be measured. The results demonstrate that reduction in both nitrogen and phosphorus are necessary if algal blooms are to be managed at desirable levels. Of particular importance is the presence of heavy metals acting as inhibitors. The discovery of these inhibitors suggests that qualitative and quantitative determination of their origin and distribution is necessary if appropriate management practices are to be employed. Future growth and development within the Beaver Lake basin requires that the management practices selected are cognizant of the role of the primary nutrients, nitrogen and phosphorus, and of the inhibiting factors on the productivity of the regions principle aquatic resource.

Based upon the information available the following recommendations are presented:

1) The algal assay bottle test protocol for nitrogen and phosphorus should be conducted at the upper lake sampling points on a monthly basis in order to more clearly define the seasonal variation in nutrient limitation.

2) The algal assay bottle test protocol for heavy metal inhibition should be conducted in parallel with the limiting nutrient analysis.

3) The principal headwater streams should be monitored to determine the contribution of nutrients from each of these sources. The influence of Lake Sequoyah and the sewage discharge should be measured. The monitoring should include determination of the algal growth potential via the algal assay bottle test.

4) Associated with the contribution of nutrients from headwater streams an investigation to determine quality and quantity of heavy metals should be conducted.

5) The preceding recommendations should be implemented immediately and also prior to and following the activation of the new sewage treatment facility.

6) Strategies and protocols should be developed to conduct _in situ_ assays of nutrient and heavy metal influence on the endemic phytoplankton assemblages in order to measure the

true "in lake" impact. These measurements would verify the applicability of the algal assay bottle test as a satisfactory protocol monitoring best management practices.

ACKNOWLEDGEMENTS

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APPENDIX

ALGAL ASSAY BOTTLE TEST DATA SHEETS

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 1 Set Ident: Spring
Sampling Date: 24 April 1984 Collector: E. Dunn
Sampling Site: White Rv/Hwy 45 Receiver: R. L. Meyer
Pretreatment: 0.45um fltr/autoclaved Responsible Technician: WRG
Innoculation Date: 26 April 1984 Completion Date: 7 May 1984
Innoculum Size: 1,000 cells per ml Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	91.2	91.0	0.2		
	2	88.4	88.2	0.2	0.2	0.0
	3	88.3	88.0	0.3		
P	4	90.9	90.2	0.7		
	5	92.6	92.0	0.6	0.7	0.1
	6	91.8	91.0	0.8		
N	7	90.6	89.7	0.9		
	8	93.5	93.1	0.4	0.5	0.3
	9	86.3	86.1	0.2		
P+N	10	91.6	90.6	1.0		
	11	88.8	87.9	0.9	1.0	0.1
	12	88.8	87.6	1.2		
E	13	91.4	90.1	1.3		
	14	90.5	89.3	1.2	1.3	0.0
	15	95.3	94.0	1.3		
P+E	16	93.2	92.4	0.8		
	17	92.8	91.5	1.3	1.2	0.3
	18	95.3	93.7	1.6		
N+E	19	88.4	86.5	1.9		
	20	91.9	90.1	1.8	1.8	0.1
	21	89.7	88.0	1.7		
P+N+E	22	92.9	87.0	5.9		
	23	93.8	89.1	4.7	5.3	0.5
	24	96.0	90.7	5.3		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 2 Set Ident: Spring
Sampling Date: 24 April 1984 Collector: E. Dunn
Sampling Site: Highway 68 Bridge Receiver: R. L. Meyer
Pretreatment: 0.45um fltr/autoclaved Responsible Technician: WRG
Innoculation Date: 26 April 1984 Completion Date: 7 May 1984
Innoculum Size: 1,000 cells per ml Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	94.9	92.9	2.0		
	2	92.5	91.3	1.2	1.4	0.4
	3	93.7	92.7	1.0		
P	4	87.9	86.5	1.4		
	5	91.3	89.7	1.6	1.6	0.2
	6	90.7	88.9	1.8		
N	7	86.4	85.7	0.7		
	8	89.8	89.2	0.6	0.7	0.1
	9	91.1	90.2	0.9		
P+N	10	96.7	95.7	1.0		
	11	94.7	93.5	1.2	1.1	0.1
	12	93.2	92.2	1.0		
E	13	94.6	93.2	1.4		
	14	87.0	85.6	1.4	1.3	0.1
	15	90.5	89.4	1.1		
P+E	16	90.3	88.1	2.2		
	17	87.4	85.6	1.8	2.0	0.2
	18	90.6	88.7	1.9		
N+E	19	93.4	90.7	2.7		
	20	94.9	92.9	2.0	2.1	0.4
	21	94.1	92.4	1.7		
P+N+E	22	nd	106.0	nd		
	23	89.0	84.7	4.3	4.3	-.-
	24	nd	87.5	nd		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 3
Set Ident: Spring
Sampling Date: 24 April 1984
Collector: E. Dunn
Sampling Site: Hickory Creek Boat Dk
Receiver: R. L. Meyer
Pretreatment: 0.45um fltr/autoclaved
Responsible Technician: WRG
Innoculation Date: 26 April 1984
Completion Date: 7 May 1984
Innoculum Size: 1,000 cells per ml
Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	87.9	86.4	1.5		
	2	nd	87.2	nd	1.5	-.-
	3	nd	89.7	nd		
P	4	95.6	94.2	1.4		
	5	nd	92.2	nd	1.5	0.7
	6	95.2	93.7	1.5		
N	7	nd	92.4	nd		
	8	90.0	89.5	0.5	0.5	0.3
	9	94.1	93.6	0.5		
P+N	10	92.4	91.1	1.3		
	11	91.0	89.4	0.6	1.1	0.4
	12	93.0	91.6	1.4		
E	13	nd	91.6	nd		
	14	93.5	93.0	0.5	0.5	0.0
	15	92.3	91.8	0.5		
P+E	16	94.5	92.2	2.3		
	17	97.4	94.8	2.6	2.4	0.1
	18	95.0	92.7	2.3		
N+E	19	88.8	88.2	0.6		
	20	91.0	90.5	0.5	0.5	0.1
	21	89.4	89.1	0.3		
P+N+E	22	94.5	91.3	8.2		
	23	95.3	91.6	3.7	3.5	0.2
	24	96.9	93.4	3.5		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 4 — Set Ident: Spring
Sampling Date: 24 April 1984 — Collector: E. Dunn
Sampling Site: Highway 12 Bridge — Receiver: R. L. Meyer
Pretreatment: 0.45um fltr/autoclaved — Responsible Technician: WRG
Innoculation Date: 26 April 1984 — Completion Date: 7 May 1984
Innoculum Size: 1,000 cells per ml — Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	92.9	92.5	0.4		
	2	92.8	92.3	0.5	0.6	0.2
	3	96.7	95.8	0.9		
P	4	90.3	88.9	1.4		
	5	94.6	92.7	1.9	1.7	0.2
	6	92.4	90.6	1.8		
N	7	89.2	88.5	0.7		
	8	91.7	91.1	0.6	0.7	0.1
	9	91.5	90.6	0.9		
P+N	10	95.3	93.7	1.6		
	11	94.5	92.6	1.9	1.6	0.2
	12	94.3	92.9	1.4		
E	13	95.0	94.4	0.6		
	14	89.1	88.8	0.3	0.4	0.1
	15	92.8	92.4	0.4		
P+E	16	98.2	96.1	2.1		
	17	95.0	92.8	2.2	2.2	0.0
	18	95.3	93.1	2.2		
N+E	19	95.5	95.2	0.3		
	20	91.5	91.3	0.2	0.4	0.2
	21	91.9	91.3	0.6		
P+N+E	22	94.0	91.3	3.3		
	23	102.9	99.9	3.0	2.9	0.4
	24	97.4	95.1	2.3		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 1 Set Ident: Summer-1
Sampling Date: 19 June 1984 Collector: S. Drown
Sampling Site: White Rvr/Hwy 45 Receiver: W. R. Green
Pretreatment: 0.45um fltr/autoclaved Responsible Technician: WRG
Innoculation Date: 27 June 1984 Completion Date: 11 July 84
Innoculum Size: 1,000 cells per ml Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT -	INITIAL WT =	NET WT**	MEAN WT	STD DEV
Contrl	1	87.5	81.0	6.5		
	2	87.8	81.4	6.4	6.4	0.1
	3	89.1	82.9	6.2		
P	4	88.6	82.1	6.5		
	5	84.9	78.4	6.5	6.7	0.2
	6	87.7	78.4	7.0		
N	7	90.4	80.7	9.7		
	8	86.7	78.1	8.6	9.1	0.5
	9	84.3	75.4	8.9		
P+N	10	91.0	83.4	7.6		
	11	88.7	79.5	9.2	8.4	0.8
	12	nd	nd			
E	13	91.5	83.4	8.1		
	14	90.7	82.7	8.0	7.8	0.4
	15	84.4	77.2	7.2		
P+E	16	90.0	82.2	7.8		
	17	86.2	78.2	8.0	8.0	0.2
	18	85.7	77.5	8.2		
N+E	19	88.7	74.7	14.0		
	20	98.5	82.7	15.8	14.5	0.9
	21	93.8	80.0	13.8		
P+N+E	22	93.7	79.6	14.1		
	23	97.3	81.3	16.0	15.1	1.0
	24	nd	80.7	nd		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake #2
Sampling Date: 19 June 1984
Sampling Site: Blue Springs
Pretreatment: 0.45um fltr/autoclaved
Innoculation Date: 27 June 1984
Innoculum Size: 1,000 cells per ml

Set Ident: Summer-1
Collector: S. Drown
Receiver: W. R. Green
Responsible Technician: WRG
Completion Date: 11 July 84
Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT -	INITIAL WT =	NET WT**	MEAN WT	STD DEV
Contrl	1	86.5	81.6	4.9		
	2	86.2	82.3	4.9	4.9	0.0
	3	86.1	81.2	4.9		
P	4	84.0	78.7	5.3		
	5	80.7	75.4	5.3	5.3	0.0
	6	89.1	83.7	5.4		
N	7	88.0	83.5	6.5		
	8	88.5	84.0	4.5	5.2	1.0
	9	88.2	83.8	4.4		
P+N	10	88.7	82.9	5.8		
	11	86.8	81.8	5.0	5.4	0.3
	12	88.2	82.9	5.3		
E	13	88.0	83.3	4.7		
	14	87.6	82.9	4.7	4.7	0.0
	15	83.7	79.0	4.7		
P+E	16	89.8	84.3	5.5		
	17	88.7	82.9	5.8	5.7	0.1
	18	91.1	85.4	5.7		
N+E	19	93.9	89.1	4.8		
	20	92.1	87.4	4.7	4.7	0.0
	21	87.6	82.9	4.7		
P+N+E	22	89.3	82.6	6.7		
	23	96.2	89.5	6.7	6.3	0.2
	24	93.8	87.6	6.2		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams per liter.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 3
Sampling Date: 19 June 1984
Sampling Site: Hickory Creek Boat Dk
Pretreatment: 0.45um fltr/autoclaved
Innoculation Date: 27 June 1984
Innoculum Size: 1,000 cells per ml

Set Ident: Summer-1
Collector: S. Drown
Receiver: W. R. Green
Responsible Technician: WRG
Completion Date: 11 July 84
Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	nd***	87.4	nd		
	2	nd	82.2	nd	nd	nd
	3	nd	85.2	nd		
P	4	86.5	80.5	6.0		
	5	89.0	82.9	6.1	6.4	0.4
	6	87.9	80.9	7.0		
N	7	nd	82.3	nd		
	8	nd	82.4	nd	5.1	-.-
	9	84.2	79.1	5.1		
P+N	10	83.0	76.3	6.7		
	11	90.4	83.8	6.6	6.5	0.2
	12	89.5	83.2	6.3		
E	13	85.5	80.3	5.2		
	14	86.8	81.7	5.1	5.2	0.0
	15	nd	82.8	nd		
P+E	16	83.7	77.7	6.0		
	17	88.5	82.4	6.1	6.3	0.3
	18	86.0	79.3	6.7		
N+E	19	82.9	77.9	5.0		
	20	78.9	73.6	5.3	5.2	0.1
	21	87.1	81.9	5.2		
P+N+E	22	87.9	80.7	7.2		
	23	88.4	81.3	7.1	7.0	0.2
	24	88.6	81.8	6.8		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.
*** nd = lack of data because of filter contamination or damage.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 4
Set Ident: Summer-1
Sampling Date: 19 June 1984
Collector: S. Drown
Sampling Site: Highway 12 Bridge
Receiver: W. R. Green
Pretreatment: 0.45um fltr/autoclaved
Responsible Technician: WRG
Innoculation Date: 27 June 1984
Completion Date: 11 July 84
Innoculum Size: 1,000 cells per ml
Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	87.1	81.8	5.3		
	2	83.7	78.4	5.3	5.3	0.0
	3	88.1	82.9	5.2		
P	4	84.4	78.3	6.1		
	5	84.7	78.2	6.5	6.4	0.2
	6	81.0	74.4	6.6		
N	7	89.5	84.4	5.1		
	8	87.9	82.6	5.3	5.2	0.1
	9	87.5	82.3	5.2		
P+N	10	88.3	81.6	6.7		
	11	88.8	81.7	7.1	6.7	0.3
	12	88.3	82.0	6.3		
E	13	86.3	81.3	5.0		
	14	89.1	84.1	5.0	4.9	0.1
	15	85.7	80.9	4.8		
P+E	16	83.4	76.9	6.5		
	17	90.8	84.4	6.4	6.3	0.2
	18	90.0	83.9	6.4		
N+E	19	89.5	84.4	5.1		
	20	82.6	77.1	5.5	5.2	0.2
	21	89.3	84.3	5.0		
P+N+E	22	89.6	81.6	8.0		
	23	92.5	85.5	7.0	7.6	0.4
	24	89.8	82.0	7.8		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 1
Set Ident: Summer-2
Sampling Date: 31 July 1984
Collector: E. Dunn
Sampling Site: Goshen / Hwy 45
Receiver: W. R. Green
Pretreatment: 0.45um fltr/autoclaved
Responsible Technician: WRG
Innoculation Date: 2 August 1984
Completion Date: 16 Aug 84
Innoculum Size: 1,000 cells per ml
Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	98.1	89.9	8.2		
	2	98.9	90.9	8.0	7.3	1.7
	3	102.3	97.1	5.2		
P	4	103.5	95.1	8.4		
	5	98.6	92.7	5.9	7.3	1.0
	6	100.4	92.8	7.6		
N	7	96.5	91.5	5.0		
	8	100.8	96.4	4.4	4.5	0.5
	9	91.9	87.9	4.0		
P+N	10	98.7	96.2	2.5		
	11	90.2	87.7	2.5	2.6	0.1
	12	93.3	90.6	2.7		
E	13	87.3	84.8	2.5		
	14	91.6	86.9	4.7	5.1	2.8
	15	93.4	85.3	8.1		
P+E	16	92.5	84.0	8.5		
	17	96.3	87.5	8.8	8.6	0.2
	18	93.3	84.7	8.6		
N+E	19	90.0	80.5	9.5		
	20	97.3	88.8	915	9.2	0.4
	21	95.8	87.0	9.5		
P+N+E	22	98.0	88.9	9.1		
	23	95.6	85.7	10.1	10.1	1.1
	24	98.7	87.5	11.2		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 2 Set Ident: Summer-2
Sampling Date: 31 July 1984 Collector: E. Dunn
Sampling Site: Highway 68 Bridge Receiver: W. R. Green
Pretreatment: 0.45um fltr/autoclaved Responsible Technician: WRG
Innoculation Date: 2 August 1984 Completion Date: 16 Aug 84
Innoculum Size: 1,000 cells per ml Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	88.1	87.5	0.6		
	2	87.0	86.6	0.4	0.5	0.1
	3	84.5	84.0	0.5		
P	4	80.7	80.1	0.6		
	5	88.3	87.9	0.4	0.6	0.2
	6	84.8	84.1	0.7		
N	7	86.8	86.4	0.4		
	8	85.5	85.2	0.3	0.3	0.1
	9	87.2	87.0	0.2		
P+N	10	83.2	82.7	0.5		
	11	88.9	88.1	0.8	0.7	0.2
	12	84.1	83.4	0.7		
E	13	83.8	83.6	0.2		
	14	88.6	88.3	0.3	0.3	0.1
	15	87.6	87.2	0.4		
P+E	16	87.8	86.6	1.2		
	17	87.2	85.9	1.3	1.3	0.1
	18	87.5	86.2	1.3		
N+E	19	86.6	86.5	0.1		
	20	85.5	85.4	0.1	0.1	0.1
	21	87.6	87.4	0.2		
P+N+E	22	86.9	85.5	1.4		
	23	87.2	85.5	1.7	1.6	0.2
	24	82.0	80.2	1.8		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 3
Sampling Date: 31 July 1984
Sampling Site: Hickory Creek Boat Dk
Pretreatment: 0.45um fltr/autoclaved
Innoculation Date: 2 August 1984
Innoculum Size: 1,000 cells per ml

Set Ident: Summer-2
Collector: E. Dunn
Receiver: W. R. Green
Responsible Technician: WRG
Completion Date: 16 Aug 84
Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	89.3	89.3	0.0		
	2	91.2	91.1	0.1	0.1	0.1
	3	89.5	89.4	0.1		
P	4	88.1	87.8	0.3		
	5	79.0	78.6	0.4	0.5	0.2
	6	84.6	83.9	0.7		
N	7	84.1	83.9	0.2		
	8	87.8	87.5	0.3	0.2	0.1
	9	81.8	81.7	0.1		
P+N	10	86.2	85.7	0.3		
	11	88.5	87.9	0.6	0.6	0.1
	12	85.7	85.0	0.7		
E	13	85.6	85.5	0.1		
	14	86.7	86.6	0.1	0.1	0.0
	15	79.1	79.0	0.1		
P+E	16	84.2	83.1	1.1		
	17	86.2	85.4	0.8	1.0	0.2
	18	87.9	86.9	1.0		
N+E	19	83.0	83.0	0.0		
	20	86.2	86.2	0.0	0.0	0.0
	21	86.0	86.0	0.0		
P+N+E	22	86.6	85.5	1.1		
	23	86.3	84.5	1.8	1.5	0.4
	24	90.7	88.4	1.7		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 4	Set Ident: Summer-2
Sampling Date: 31 July 1984	Collector: E. Dunn
Sampling Site: Highway 12 Bridge	Receiver: W. R. Green
Pretreatment: 0.45um fltr/autoclaved	Responsible Technician: WRG
Innoculation Date: 2 August 1984	Completion Date: 16 Aug 84
Innoculum Size: 1,000 cells per ml	Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	80.3	80.1	0.2		
	2	85.3	84.9	0.4	0.2	0.2
	3	89.0	89.0	0.0		
P	4	88.1	87.3	0.8		
	5	85.9	85.3	0.6	0.7	0.1
	6	86.2	85.4	0.8		
N	7	86.0	85.8	0.2		
	8	87.5	87.3	0.2	0.2	0.1
	9	87.9	87.8	0.1		
P+N	10	91.3	90.3	1.0		
	11	81.9	80.9	1.0	1.1	0.2
	12	85.2	83.9	1.3		
E	13	88.9	88.6	0.3		
	14	84.8	84.3	0.5	0.3	0.2
	15	84.9	84.9	0.0		
P+E	16	83.2	82.5	0.7		
	17	84.7	84.0	0.7	0.7	0.1
	18	89.4	88.6	0.8		
N+E	19	87.4	87.4	0.0		
	20	88.7	88.7	0.0	0.0	0.1
	21	81.9	81.8	0.1		
P+N+E	22	89.7	88.9	0.8		
	23	88.5	87.7	0.8	0.8	0.1
	24	88.5	87.8	0.7		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 1
Sampling Date: 30 October 1984
Sampling Site: White Rv/Hwy 45
Pretreatment: 0.45um fltr/autoclaved
Innoculation Date: 2 November 1984
Innoculum Size: 1,000 cells per ml

Set Ident: Fall
Collector: E. Dunn
Receiver: R. L. Meyer
Responsible Technician: WRG
Completion Date: 17 Nov 84
Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	98.3	97.3	1.0		
	2	94.6	93.6	1.0	0.9	0.1
	3	98.0	97.2	0.8		
P	4	96.4	95.3	1.1		
	5	95.0	93.8	1.2	1.3	0.2
	6	81.2	79.6	1.6		
N	7	87.8	86.9	0.9		
	8	84.4	83.8	0.6	0.7	0.1
	9	88.5	87.8	0.7		
P+N	10	93.0	92.3	0.7		
	11	99.1	98.6	0.5	0.5	0.2
	12	97.7	97.4	0.3		
E	13	98.7	97.9	0.8		
	14	96.3	95.6	0.7	0.7	0.1
	15	95.5	94.9	0.6		
P+E	16	87.8	87.2	0.6		
	17	87.6	87.1	0.5	0.5	0.0
	18	93.1	92.6	0.5		
N+E	19	87.9	87.3	0.6		
	20	93.6	92.9	0.7	0.6	0.0
	21	94.4	93.8	0.6		
P+N+E	22	93.0	92.5	0.5		
	23	95.8	95.2	0.6	0.6	0.0
	24	93.7	93.1	0.6		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 2 Set Ident: Fall
Sampling Date: 30 October 1984 Collector: E. Dunn
Sampling Site: Highway 68 Bridge Receiver: R. L. Meyer
Pretreatment: 0.45um fltr/autoclaved Responsible Technician: WRG
Innoculation Date: 2 November 1984 Completion Date: 17 Nov 84
Innoculum Size: 1,000 cells per ml Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	84.1	83.4	0.7		
	2	82.8	82.3	0.5	0.5	0.1
	3	87.3	86.9	0.4		
P	4	82.6	81.7	0.9		
	5	89.5	88.7	0.8	0.8	0.1
	6	94.4	93.8	0.6		
N	7	91.7	90.8	0.9		
	8	87.1	86.3	0.8	0.8	0.1
	9	88.2	87.8	0.4		
P+N	10	90.5	89.4	1.1		
	11	98.2	97.1	1.1	1.1	0.0
	12	95.4	94.3	1.1		
E	13	96.0	94.4	1.6		
	14	93.2	91.8	1.4	1.3	0.3
	15	97.3	96.4	1.1		
P+E	16	96.5	93.8	2.7		
	17	92.9	90.7	2.2	2.5	0.2
	18	87.7	85.2	2.5		
N+E	19	88.2	87.2	1.0		
	20	88.0	87.2	0.8	0.8	0.1
	21	90.3	89.6	0.7		
P+N+E	22	97.5	94.0	2.5		
	23	100.8	98.4	2.4	2.4	0.0
	24	86.8	94.4	2.4		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 3 — Set Ident: Fall
Sampling Date: 30 October 1984 — Collector: E. Dunn
Sampling Site: Hickory Creek Boat Dk — Receiver: R. L. Meyer
Pretreatment: 0.45um fltr/autoclaved — Responsible Technician: WRG
Innoculation Date: 2 November 1984 — Completion Date: 17 Nov 84
Innoculum Size: 1,000 cells per ml — Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	INITIAL WT	NET WT**	MEAN WT	STD DEV
Contrl	1	99.3	98.7	0.6		
	2	96.7	96.0	0.7	0.7	0.0
	3	92.6	91.9	0.7		
P	4	86.0	84.5	1.5		
	5	86.9	85.9	1.0	1.2	0.2
	6	86.1	85.1	1.0		
N	7	89.2	88.6	0.6		
	8	92.2	91.9	0.3	0.4	0.1
	9	95.6	95.2	0.4		
P+N	10	95.8	94.4	1.4		
	11	94.5	92.9	1.6	1.5	0.1
	12	96.0	94.0	2.0		
E	13	84.8	83.6	1.2		
	14	88.7	87.9	1.2	1.2	0.0
	15	84.3	83.0	1.3		
P+E	16	91.4	89.2	2.2		
	17	95.1	92.9	2.2	2.1	0.1
	18	96.0	94.0	2.0		
N+E	19	92.1	91.9	0.2		
	20	92.3	92.0	0.3	0.2	0.0
	21	85.6	85.4	0.2		
P+N+E	22	86.2	84.6	1.6		
	23	89.6	87.9	1.7	1.6	0.1
	24	84.9	83.4	1.5		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

ALGAL ASSAY BOTTLE TEST DATA SHEET

Sample Ident: Beaver Lake # 4 | Set Ident: Fall
Sampling Date: 30 October 1984 | Collector: E. Dunn
Sampling Site: Highway 68 Bridge | Receiver: R. L. Meyer
Pretreatment: 0.45um fltr/autoclaved | Responsible Technician: WRG
Innoculation Date: 2 November 1984 | Completion Date: 17 Nov 84
Innoculum Size: 1,000 cells per ml | Test Volume: 50 ml

SPIKE*	BTL #	FINAL WT	- INITIAL WT	= NET WT**	MEAN WT	STD DEV
Contrl	1	90.3	90.1	0.2		
	2	98.4	98.3	0.1	0.1	0.1
	3	87.2	97.2	0.0		
P	4	98.9	98.7	0.2		
	5	97.0	96.9	0.1	0.1	0.0
	6	93.3	93.2	0.1		
N	7	86.2	86.2	0.0		
	8	86.3	86.3	0.0	0.0	0.0
	9	87.6	87.6	0.0		
P+N	10	89.4	89.1	0.3		
	11	99.8	99.6	0.2	0.2	0.0
	12	97.8	97.6	0.2		
E	13	86.5	86.2	0.2		
	14	87.2	87.0	0.2	0.3	0.1
	15	85.7	85.3	0.4		
P+E	16	84.4	84.0	0.4		
	17	94.0	93.6	0.4	0.4	0.0
	18	97.9	97.4	0.5		
N+E	19	90.0	90.0	0.0		
	20	97.8	97.8	0.0	0.0	0.0
	21	96.4	96.3	0.1		
P+N+E	22	97.6	97.3	0.3		
	23	95.6	95.4	0.2	0.3	0.0
	24	93.7	93.4	0.3		

*Additions: 0.05 mg P l^{-1}, 1.00 mg N l^{-1}, 1.00 mg Na-EDTA l^{-1}
**Milligrams dry weight.

PART II

A STRATEGY FOR MANAGING WATER QUALITY IN BEAVER LAKE

Final Report

Prepared by: Larry R. Aggus
Aquatic Ecosystem Analysts

For: Beaver Lake Water Quality Management Strategies Committee

Submitted to: Arkansas Water Resources Research Center

April, 1985

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COMMITTEE MEMBERS

The following individuals gave their time freely to participate in committee meetings, provided guidance and council, and adapted to a changing schedule of delivery dates.

Robert Anderson	Resident Engineer, Beaver Lake Project, U. S. Army Engineers
James Beard	Beaver Lake Project, U. S. Army Engineers
James Brigance	Arkansas Forestry Commission
Joel Bunch	Elkins, Arkansas
Lewis Epley, Jr.	Boone-Carroll Water District
Ralph Fourt	Arkansas Game and Fish Commission
Joe Gaston	Soil Conservation Service, Washington Co.
Les Heileman	University of Arkansas, Agronomy
David Herdlinger	Springdale City Attorney
James House	Washington County Health Department
Will Jeffery	Soil Conservation Service, Madison Co.
Hugh Jeffus	University of Arkansas, Civil Engineering
Charles Johnson	Washington County Judge
Edward Lawson	Southern Forest Experiment Station, U. S. Forest Service
James McCord	Fayetteville City Attorney
Richard Meyer	University of Arkansas, Botany
Ellen Neaville	Beaver Lake Advisory Committee
Phillip Norvell	University of Arkansas, Law School
A. L. Norwood	Benton County Judge
Wallace Phillips	Soil Conservation Service, Washington Co.
R. Douglas Schrantz	Rogers City Attorney
Richard Starr	Beaver Water District
Larry Wood	Northwest Arkansas Regional Planning Commission

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A STRATEGY FOR MANAGING WATER QUALITY IN BEAVER LAKE

Part 1. INTRODUCTION

The quality of water in Beaver Lake reflects a balance between natural features of the watershed, the effects of human activities, and the capacity of the reservoir to assimilate nutrients or pollutants. Compared to many other sections of the state, historical water quality of streams in the Northwest Arkansas Area (NWA) has been good. Large tracts of forest land and high-gradient streams contributed to good surface water quality. However, since the 1950s, rapid growth in population and associated urban development, agriculture, and light industry in Northwest Arkansas have significantly changed land uses and the associated delivery of nutrients and other pollutants to surface waters. This growth will continue, and finding ways to maintain high quality water while accommodating increasing population and the associated development will be a major challenge for community leaders.

Impoundment of Bull Shoals, Table Rock, and Beaver lakes on the main stem of the White River significantly altered land use patterns and population distribution in the upper White River basin, and provided impetus for rapid economic growth in North Arkansas. These reservoirs have excellent water quality which has greatly enhanced the recreational potential of the White River, which currently represents an important element in the regional economy.

Beaver Lake impounds 28,200 acres in Benton, Carroll, Madison and Washington counties. It serves residents in the four-county area through the authorized project functions of flood control, hydropower generation, and municipal and industrial water supply. Although not an authorized function, recreation is a major economic benefit of the impoundment. Use of the reservoir for water supply and primary contact water-based recreation requires a high level of water quality. Residents of NWA have strongly supported actions to insure that good water quality is maintained.

Historically, water quality management in Beaver Lake has been approached as a series of specific problems, each requiring appropriate actions. Not surprisingly, these efforts have focused on the Fayetteville Waste Treatment Plant (FWTP), the largest point source of pollution to the reservoir, and have resulted in a series of corrective measures designed to reduce the delivery of primary nutrients and other pollutants to the reservoir.

During the past decade, the facility has been the subject of intense debate by concerned citizens and state and federal regulatory agencies in regard to nutrient discharges. The effluent has been linked to severe degradation of water quality in the White River downstream from the plant during periods of low streamflow.

Previous modeling studies have indicated that from 28 to 62 percent of the total annual phosphorus load to Beaver Lake comes from this source (Gearheart, 1974; Black and Veach, 1982, respectively). The city of Fayetteville completed a plan to upgrade the facility which was approved by the Department of Pollution Control and Ecology and the Environmental Protection Agency during 1984. Construction of an advanced waste treatment facility utilizing state-of-the-art engineering technologies began in early 1985.

Future water quality management must address methods to control the input of primary nutrients and pollutants from many other sources at diverse locations in the basin. This will require a long-term commitment of time and resources wherein pollutants resulting from various land-use practices must first be quantified to determine if they significantly influence the total load of the reservoir. Priorities must then be established to assess the feasibility and cost of their control, and to target those sources which pose the most serious threats to reservoir water quality.

Unlike the Fayetteville Waste Treatment Plant, most of these sources will 1) violate no state water quality standards, 2) contribute nutrients or pollutants primarily during times of high stream flow, and 3) have little visible effect on stream water quality. However, they may represent a greater total contribution of pollutants to Beaver Lake than the FWTP point source. Management solutions may require actions such as planning and zoning, education and information transfer, financial incentives, and regulation. They may also require multi-agency involvement to collectively address problems. Several federal, state, and local agencies currently have authority to regulate surface-water quality and they are actively engaged in management activities which impact directly on the reservoir. Efforts to develop a management strategy at the community level will require a high level of communication and coordination among existing authorities.

In December, 1983, the Department of Pollution Control and Ecology and the Arkansas Water Resources Research Center entered into an agreement to develop a water-quality management strategy for Beaver Lake. The Beaver Lake Water Quality Management Strategies Committee was formed in response to this action. The committee was composed of representatives of county and city governments in the basin and federal and state management and regulatory agencies. This group was asked to examine the status of water quality in the basin, identify significant pollution concerns and methods of control, describe available data sources and information gaps, and provide recommendations for an organizational and legal framework to initiate a management program made up of local citizens. The effort was predicated on the hypothesis that residents of Northwest Arkansas should assume the lead in making important decisions concerning the future water quality of Beaver Lake. An organization made up of representatives of local governments, concerned citizens, and special interests should work collectively to identify important water-quality problems, establish priorities for their control, and take needed management actions to communicate interests to the appropriate regulatory agencies.

The main body of this report is organized to provide background information needed to formulate a basinwide water-quality management strategy. Following this introductory section (Part 1). Historical biological, chemical, and physical information on the reservoir from a variety of published and unpublished s@]ources are presented to show how Beaver Lake responds to nutrient loading, and how its water quality compares to that of other impoundments in the South and throughout the U.S. (Part 2). In Part 3, general land uses in the watershed are reviewed, and management strategies to control the major nutrient sources to the reservoir are discussed. Historical water-quality information available from existing sources, and major data gaps are summarized in Part 4. This section also contains recommendations for a minimal water-quality monitoring program which would detect long-term changes in reservoir water quality. A summary of existing regulatory authorities and possible alternatives for organizational structures are included in Part 5. A brief summary of concepts presented in the previous sections is included in Part 6. Recommendations are included in Part 7.

Part 2. WATER QUALITY CHARACTERISTICS OF BEAVER LAKE

Background

A long-term strategy to manage water quality in Beaver Lake must be based on a general understanding of existing conditions and the benefits to be expected from management actions. It will require insight into 1) the dominant physical, chemical, and biological features of the reservoir and how these compare to those in other impoundments; 2) how the reservoir functions to process or assimilate nutrients; and 3) the changes in water quality that have occurred through time to determine the rate of enrichment or eutrophication. This information is available primarily from published and unpublished studies on this reservoir and impoundments with similar physical and chemical features.

In this section we compare important water-quality and biological features of Beaver Lake with those of other reservoirs in the United States, describe in very general terms how large storage reservoirs like Beaver Lake receive and process nutrients, and identify documented trends in water quality and biological productivity measured from 1969 (the year after the reservoir filled) until 1981.

Beaver Lake Water Quality Compared to that of Other Reservoirs

Both the concentration (quantities present per unit volume of water) and loading (quantities arriving per unit of time, expressed per unit of surface area) of nitrogen and phosphorus are widely used to evaluate trends in water quality. Concentrations of these nutrients may limit (separately or together) the production of algae in reservoirs, and their concentrations are used to characterize the trophic status or productivity of water bodies. Loading provides a measure of the total quantity of nutrients entering a reservoir per unit of time. Chlorophyll *a*, a pigment extracted from algae, is useful for indexing algal biomass. Water transparency (i.e., water clarity), when measured with a Secchi disk in late summer when silt concentrations are low, provides a good index of algal biomass.

Concentrations and loadings of nutrients are not always accurate indicators of water quality in reservoirs. Hern *et al*. (1978), concluded that nutrient concentrations or loadings to reservoirs may suggest that water quality is degraded more than it actually is. The authors recommended measuring chlorophyll *a* or primary productivity in addition to nutrients because the biological manifestations of nutrient loading are what truly reflect water-quality degradation. High nutrient concentrations reveal only the potential for water quality problems. The ability of algae to use these excess nutrients depends, among other things, on the availability of light and micronutrients (silica, iron, etc.) and the presence of inhibitory substances, as well as on the concentrations of phosphorus and nitrogen.

The major work available for comparing the water quality of Beaver Lake with that of other U.S. reservoirs is the National Eutrophication Survey (NES) which was conducted between 1972 and 1977 (Environmental Protection Agency, Working Paper No. 476, 1978). This study included the sampling of more than 800 U.S. lakes and reservoirs over a four-year period. Reservoirs in the central and southern U.S. were sampled during 1974. While these data were obtained over a decade ago, they provide good insights into how the water quality of Beaver Lake compared with that of other large reservoirs sampled at the same time.

The NES data showed that concentrations in and annual loadings of nitrogen and phosphorus to Beaver Lake were lower than the average for 119 southern reservoirs and 757 reservoirs nationwide (Table 1). Total nitrogen concentrations in Beaver Lake were lower than those in 54 percent of the sample of southern reservoirs, and concentrations of total phosphorus were lower than concentrations measured in 75 percent of the southern reservoirs sampled and in 76 percent of the reservoirs sampled nationwide. Loadings of total nitrogen and total phosphorus were lower than 62 percent and 68 percent, respectively, of the loadings to other reservoirs in the southern sample.

Chlorophyll *a* concentrations in Beaver Lake were very low when compared to those in other reservoirs in the NES. Average summer chlorophyll *a* concentrations in the reservoir were lower than those in 90 and 93 percent of the impoundments in the southern and national samples, respectively. As would be expected with the low chlorophyll *a* concentrations, the summer Secchi disk transparency of Beaver Lake was comparatively high. Transparency in Beaver Lake was higher than 77 and 75 percent of the southern and U.S. reservoirs sampled, respectively.

To illustrate how the water quality of Beaver Lake compared with that of other impoundments in surrounding watersheds, total nitrogen and total phosphorus loadings for several area reservoirs were summarized (Table 1). Loadings of both nitrogen and phosphorus to Beaver Lake, other large White River impoundments, and DeGray Lake were low when compared with those of other reservoirs in the area. DeGray Lake is included here because it is similar in morphology to the major White River storage impoundments, and it has been studied intensively with respect to nutrient cycling and biological production. These storage reservoirs impound very large volumes of water relative to their average annual inflows, and therefore exchange water more slowly than do non-storage reservoirs. For example, at power pool level, Beaver Lake contains a volume of water equal to 1.5 years of inflow from the watershed under average conditions. This storage ratio is

0.7 years for Bull Shoals Lake, 1.0 years for Table Rock Lake, and 1.2 years for DeGray Lake. As a comparison, Jenkins (1982) reported an average storage ratio of 0.67 years for a sample of 290 large U.S. reservoirs.

Table 1. Annual loadings of total phosphorus (TP) and total nitrogen (TN) to selected reservoirs in Arkansas and Oklahoma

	Nutrient loading (lbs./acre/year)	
	TP	TN
DeGray, AR	2	30
Bull Shoals, AR	5	340
Beaver, AR	6.4	125
*Beaver (above BWD intake), AR	54	990
Table Rock, AR	14	250
Grand Lake, OK	63	650
Lake Frances, AR	330	5200
Average for 115 Southern Reservoirs	40	380

*Assumes 100% of loading above Beaver Water District (BWD) intake structure.

Because water moves very slowly through these large storage impoundments, the reservoirs assimilate or trap a large percentage of the incoming nutrients in the upstream reaches. Water quality in these reservoirs tends to reflect the accumulation of natural and man-induced loadings which occur throughout the year.

In spite of the relatively low nutrient loadings to these storage impoundments, tributaries often contain high concentrations of nutrients, and this causes serious water quality problems in the uplake reaches. In Beaver Lake, the White River and War Eagle Creek have contributed a high percentage of the total nutrient load to the reservoir since impoundment. Nutrients are more concentrated in the uplake area, and biological production there is high when compared to downlake areas. For example, total phosphorus and total nitrogen loadings calculated only for the area above the intake of the Beaver Water District's treatment plant are about 9 times that for the entire reservoir (Table 1), and higher than the average for the 119 southern reservoirs sampled in the NES. At conservation pool, this area includes only about 5 percent of the volume and 11 percent of the surface area of the reservoir. Future water quality in the extreme uplake reach is of special concern because much of Northwest Arkansas receives drinking water from this source. From a recreational perspective, much of the reservoir has good water quality.

Severe degradation of water quality in the White River downstream from the Fayetteville Waste Treatment Plant when streamflows are low is well documented. State water quality standards are violated annually in this area, and fish kills have occurred seasonally downstream of the plant's outfall. Field and associated water quality modeling studies have provided excellent documentation of the effects of the Waste Treatment Plant on water quality in the White River. For example, Terry, Morris and Bryant (1983), found that temperature, dissolved oxygen, dissolved solids, unionized ammonia, total phosphorus, floating solids, and depositable materials did not meet Arkansas water quality standards for several miles downstream from the Fayetteville Waste Treatment Plant.

Factors Influencing Nutrient Loading and Assimilation

Nutrients enter Beaver Lake from many diverse point and nonpoint sources throughout the basin. In the past several years, contributions from the Fayetteville Waste Treatment Plant (the largest point source) have been accurately measured. However, total loadings from many nonpoint and small agricultural and urban point sources remain poorly defined.

A large number of engineering, water quality, and biological studies have been directed at describing the potential for nutrient loading from different sources such as septic systems, urban runoff, and agricultural lands. However, these studies have historically been of short duration and therefore do not afford the quantitative information needed to define the relative contributions of different sources to the total nutrient load of

Beaver Lake. These studies will not be reviewed in this report, but the interested reader is referred to summaries by Hogue, *et al.* (1971), Ashworth and Mitchell (1982), and National Reservoir Research Program (1982).

Two important water quality studies have addressed the relative loadings of nitrogen and phosphorus to Beaver Lake from various point and nonpoint sources, and these produced different results. An extensive field and modeling study by Gearheart (1973) indicated that Fayetteville Waste Treatment Plant effluent contributed about 28 percent of the annual phosphorus load to Beaver Lake. Nonpoint sources, primarily agricultural runoff, were identified as the primary phosphorus source; these accounted for about 72 percent of the annual phosphorus load. A more recent water-quality modeling study of the area of Beaver Lake upstream of the Beaver Water District intake structure by Black and Veatch (1982) indicated that about 60 percent of the total phosphorus entering the reservoir annually was being contributed as a point source from the Fayetteville Waste Treatment Plant. The National Eutrophication Survey, Environmental Protection Agency, op. cit, produced results similar to those of Black and Veatch. Without speculating on the accuracy of these studies, it is apparent that identifying and quantifying the major nutrient sources remains difficult. The efforts have consistently identified the Fayetteville Waste Treatment Plant as the primary point source of phosphorus, and this has provided additional justification for upgrading the effluent from that facility.

The process of nutrient assimilation in Beaver Lake has not been accurately documented. However, an excellent case history study of nutrient loading and internal cycling in a similar reservoir (DeGray Lake near Arkadelphia, Arkansas) was completed in 1983. Between 1972 and 1980 the Waterways Experiment Station, U.S. Army Corps of Engineers, and the National Reservoir Research Program, U.S. Fish and Wildlife Service, sponsored intensive water quality and biological studies on DeGray Lake and its watershed. These studies were designed to evaluate the effects of releasing water at different outlet depths on reservoir water quality and fishery resources and to provide information needed for improved reservoir water quality and biological modeling.

DeGray Dam is located on the Caddo River on the south face of the Ouachita Mountains; its watershed is primarily forest and agricultural land. The largest town in the basin is Glenwood, Arkansas (population 1400). The reservoir is similar to Beaver Lake with respect to basin morphometry and water exchange rates (Table 2). Intensive water-quality studies on DeGray Lake were conducted under the direction of Dr. Joe Nix, Ouachita Baptist University, although a number of agencies, including the Waterways Experiment Station, U.S. Army Corps of Engineers, the U.S. Fish

Table 2. Selected physical characteristics of Beaver Lake and DeGray Lake, Arkansas

	Beaver	DeGray
Area (acres)	28,220	13,420
Average Depth (feet)	58	49
Maximum Depth (feet)	216	195
Thermocline Depth (feet)	25	20
Outlet Depth (feet)	140	60
Fluctuation (feet)	15	20
Storage Ratio (years)	1.5	1.2
Shore Development	19.1	12.8

and Wildlife Service, and the University of Arkansas contributed substantially to the field effort.

The DeGray work produced several important findings which provide valuable insights into how nutrient loading and cycling may occur in Beaver Lake. These studies demonstrated the importance of storms (major rainfall events) and seasonal variations in stream flow to the annual loading of nutrients to the reservoir. Accurate measurements of runoff patterns to DeGray Lake between 1976 and 1980 showed that much of the annual inflow to that reservoir occurred during a few storms (Figure 1). Runoff from storms contributed from 54 to 80 percent of the total volume of inflow to the lake annually (Figure 2). Seasonally, a large percent of the inflow came during the winter and spring. Patterns of seasonal inflow are similar in Beaver Lake.

Cumulative effects of inflows are of particular importance in reservoirs like Beaver and DeGray because of their long retention times. Water quality in these types of impoundments is influenced by inflows over periods of several months, and therefore tends to be very responsive to annual runoff patterns.

Findings with respect to phosphorus loading in DeGray Lake were also of interest, as concentrations of this nutrient increased in storm runoff. Loadings during storms accounted for between 90 and 94 percent of the total phosphorus entering that reservoir annually between 1976 and 1980 (Figure 3). The disproportionate loading of phosphorus during a few storms suggests that a large part of the annual loading to many storage impoundments may occur during brief time intervals, and therefore may be unmeasured because water-quality sampling in tributary streams is seldom attempted during high flows. In addition, conventional models for estimating nutrient loadings do not account for these large rapid or pulsed inputs of nutrients from nonpoint sources.

The DeGray work showed that the error associated with not measuring phosphorus loadings in storm runoff can be substantial. Montgomery (1982) estimated that 62,250 pounds of phosphorus entered DeGray Lake annually between 1976 and 1980 when storms

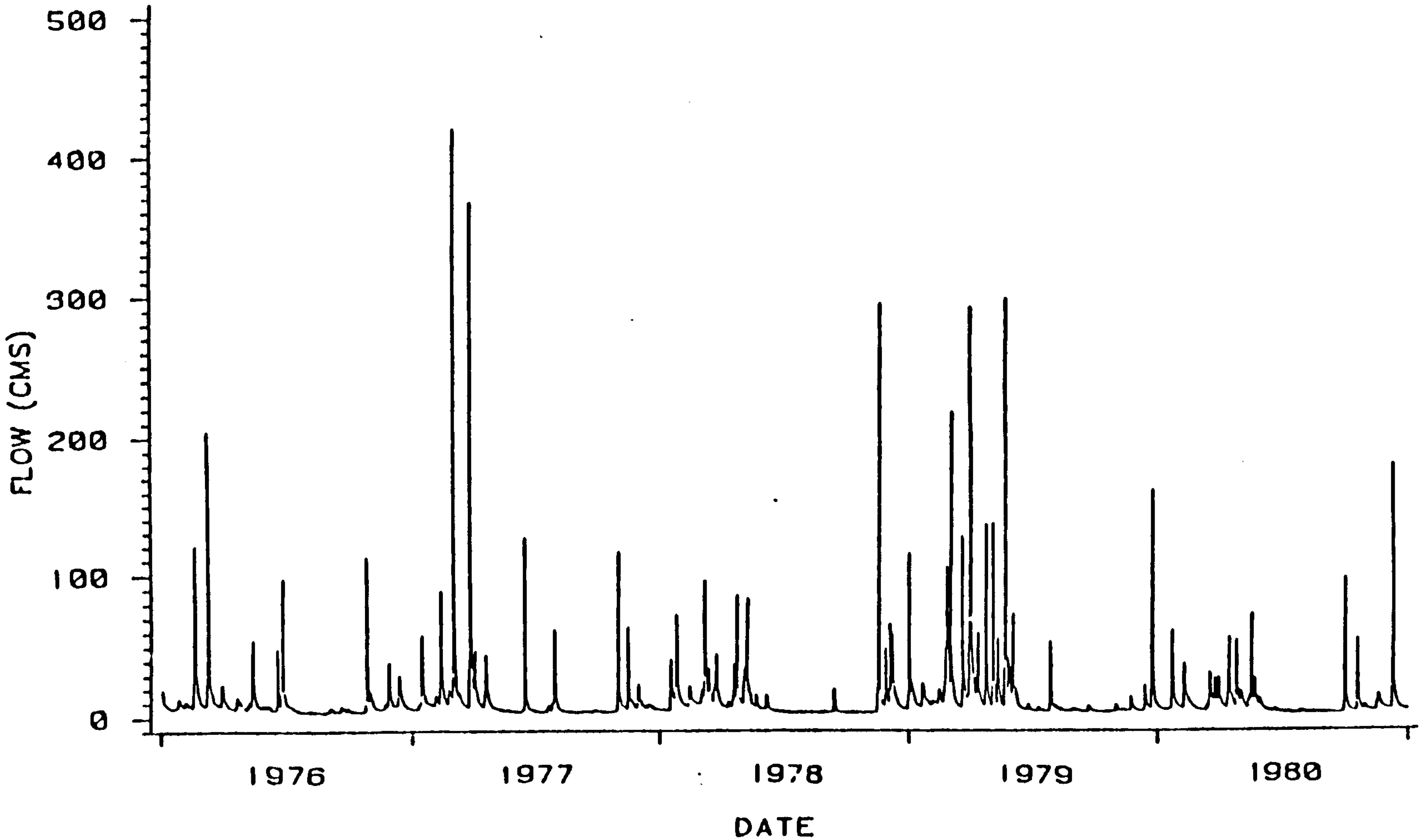

Figure 1. Daily hydrograph for the Caddo River above DeGray Lake (Highway 84 bridge) showing the amount of daily variation in inflow to the reservoir from 1976 to 1980. Flows are in cubic meters per second (CMS). Figure is from Montgomery (In press).

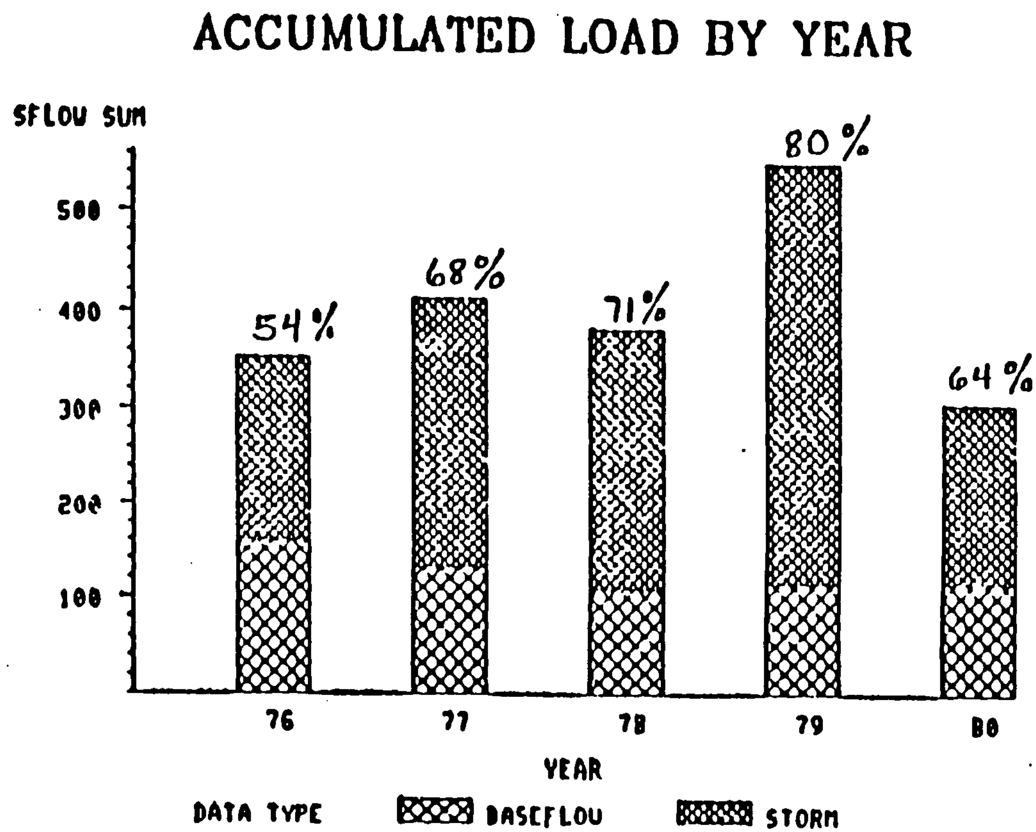

Figure 2. Accumulated annual water load (inflow) to DeGray Lake from baseflow and storm events from 1976 to 1980. Figure is from Montgomery (In press).

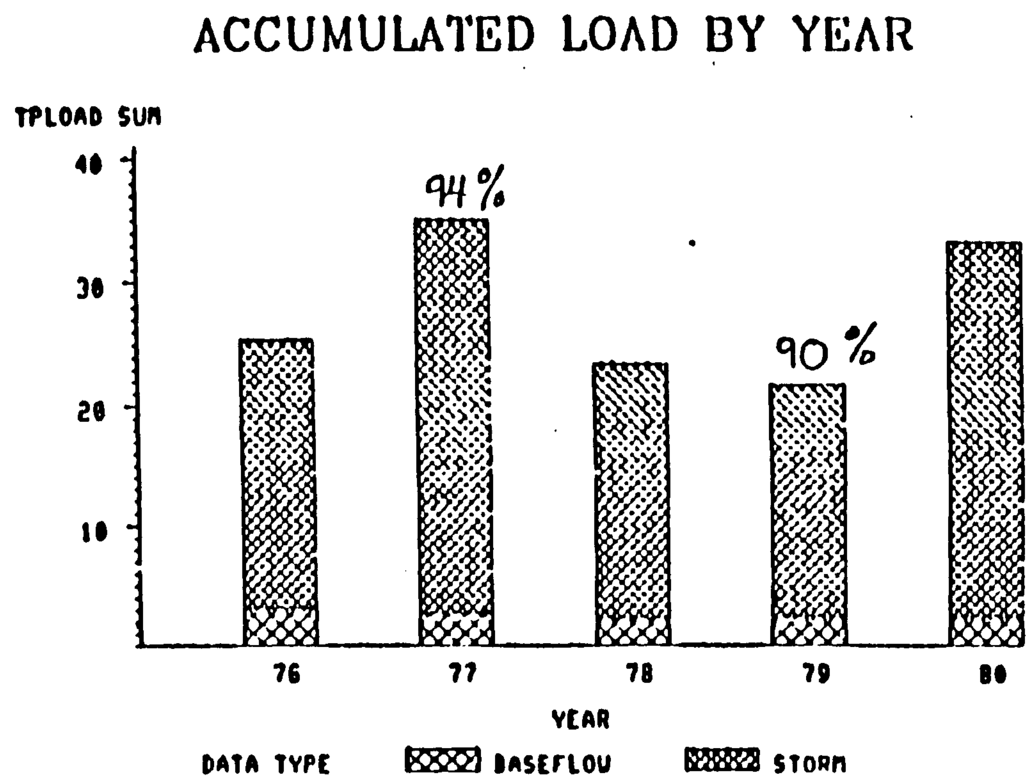

Figure 3. Accumulated annual total phosphorus load to DeGray Lake from baseflow and storm events from 1976 to 1980. Figure is from Montgomery (In press).

were included. By contrast, the National Eutrophication Survey placed annual phosphorus loading at only 25,880 pounds in 1974, an unusually wet year. The inclusion of the storm-event data more than doubled the estimated annual loading of total phosphorus and more importantly, it indicated an error of omission in conventional methods of calculating phosphorus loading. This largely represents nonpoint loading and suggests that significant errors may occur in estimated loadings from point and nonpoint nutrient sources when storm contributions are not measured.

The DeGray studies also provided good insight into the seasonal cycling of phosphorus and other materials in large storage impoundments. When compared to most other reservoirs, DeGray Lake and Beaver Lake are physically similar (Table 2). Both reservoirs have long theoretical retention times and similar average and maximum depths. Although DeGray is smaller with a shallower outlet depth, the two reservoirs exhibit similar seasonal patterns of thermal stratification.

The seasonal patterns of phosphorus loading, sedimentation, and resuspension in DeGray Lake have been described (see Figure 4, from Kennedy, et al., 1983), and indicate a predictable pattern of internal nutrient cycling. Loading of phosphorus to that reservoir was highest during the winter and spring. Much of this phosphorus was deposited in sediments in the upper reach of the reservoir where it remained until the onset of thermal

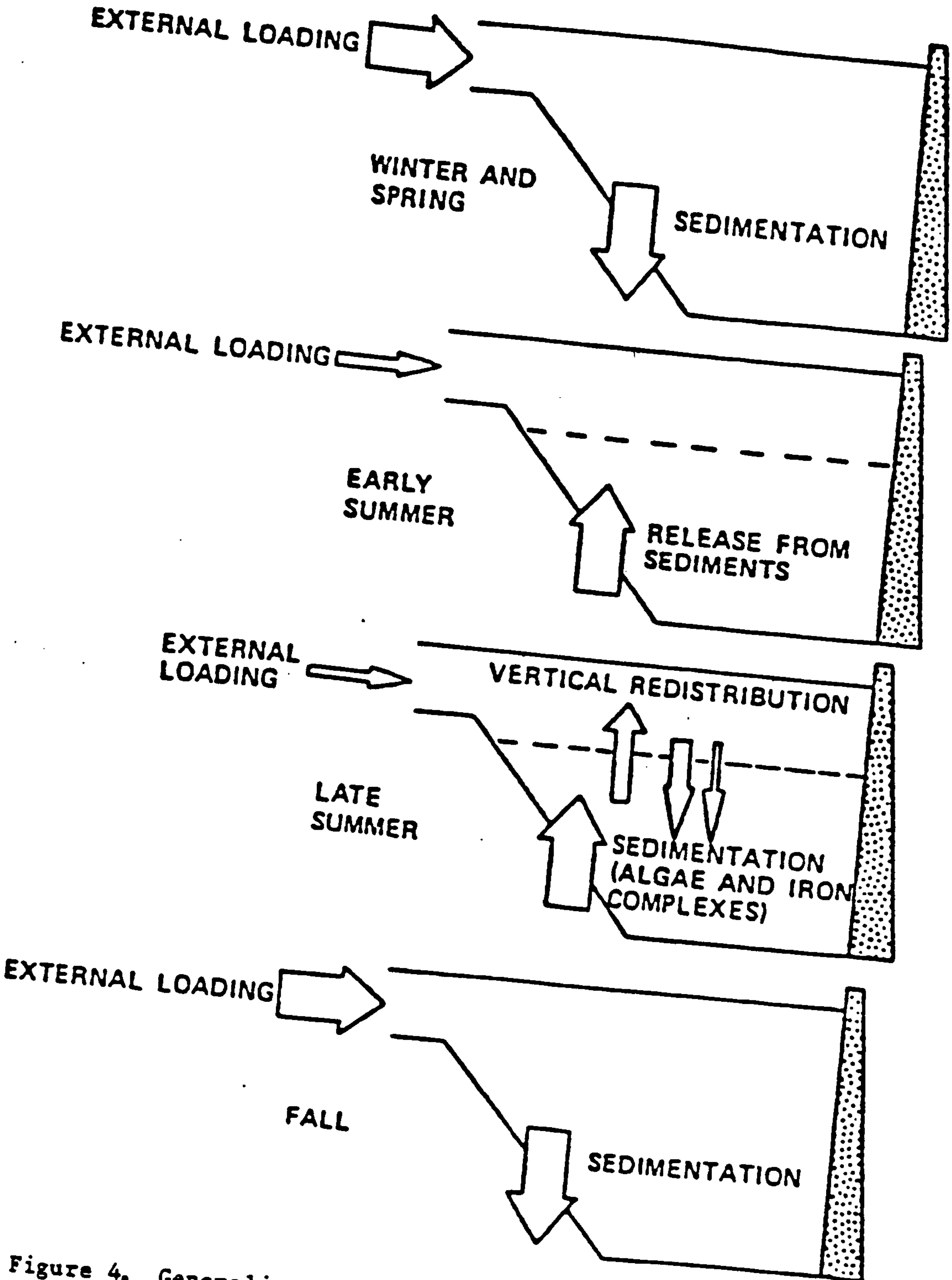

Figure 4. Generalized diagram of major phosphorus fluxes in DeGray Lake (importance of exchanges are indicated by arrow thickness). Figure is from Kennedy, *et al.* (1983).

stratification in late spring or early summer. When the reservoir stratified, the deeper areas were effectively sealed off from the surface and dissolved oxygen in deeper upstream areas was rapidly depleted. Under these reduced, or anoxic conditions, phosphorus and other materials (i.e., iron and manganese) become soluble. The materials accumulated in the deeper uplake areas during the summer. In late summer and early autumn, surface waters cooled and a period of mixing of nutrients into the surface waters occurred. Nutrient circulation to the surface waters where light was available stimulated algal production in the uplake area. Continued cooling and mixing increased oxygen concentrations. Under these conditions, phosphorus and other nutrients and metals were rapidly precipitated to the sediments, and concentrations in water decreased.

A recently completed study by Larson (1983) suggests a similar effect of late-summer mixing on the production of algae in Beaver Lake. The author found that algal production at this time was high in the upstream area of Beaver Lake but decreased downlake from the Highway 12 Bridge. This gradient occurs annually in reservoirs like DeGray Lake and Beaver Lake because anoxic conditions do not occur in the hypolimnion of the downlake reaches.

Sedimentation patterns and the presence of oxygen in the hypolimnion downlake results in these reservoirs serving as efficient nutrient traps, where nutrients are deposited and recycled primarily in the uplake reaches. The ultimate fate of these inflowing nutrients is an important concern in the development of a water-quality management strategy. If nitrogen, phosphorus and other pollutants are deposited in and covered with sediments in the extreme uplake areas, they may be effectively sealed off from future biological activity. Conversely, if these materials re-enter the water column each year through the mechanisms described for DeGray Lake, effects of nutrient loading could become cumulative. Feeney (1971) examined sediment cores from the uplake areas of Beaver Lake and found that nitrogen and phosphorus were indeed being deposited in uplake areas near the confluences of major tributaries. However, he did not determine if nutrients were recycled.

Long-Term Trends in Water Quality and Biological Processes

Long-term data collection is required to evaluate enrichment or eutrophication in reservoirs as there is much year-to-year variation in water quality because of different runoff patterns. Trends in water quality must be evaluated relative to these variations. Between 1969 and 1980, the National Reservoir Research Program systematically monitored several water-quality and biological characteristics of Beaver Lake. These did not include direct measures of nitrogen, phosphorus, or chlorophyll a, but included dissolved oxygen concentration, water transparency, and estimates of the biomass and harvest of fish. These measures reflect biological productivity of the reservoir, and provide good indices to trends in water quality.

Dissolved oxygen concentration and water transparency were sampled monthly throughout the period. Sampling was conducted at Hickory Creek (Station 6), Horseshoe Bend (Station 5), Prairie Creek (Station 4), Rocky Branch (Station 3), the mouth of Big Clifty Creek (Station 2), and at the dam (Station 1) to characterize seasonal and spatial trends in water quality.

Dissolved Oxygen: The amount of dissolved oxygen present in water is a direct indication of biological productivity. In reservoirs, the concentration of dissolved oxygen reflects a balance between photosynthesis and respiration in the biological community. The rate at which dissolved oxygen is depleted in deeper parts of storage reservoirs during summer stratification is a general index of the level of biological productivity. Personnel from the National Reservoir Research Program monitored dissolved oxygen monthly at 3 m (9.8 ft) depth intervals at each of the previously listed stations from 1968 through 1980. These data provide the only long-term record of spatial, temporal, and annual variations in dissolved oxygen patterns since the reservoir reached power pool level in 1968. This data base is large, and a thorough analysis was not within the scope of this summary. However, by using data from selected stations, depths, and times of year, insight into seasonal, spatial, and long-term trends is possible. We used measurements from a depth of 40 feet (12 m) to demonstrate spatial, seasonal, and annual variation in dissolved oxygen. This depth represents an approximate midpoint of the metalimnion. It is an area of comparatively high biological and chemical oxygen demand in a reservoir.

Comparison of dissolved oxygen (O_2) data obtained during mid-August from the 12-m depth stratum at each of the six sampling stations indicated substantial year-to-year variation in the spatial distribution of dissolved oxygen in the reservoir (Figure 5). The amount of dissolved oxygen present in deeper parts of the lake was related to the volume of inflow to the reservoir during the previous winter and spring. Dissolved oxygen levels were much lower during wet years (1973 and 1978) than during dry years (1972 and 1977). The greatest year-to-year variation occurred in the downlake areas of the reservoir.
A series of August depth profiles for dissolved oxygen from all stations and depths during a wet (1973) and a dry (1977) year illustrate the amount of variation that has occurred annually in Beaver Lake (Figure 6). Dissolved oxygen data collected during August, 1977 from Bull Shoals Lake were included to demonstrate that the spatial patterns and rates of oxygen depletion are similar for the major storage reservoirs on the White River.

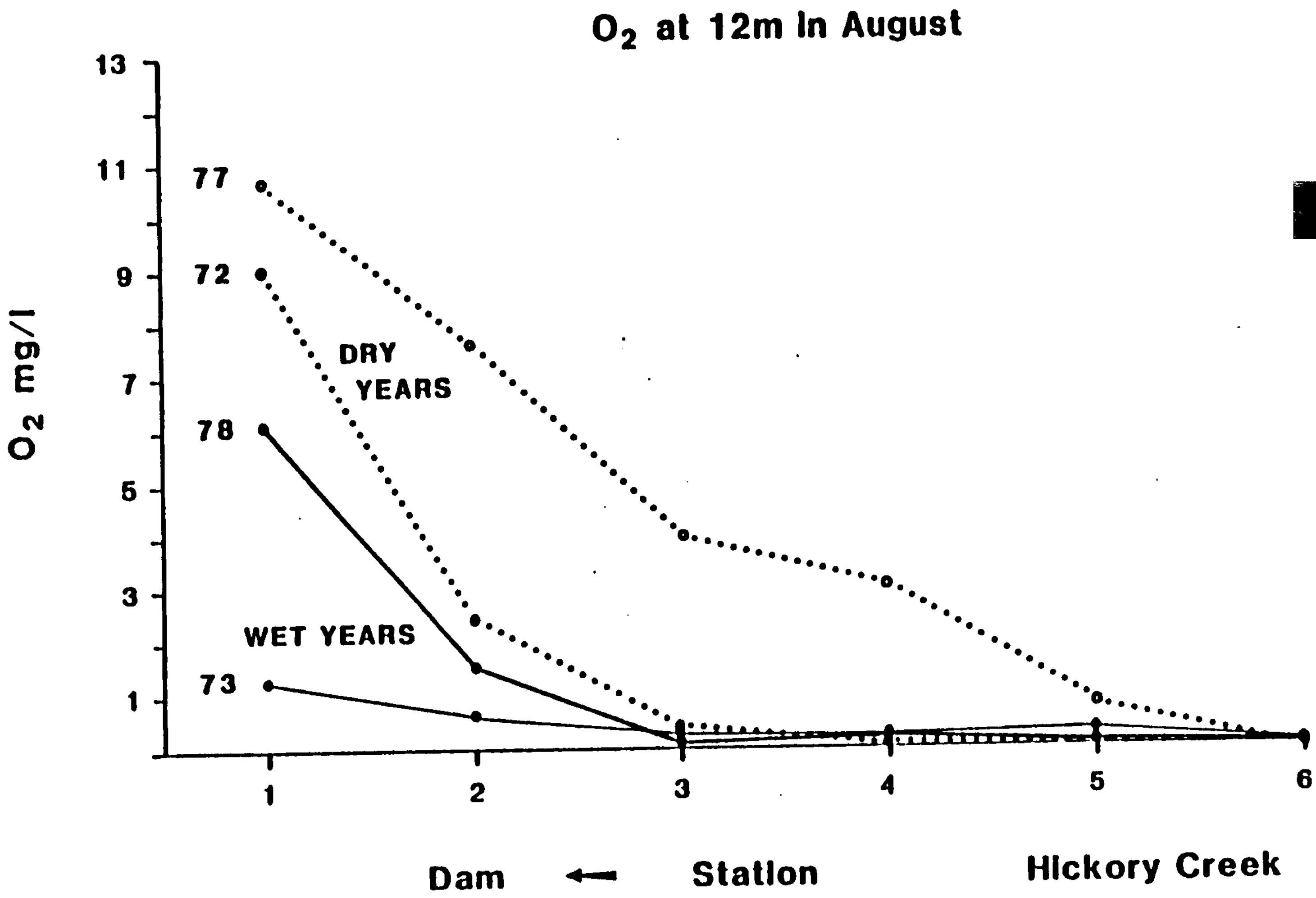

Figure 5. August dissolved oxygen concentrations at depths of 12 meters (= 40 feet) from Stations 1 through 6 in Beaver Lake. Solid lines are wet years (1973, 1978) and dotted lines are dry years (1972, 1977). Data collected by the National Reservoir Research Program, USFWS.

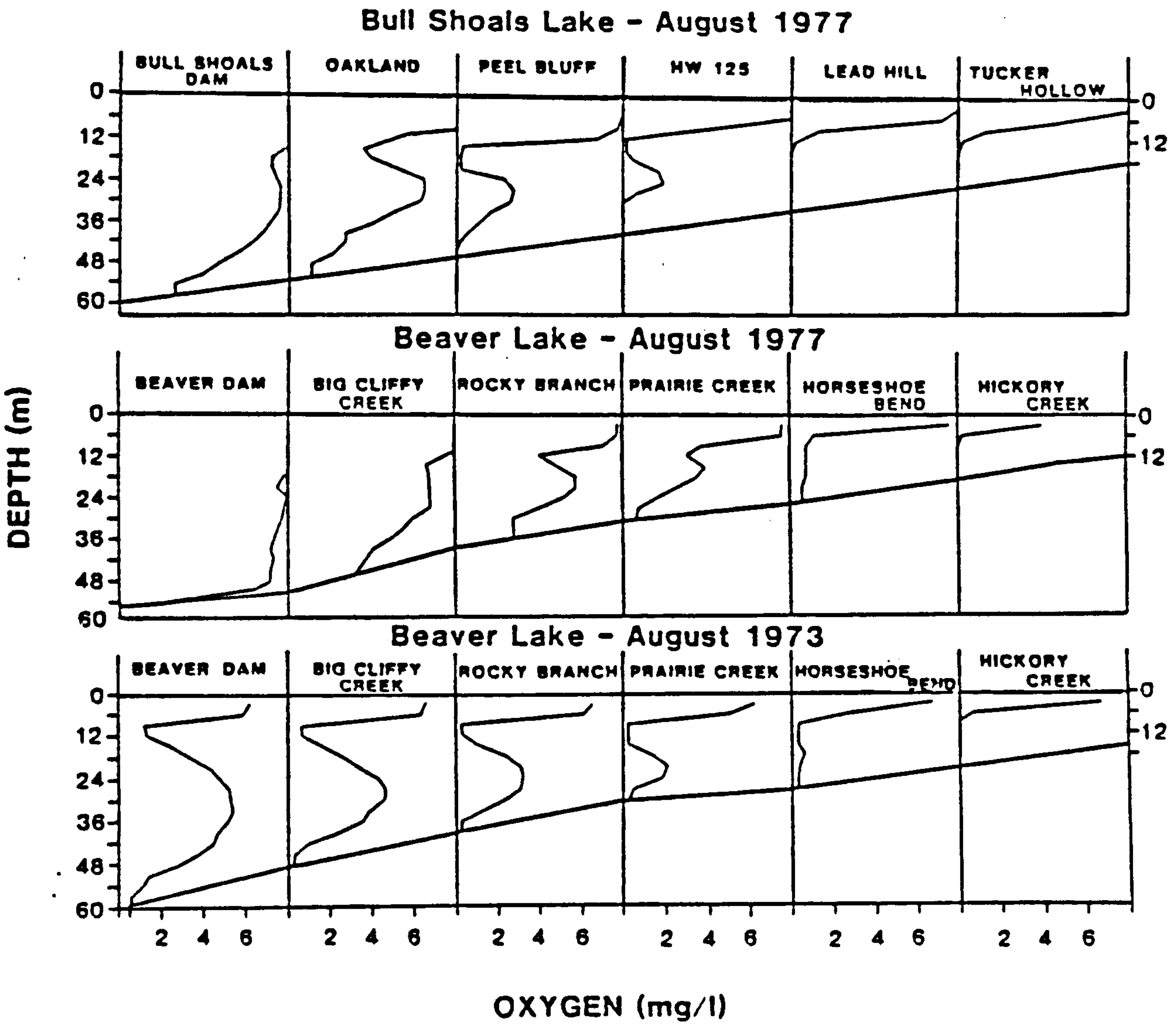

Figure 6. August dissolved oxygen profiles at six sampling stations in Beaver Lake during a dry year (1977), and a wet year (1973). Data from similar locations in Bull Shoals Lake (1977) are provided for comparison. Data were collected by the National Reservoir Research Program, USFWS.

As stated previously, the uplake area of Beaver Lake experiences the highest rates of chemical and biological activity, and consequently the most severe oxygen deficits during stratification. We examined the rates at which dissolved oxygen was depleted seasonally and from 1969-1979 in the Horseshoe Bend area to determine if these rates were increasing through time. This site was selected because it is far enough downlake to be buffered from the effects of individual storm events, but in an area of comparatively high biological production. Using the 12-m depth interval and measurements obtained from March through November each year, we were able to describe a seasonal pattern of oxygen concentrations for the station (Figure 7). Stratification usually was established by mid-April, and for the period from mid-April to mid-July the amount of dissolved oxygen present at this depth decreased by an average of about 2.5 mg/l/month. The rate varied annually from 2 to 3.5 mg/l/month, in relation to increasing inflows. Dissolved oxygen has essentially been depleted from this area by July each year since impoundment.

We compared average monthly rates of oxygen depletion each year to determine if rates had changed through time—an increase would indicate that the reservoir is becoming more eutrophic. Average rates of oxygen depletion for the period mid-April to mid-July at Horseshoe Bend showed no statistically significant increase with time (Figure 8). There were substantial year-to-

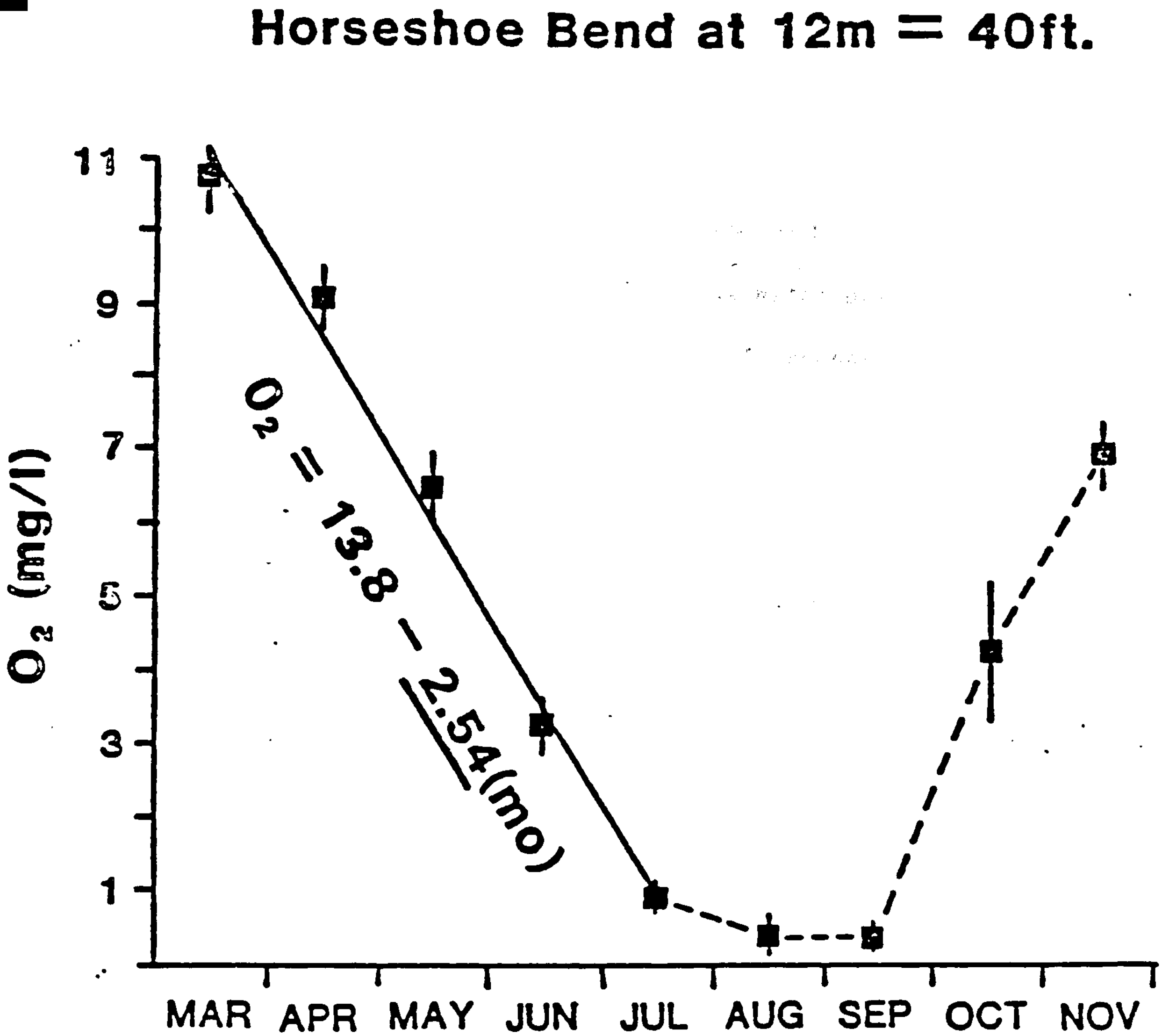

Figure 7. Average dissolved oxygen concentrations at 12 meters depth from the Horseshoe Bend sample site (Station 5) on Beaver Lake from mid-April to mid-November (1969-1979). Vertical lines represent one standard deviation. Data were collected by the National Reservoir Research Program, USFWS.

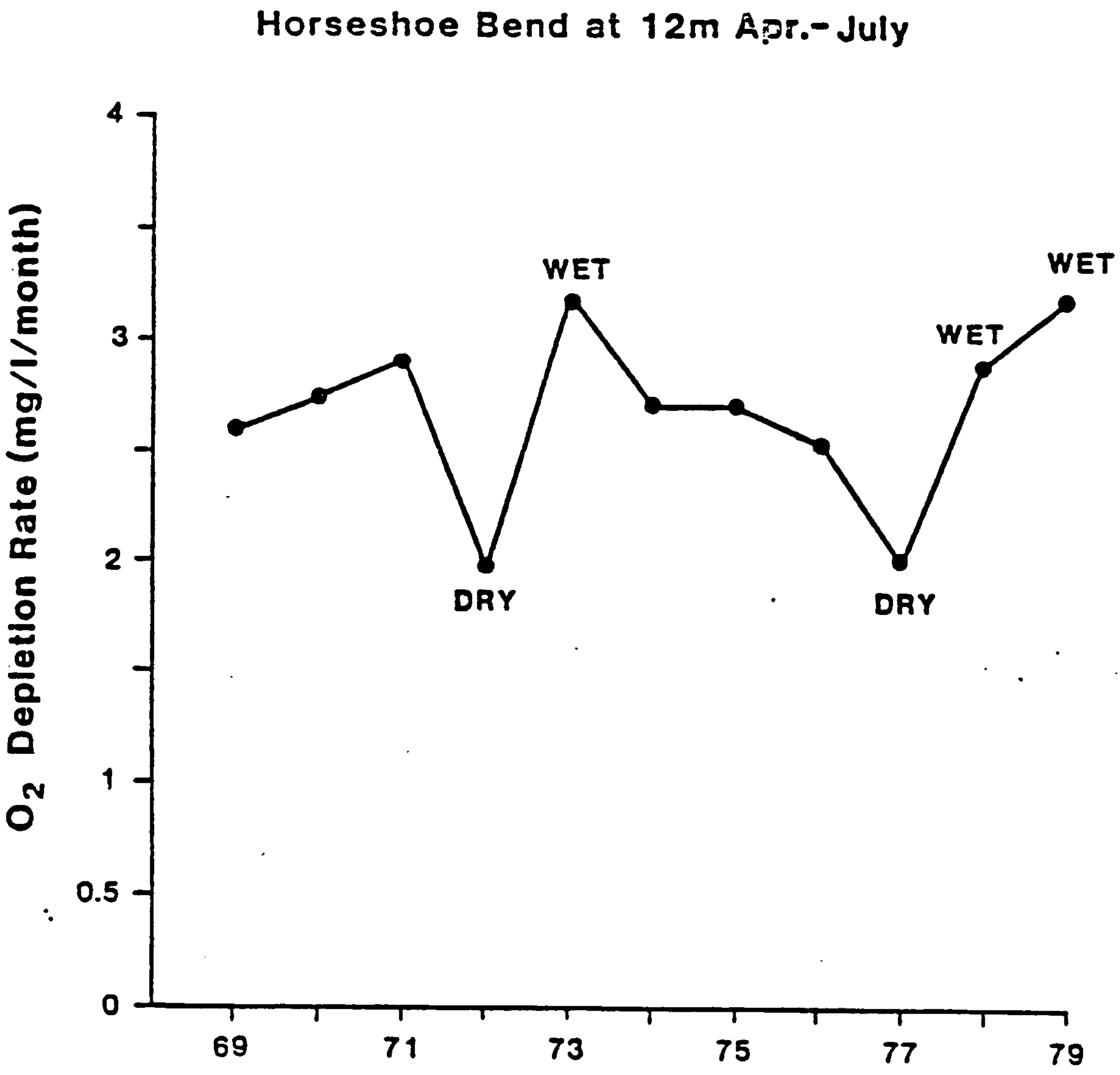

Figure 8. Average monthly (April-July) rate of dissolved oxygen depletion at a depth of 12 meters at the Horseshoe Bend sampling station on Beaver Lake (1969-1979). Data were collected by the National Reservoir Research Program, USFWS.

year differences in rates of oxygen depletion associated with wet and dry years, which suggests that the reservoir responds primarily to annual runoff patterns rather than to a cumulative influence of nutrient loading.

Water Transparency: Water transparency measured with a Secchi disk provides an index to the abundance of algae if measurements are made when large quantities of nonliving suspended materials are not present. Measurements of water transparency during August meet this criterion and provide an index of algal chlorophyll *a* biomass in Beaver Lake. August transparency measures from each of the National Reservoir Research Program's regularly monitored stations indicated a substantial increase in the transparency toward the downlake reach (Figure 9). Average August transparency measurements increased from about 2 meters at Hickory Creek to near 6 meters at the dam. As with dissolved oxygen, there was substantial year-to-year variation in the average water transparency (Figure 10). It was lowest during wet years (1973, 1978) but no significant increase or decrease in transparency was observed during the period of monitoring.

Fish Community: The status of fish populations is an important concern for the recreational interests of Beaver Lake. The health of the fish community also provides a good measure of the long-term biological productivity of the reservoir, as fish represent upper levels of aquatic food chains and live longer

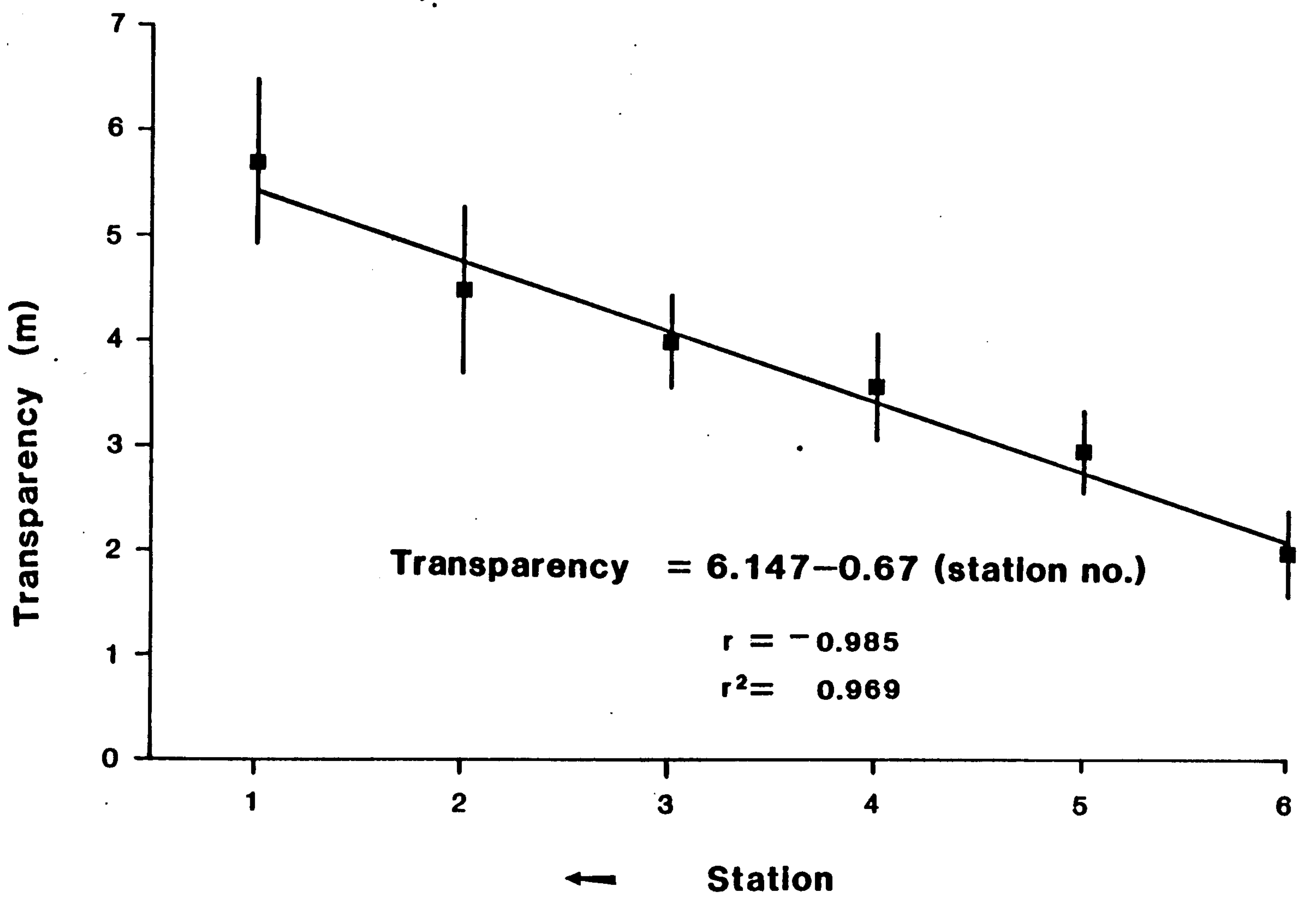

Figure 9. Average August Secchi disk transparency at six stations on Beaver Lake (1969-1980). Vertical lines represent one standard deviation. Data were collected by the National Reservoir Research Program, USFWS.

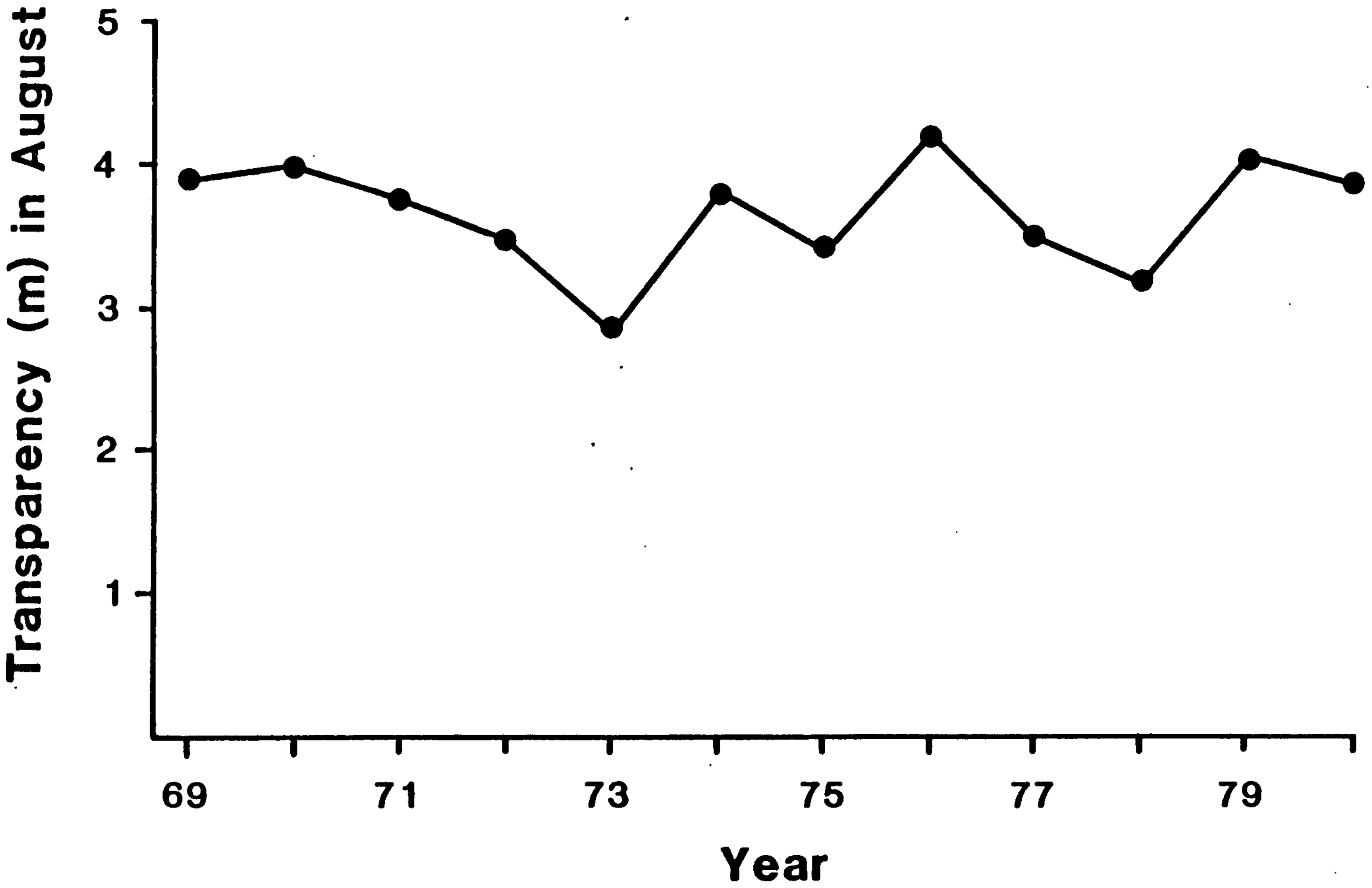

Figure 10. Average August Secchi disk transparency (Stations 1 through 6 combined) from Beaver Lake (1969-1980). Data were collected by the National Reservoir Research Program, USFWS.

than most aquatic organisms, and therefore reflect long-term trends in water quality.

Personnel from the National Reservoir Research Program and the Arkansas Game and Fish Commission conducted fish population and angler use and harvest studies on Beaver Lake from impoundment in 1968 through 1982. Numerous reports have been published by the National Reservoir Research Program (U.S. Fish and Wildlife Service, 1982).

Annual cove-rotenone samples of fish taken in August from uplake, midlake, and downlake reaches provided annual measures of fish standing crop biomass in the reservoir. The uplake area of Beaver Lake has supported the highest standing crops of fish since impoundment. There is a progressive decline in fish biomass downlake (Table 3). This distribution is consistent with results of other water-quality and biological studies on Beaver Lake which indicate that nutrient cycling and biological production is highest in the uplake area. It also reflects a pattern of production common to most large storage impoundments. (See comparable biomass estimates from Bull Shoals Lake in Table 3.)

Harvest of sport fish has reflected this distribution pattern. Since impoundment, the area upstream of the Highway 12 Bridge has produced about three times the weight of sport fish per unit area and contributed about 50 percent of the annual harvest

Table 3. Average August fish standing crop and annual sport fish harvest (pounds/acre) from uplake, midlake, and downlake areas of Beaver Lake and Bull Shoals Lake, Arkansas; values are averages for the period 1968 to 1982

	Uplake	Midlake	Downlake
	Beaver Lake		
Standing crop	451	315	240
Harvest	23.8	8.8	8.8
	Bull Shoals Lake		
Standing crop	263	209	177

lakewide. The uplake areas also experience much higher fishing pressure than downlake areas. The area above the bridge includes only about one-fourth of the total surface area of the reservoir.

The biomass of fish in each of the major areas of the reservoir has shown little long-term increase or decrease since impoundment (Figure 11). The biomass of gizzard shad increased substantially in the uplake area in 1979 and 1980 as a result of extremely high production of young folllowing a major die-off of adults during the cold winters of 1977 and 1978, This population has since declined to near the long-term average for that area. Fish populations in the midlake area may have declined slightly since impoundment, although no statistically significant trend was evident.

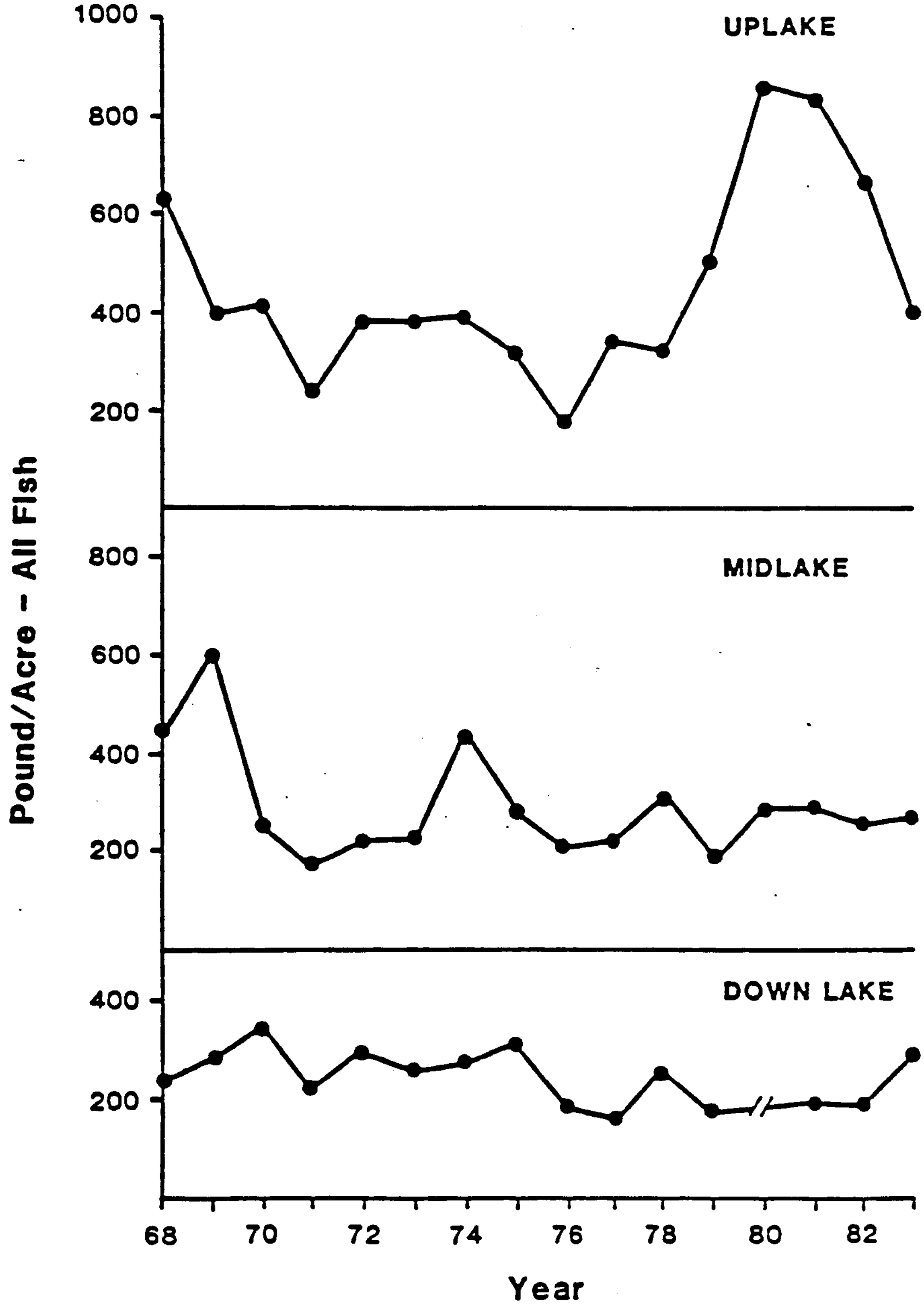

Figure 11. Total standing crops of fish from cove samples representing the uplake, midlake and downlake areas of Beaver Lake (1968-1983). Data were collected by the National Reservoir Research Program, USFWS, and the Arkansas Game and Fish Commission.

Part 3. IMPORTANT LAND USES AND BEST MANAGEMENT STRATEGIES

Background

A long-term management strategy for Beaver Lake must consider the wide range of land uses in the basin and seek to control nutrient delivery to the reservoir in accordance with Best Management Practices (BMP). It must recognize that the amount of land in different uses will have a significant, if not overriding, influence on the quantities of nutrients entering the reservoir and on their controllability. For example, more than one-half of the Beaver Lake watershed is presently forested. When undisturbed, these areas contribute nitrogen, phosphorus, and other nutrients and sediments to the reservoir at comparatively low levels which reflect minimal human impact on the basin. Accepted agricultural practices will contribute larger quantities of nitrogen, phosphorus, and other materials per unit area even when they follow BMP. However, from a practical standpoint, only limited controllability may be feasible, inasmuch as they may incorporate accepted BMP for containing agricultural pollutants. Continued urban development may produce still higher levels of nutrient loading and sediments to the reservoir, even with strict controls on point sources.

Future trends in land use will be a key element in reservoir management strategy, wherein some reduction in water quality will be accepted for continued population, economic, and agricultural growth. This relationship is well illustrated for surface waters nationally by Omernik (1977), and specifically for Ozark streams by Smart, Jones, and Sebaugh (1983) who found that concentrations of nitrogen and phosphorus in streams draining forested lands in the Ozarks of southern Missouri were about one-half those of streams draining pastureland, and about one-fourth those of urban watersheds.

The amount of resources that the community can use to solve water quality problems will be limited, and it is important that future actions stress the most efficient use of these resources. In its 1984 Report to Congress on Nonpoint Source Pollution in the U.S., the Environmental Protection Agency recognized that current surface water quality standards are designed primarily for low-flow conditions and are most effective in detecting large point-source pollutants. These standards often afford little resolution for nonpoint sources. The agency recommended evaluating land uses and targeting those activities which contribute the greatest quantities of nutrients to a body of water. A system of BMP should then be developed to control the delivery of nutrients from these sources. Braden et al., 1982, followed a similar line of reasoning and proposed concentrating assistance on BMP in critical problem areas as the key to effective management of nonpoint pollution problems.

Solutions of nonpoint pollution problems include education, training, financial incentives, and regulation to foster wiser uses of existing resources. These may involve actions within accepted BMP to produce small incremental improvements in water quality. Accurate measures of existing and predicted land uses and associated yields of nutrients, coupled with an understanding of the controllability of the different nutrient sources, will therefore be needed to target land-management strategies which offer the greatest promise for water-quality improvement in the Beaver Lake basin.

The following discussion of major effluent sources and land uses in the Beaver Lake basin describes the portions of the watershed in major land uses and the kinds of water quality problems that might be expected from each use type. The information on land use draws heavily from the "Nonpoint Source Pollution Summary for the White River Basin, Section 4K" prepared by the Arkansas Soil and Water Conservation Commission (1979) and information supplied by Committee Members representing the Soil Conservation Service, Arkansas Forestry Commission, and Southern Forest Experiment Station.

Municipal Waste Treatment Facilities, Major Point Sources

a) Huntsville contributes treated effluent indirectly into War Eagle Creek. The plant is old, but it has not been linked to excessive nutrient loading to Beaver Lake. Nutrient studies near the confluence of War Eagle Creek with Beaver Lake have not indicated elevated concentrations of nitrogen or phosphorus which can be tied directly to this effluent.

b) The Fayetteville Waste Treatment Plant is the largest point source of municipal discharge to Beaver Lake. Previous workers (Gearhart et al., 1974; Black and Veach, 1982) estimated that the facility contributes from 28 to 62 percent of the annual phosphorus load to the reservoir. Plans for upgrading and funding the Fayetteville facility have been approved. A demonstration project to show the feasibility of the treatment process is underway, and the new plant is scheduled to be in operation by 1988. This action should accommodate population and industrial growth by the Fayetteville community until the early 21st century. With increased control of this major nutrient source, the emphasis for future water quality management will shift to the many smaller and diverse point and nonpoint sources in the watershed.

Septic Tanks and Small Package Plants

Since the early 1970s, there has been much concern over the discharge of nutrients from septic tanks and small package plants into Beaver Lake. Ransom et al. (1975) found that many soil types in the watershed have variable rates of permeability, have steep slopes, are underlain with shallow bedrock, or overlay natural fractures or solution channels which can foster rapid and extensive movement of waste materials. Using these criteria, the Northwest Arkansas Regional Planning Commission and the Soil Conservation Service (1975) classified most soils in the Beaver Lake basin in Washington and Benton counties as having severe limitations as septic disposal sites. Exceptions are found primarily along the White River flood plain in Washington County.

Stone (1972) documented elevated bacterial and nutrient (nitrogen and phosphorus) concentrations at several small domestic inflows in the uplake area of Beaver Lake, confirming that these effluents represent concentrated sources of nutrients, and can indeed move considerable distances and enter the reservoir when improperly treated.

Development around the lake was rapid following impoundment. Russell (1975) reported that 13,512 potential building sites had been recorded and plotted in an area 2 miles wide around the shoreline of the reservoir by 1974. Although this level of development may ultimately occur, it has not progressed rapidly to date. In 1979, there were approximately 7,100 septic or small package systems in the Beaver Lake watershed. About 2,200 of these were in the area around Beaver Lake.

Development has been concentrated at several locations around the reservoir, and future effects on water quality should therefore be localized in the areas or embayments immediately adjacent to these developments. At Lake Hamilton, cove areas adjacent to developments experienced the greatest water quality problems (McClelland Consulting Engineers, et. al., 1984). There has not been a concerted recent effort to quantify nutrient loadings from these developments around Beaver Lake, and it would be difficult because the movement of nutrients and pollutants underground is difficult to track.

The regulation of septic and package systems has public appeal, inasmuch as many soils in the basin are poorly suited for disposal fields. Improperly functioning units are not easily identified, and the potential of future groundwater contamination could pose serious problems for the NWA community. Waste materials that move through fractures or solution channels and mix with larger uncontaminated sources of groundwater are difficult to locate and virtually impossible to correct once contamination has occurred. Although not the subject of this report, groundwater contamination may pose a greater problem to the NWA community than direct pollution of the reservoir. Many homes obtain drinking water from wells, and an important long-term effect of improperly treated wastes may be the contamination of these sources.

Total nutrient discharge to the reservoir from septic and small package systems should be assessed. However, with the current level of development around the reservoir, nutrient loading from these sources appears to be relatively small compared to the combined effects of other point and nonpoint sources in the basin. Presently, an unknown percentage of dwellings near the reservoir are summer cabins and receive only periodic use. There also appears to be a high rate of turnover of existing cottages, and the rate of future construction is unknown. Management actions which target specific violations, and provide more stringent controls on the installation of new septic and package systems could be accomplished within the Health Department and DPC&E's existing regulatory authority. This probably affords the most feasible short-term solution. Over the longer term, it will be desirable to monitor rates of growth, and as population densities increase, develop community or regional collection and treatment systems.

Major Land Uses

Forest Lands. Approximately 460,000 acres (62 percent) of the upper White River basin is forested, although the amount of forest land has declined in the past 20 years. About 10 percent of the forested land in Benton and Washington Counties was cleared between 1970 and 1980 based on land-use mapping by the Northwest Arkansas Regional Planning Commission. Clearing slowed appreciably during the late 1970s, as the most desirable areas were already cleared, and cattle prices declined. The acreage of forest will continue to decrease slowly in the future, as most land suitable for agriculture is being farmed, and urban development requires a relatively small percentage of the total land area.

Total nutrient runoff from forested land varied substantially from year-to-year as a result of differences in rainfall and silviculture practices (Southern Forest Experiment Station, unpublished), but compared to other land uses this represents a minor and relatively stable long-term nutrient source. Since 1974, the U.S. Forest Service's Southern Forest Experiment Station has conducted water quality studies on four small forested watersheds located on Fleming Creek, a tributary to the East Fork of the White River. Scientists from the Station reported average concentrations of nitrate nitrogen and total phosphorus in streams flowing from these experimental watersheds in the upper Beaver Lake basin to be 1.95 and 0.18 mg/l, respectively. In 1982, three of the watersheds received silvicultural treatments. These included: 1) shelterwood thinning, 2) clearcutting and 3) conversion from hardwoods to pine. Collection of data was continuous before, during, and after treatment. These studies will continue unless reductions in congressional appropriations force closure of the research program, and should provide excellent baseline information for the Arkansas Forestry Commission in developing future silviculture BMP in the basin. The Commission recommends BMP for most silviculture activities on a site-specific basis. This voluntary program is designed to minimize erosion and represents an important program for controlling water quality in the reservoir.

Agricultural Lands. About 32 percent (240,000 acres) of the upper White River basin is currently being farmed. The area is one of relatively high livestock use, primarily for the production of cattle, swine, and poultry. In 1978, annual production of livestock in the watershed included 128,000 hogs, 61,000,000 chickens, and an undetermined number of cattle. Animal wastes, major agricultural by-products, are applied primarily as organic fertilizer to pastures. Most of these wastes are distributed within five miles of the sites where they are produced.

A recently completed study of fertilization patterns in the upper White River basin (Soil Conservation Service, in preparation) indicated that about 58 percent of the fertilizer applied annually to randomly sampled test plots during 1982-1983 was animal waste, whereas 41 percent was commercial inorganic formulation. Poultry litter applied dry was the primary organic fertilizer. Dried animal wastes made up about 94 percent of the total organic source. Liquid wastes from swine and caged layer operations contributed the remaining 6 percent. Assuming that these application patterns accurately reflect practices in the basin, average annual rates for both organic and inorganic fertilizers are near recommended agricultural levels for the region. However, only about one-half of the area received fertilizer treatments during the study, which suggests that the application of animal wastes could be approximately doubled without exceeding recommended agricultural levels.

Both organic and inorganic fertilizers were applied mostly during spring and autumn to the more productive soils of moderate to gentle slope. Organic fertilizer was applied at an average rate of 2.3 tons/acre/year. Inorganic formulations were applied at an average annual rate of 360 pounds/acre, but rates ranged from 100 to 800 pounds/acre. The higher rates represented multiple applications. The demand for organic fertilizer presently exceeds supply, although an estimated 11,400 tons were applied annually to the watershed in the late 1970s.

The study indicated that liquid animal wastes make up a relatively small percent of the total organic fertilizer, but it presents special problems in that swine and caged layer operations frequently have limited storage capacity and the liquid wastes must be applied several times during the year. Recently, there has been a trend toward larger operations that localize production and therefore compound problems with distribution of wastes. Spills at several operations in the basin have prompted action by the DPC&E.

Most farm operations practice BMP as these are economically sound. However, there will continue to be a portion of the agricultural operators who are unwilling, or are financially unable to implement sound management practices. Assisting these operators in making best use of their resources would benefit the entire community, and this should represent an important element of a basinwide management strategy. State and federal agencies currently provide information and education, limited financial assistance and/or other incentives to encourage land use, and regulation of the larger point source agricultural operations. A management strategy group should stress close working relations with these agencies to accomplish needed management actions.

The total quantity of primary nutrients (nitrogen and phosphorus) that reach Beaver Lake annually from various agricultural functions is not well known. The National Eutrophication Survey (Environmental Protection Agency, 1978) indicated that about 79,600 lbs. (44 percent) of the annual phosphorus and 3,224,000 lbs. (90 percent) of the annual nitrogen loads entered Beaver Lake from nonpoint sources. This included forest, agricultural, and urban runoff. Quantities of organic matter entering the reservoir have likewise not been defined. The above estimates of agricultural loading to the reservoir have not included storm runoff, and therefore may represent extremely conservative estimates.

The Soil Conservation Service's recently completed study of fertilization patterns in the upper White River basin predicts the quantities of certain nutrients from organic and inorganic fertilizer applications that reach the edge of test plots under various application rates and climatic conditions. However, this modeling effort will not quantify the ultimate delivery of these nutrients into Beaver Lake, and it reveals an important data gap in terms of understanding the effects of different agricultural nutrient sources on the water quality of the reservoir. An intensive water quality study of the type needed to accurately quantify the relative contributions of agricultural runoff would require an assessment of pulsed or storm loadings and careful sample design. It would therefore be labor intensive. Without this type of effort many sources of nonpoint pollution will remain poorly defined, and it will not be possible to accurately evaluate other management actions with respect to incremental effects on reservoir water quality.

Significant changes in land use and in the application of animal waste products is unlikely; therefore, large reductions in nutrient loadings with current agricultural practices are improbable. Land application of animal wastes represents an economical method of disposing of these materials. Potential reductions in nutrient delivery to the reservoir will be realized to the extent that the timing and quantities of wastes applied are altered.

Buffer zones where livestock and fertilizer application would not be permitted within certain distances of streams would offer limited control over the entry of agricultural wastes into surface waters. These actions would impact a small percentage of farmers, but could provide benefit to the basin when viewed relative to all point and nonpoint sources of agricultural nutrient loading. If protection of riparian habitat is included, the approach would reduce stream-bank erosion.

There will be misuse of agricultural wastes on a site-specific basis. A management strategy which stresses efficient waste application and sets constraints on the design of new package systems may be the most effective short-term approach to controlling small point and nonpoint agricultural sources. Presently, the Soil Conservation Service, County Extension offices, and Soil and Water Conservation districts provide guidance through BMP designed to control nutrient and soil losses. These plans are developed for each farm, and they have become very effective in controlling nutrient and soil losses. They should be considered important elements of a long-term water quality management strategy.

Future agricultural trends in the upper White River basin will be influenced by the location of processing plants, the market value of agricultural products, and access to the basin. Springdale presently serves as the center for poultry processing in the immediate area, and rising fuel costs may result in the production sites being moved closer to these processing centers—a move which could reduce agricultural growth in the White River basin. Similarly, the market value of cattle will determine if more marginal land is converted to pasture. Presently, it is not profitable to clear the steeper sloping forest land for cattle production. A substantial increase in the market price could result in more land being cleared in a very short time.

Urban Lands. Runoff from urban areas contributes an unknown quantity of organic material, nutrients, heavy metals toxic substances, and oil and grease to the reservoir. Livingston (1973) measured nutrient concentrations in Town Branch, which drains the south part of Fayetteville, and concluded that urban runoff could contribute substantial quantities of nutrients to the reservoir. Unfortunately, the study had limited predictive value, as it included only a small area in Fayetteville and was conducted during a 3-month period in late winter of 1972-73 when runoff was high. With continued urban growth, better knowledge of the types and quantities of nutrients from these areas is needed.

Presently, population distribution in NWA is such that much of the runoff from urban areas does not flow into Beaver Lake. The divide between the White River and Illinois River basins is close to Beaver Lake on the west edge of the drainage, and much of the runoff from the more densely populated urban areas of

Northwest Arkansas presently flows into the Illinois and Grand River basins. The south and east parts of Fayetteville, east parts of Rogers and Springdale, and all of West Fork, Greenland, Elkins, Huntsville, and the developments surrounding Beaver Lake contribute urban runoff to the Beaver Lake basin. These urban areas made up about 17,500 acres of the basin in 1979 (about 2 percent of the watershed). Barring some unforseen shift in future population growth, urban development should be concentrated in the areas directly east of Fayetteville, Springdale, and Rogers. Urbanization of the White River basin should accelerate in the next two decades, as the population of Northwest Arkansas is expected to approximately double by the early 21st century. This future development will likely pose a serious water-quality concern. Burby et. al. (1982) surveyed water-system managers from throughout the U.S. and reported a much greater perception of water-quality problems as watershed development increased from 1 to 25 percent.

Erosion and Sedimentation.

Based on information presented by the Arkansas Soil and Water Conservation Commission (1979), sheet and rill erosion accounts for about 79 percent of the annual soil loss in the upper White River basin. Erosion of unpaved roads and road banks accounts for an additional 18 percent. Construction activity produces short-term highly localized and variable erosion that may exceed 50 tons of soil per acre per year, but the cumulative effects are small when compared to other sources. Beaver Lake has a long theoretical water retention time (1.5 years), and it therefore serves as an extremely efficient nutrient and sediment trap. Materials eroded from the White River and War Eagle watersheds are deposited mostly in the uplake areas of the reservoir. The rate at which future erosion occurs will directly influence the life of the reservoir, but particularly the physical and water-quality characteristics uplake from the Beaver Water District's intake structure.

Current forest and agricultural practices in the watershed are producing low rates of sediment loss compared to many other areas in Arkansas, and erosion has apparently decreased since 1980. During the mid-1970s, soil losses from the major watersheds in the Beaver Lake basin averaged about 3 tons/acre/year. This was a period of rapid land clearing, as approximately 10 percent of the upper White River basin was cleared between 1970 and 1980. The War Eagle Creek basin experienced the highest rate of erosion. Clearing of the steeper hillsides has slowed substantially, and most of the more valuable agricultural land is presently in pasture. Recent studies (Soil Conservation Service, unpublished) indicate that erosion from the major drainages in the upper White River basin currently averages less than 2 tons/acre/year. This about equals the annual rate of soil formation on steeper sloping land and relects the implementation of BMP as recommended by several management agencies over much of the watershed. Future changes in land use will involve clearing of more forest land and subsequent replacement by urban and agricultural use. Rates of erosion are therefore likely to increase again in the future.

As would be expected, most of the sediment losses in the Beaver Lake basin occur on nonforested lands. In 1982, the Arkansas Forestry Commission began sampling erosion losses on all types of forestry logging activities in Arkansas. To date, the Commission has monitored 1465 sites statewide and has estimated average annual soil loss at 0.37 tons per acre. In Northwest Arkansas, 83 logging sites have been monitored, and average soil losses were 0.53 tons per acre. These samples were taken from a wide range of soil types and slopes and probably reflect accurate losses for lands where logging occurs. By comparison, undisturbed forest lands produce negligible annual soil losses—generally less than 0.05 tons per acre (Dr. Edward Lawson, Southern Forest Experiment Station, personal communication).

Strategies for Implementing Best Management Practices

Conceptually, control of nutrients from point and nonpoint agricultural sources can be approached from two perspectives. One is to limit nutrient delivery through regulatory action. The second is to optimize use of existing BMP and identify new technologies which will lead to improved techniques which contribute smaller amounts of nutrients to the reservoir.

Attempts to regulate nonpoint nutrient sources are difficult, as most existing agricultural practices incorporate accepted BMP. For example, the application of animal wastes to lands in the Beaver Lake basin is frequently within recommended agricultural levels and at the recommended times. Improper applications occur and are subject to regulatory action by the Department of Health, the Department of Pollution Control and Ecology, and the Environmental Protection Agency. However, these applications make up a relatively small part of the total nutrient loading from agricultural activities. Efforts to eliminate land application of animal wastes by regulatory action would face stiff resistance in the community, and in fact would be very difficult to justify, based on the current levels of nutrient loading to the reservoir and the economic importance of agriculture to the NWA community. This type of regulatory approach offers a stop-gap protection for the reservoir.

A strategy which encourages the development of new technologies for specific land use practices offers an effective long-term approach to managing water quality in the basin. For example, as protein costs rise, new techniques which use poultry wastes as feed for livestock promise an economically viable alternative to land application. Similarly, methods to remove solid wastes from swine or caged-layer operations could significantly reduce the volume of liquid wastes produced from these activities. Actions which reduce pollutants as a part of better land use or agricultural practices afford permanent solutions at no direct cost to the community. Staff members at the University of Arkansas are engaged in agricultural and engineering research design to provide solutions to many pollution problems. A water-quality management organization could work to effectively target promising management approaches for problems in the basin.

New methods for controlling the delivery of primary nutrients and pollutants to streams are constantly being developed. A major constraint in recommending specific BMP is that they will change through time. Therefore, specific recommendations are not included in this report. Several state, federal, and local agencies currently provide state-of-the-art BMP. A best management strategy should include strong communication with these agencies to insure that new concepts or techniques are adopted.

Part 4. WATER QUALITY MONITORING, IMPORTANT DATA GAPS, AND DATA BASE MANAGEMENT

Background

An efficient water-quality management strategy for Beaver Lake should 1) identify sources of excessive nutrients; 2) pinpoint specific land-use or industrial practices that give rise to these materials; and 3) measure the success of different treatments or management actions. A program of water-quality monitoring would be required to meet these needs.

Previous studies have shown that Beaver Lake experiences substantial seasonal and year-to-year variations in water quality because of differences in runoff patterns (see Part 1). This creates a variable baseline of nutrient concentrations in the reservoir during any year. Changes in water quality that indicate the presence of excess nutrients or result from future management actions must therefore be assessed relative to these natural variations. Long-term records of selected water-quality characteristics must therefore provide the basis for identifying significant pollution problems and evaluating future management actions.

Important Data Bases

Water quality and biological monitoring is currently being conducted in the Beaver Lake basin by the Little Rock District Corps of Engineers, the U.S. Geological Survey and the Department of Pollution Control and Ecology jointly, the Beaver Water

District, the Fayetteville Waste Treatment Plant, the Southern Forest Experiment Station, and the Arkansas Game and Fish Commission. The National Reservoir Research Program, U.S. Fish and Wildlife Service, conducted water quality and biological monitoring from 1968 to 1982. In addition, the Arkansas Water Resources Research Center and Northwest Arkansas Regional Planning Commission have supported many water-quality studies to address specific engineering and biological problems. The National Reservoir Research Program funded or conducted approximately 65 pre- and post-impoundment fishery and related limnological studies from 1961 to 1982. Historical studies are summarized by Hogue _et al._ (1971), Ashworth and Mitchell (1982), and National Reservoir Research Program (1982) and will not be detailed in this report.

Short-term studies followed a variety of sampling protocols to address specific engineering, water quality, or biological problems. Consequently, they have limited application for assessing changes in water quality since impoundment. The following long-term data bases provide chemical, physical, and biological information suitable for evaluating water quality trends in the reservoir:

U.S. Geological Survey (USGS) and Department of Pollution Control and Ecology (DPC&E). These agencies have conducted quantitative sampling of major nutrients, heavy metals, pesticides, and coliforms at two locations on the White River east of Fayetteville at least four times a year since 1974. The sites are located upstream and downstream of the Fayetteville Waste Treatment Plant. Both sampling frequency and number of parameters measured have increased in recent years. This information is published as Annual Water Data Reports for Arkansas distributed by the USGS, and is accessable through the STORET system maintained by the EPA.

Little Rock District, Corps of Engineers (COE). The COE has monitored selected nutrients, heavy metals, and coliforms at several locations in the reservoir since 1975. These locations include the major tributaries, the water intake for the Beaver Water District, selected COE recreation areas, and permanent stations immediately above and downstream from Beaver Dam. Sampling has been conducted at irregular intervals, but spring/summer sampling has occurred during most years. Data from sites around public use areas are on file at the Little Rock District, COE office in Little Rock. Information from stations located upstream and downstream from Beaver Dam are available through the USGS Annual Water Data reports for Arkansas.

Beaver Water District (BWD). The BWD has conducted monthly sampling of important nutrients at nine locations on major tributaries to Beaver Lake since 1979. In addition, seasonal chemical and biological sampling is conducted at the Hwy. 45 and

Hwy. 68 bridges. Systematic monitoring of water entering the treatment system provides a long-term data base for identifying trends in biological and chemical characteristics of the drinking water supply for Northwest Arkansas (NWA). These data are filed at the BWD treatment plant.

Fayetteville Waste Treatment Plant (FWTP). The plant monitors chemical and biological parameters in the effluent. These include measures of important nutrients (N&P) and provide a long-term track of chemical characteristics of the plant's effluent. These data are retained by the City of Fayetteville.

National Reservoir Research Program (NRRP). This field program of the U.S. Fish and Wildlife Service monitored temperature, specific conductance, and dissolved oxygen monthly at six stations from the time the reservoir filled in 1968 through 1980. These parameters were measured at 3-m intervals at stations located near Hickory Creek, Horseshoe Bend, Prairie Creek, Rocky Branch, the mouth of Clifty Creek, and at the Dam. Secchi disk transparency was also measured at each station. Zooplankton abundance and biomass was measured at all stations from 1972 to 1980, and annual estimates of fish standing crop, sport fish harvest, and fishing pressure were made from 1968 to 1981. The program was terminated in 1983, and raw data (water quality and biological) were archived at the Arkansas Water Resources Research Center. Analysis of these data were not complete when the program closed, but they provide the primary long-term measure of trends in water quality of Beaver Lake since impoundment.

Southern Forest Experiment Station (SFES). The U.S. Forest Service's Research Work Unit at Fayetteville has conducted water quality studies on four relatively undisturbed watersheds in the Fleming Creek drainage located in the upper White River basin since 1974. Meterological, sediment, and water quality parameters have been measured frequently enough to assess annual yields of important nutrients and the effects of storm runoff on nutrient and sediment transport. These studies have included measures of phosphorus, total nitrogen, and nitrate nitrogen. The data base affords unique measures of the yield of nutrients from undisturbed forested portions of the basin. In 1982, three of the watersheds received silviculture treatments including shelterwood thinning, clear cutting, and conversion from hardwood to pine.

Historical water-quality data from the Beaver Lake basin have included a wide range of parameters, sampling techniques, and collection sites. There has not been a concerted effort to analyze these data, but they provide a large potential source of information for examining future trends in reservoir water quality. Presently, the multi-agency water-quality monitoring programs in the basin are poorly coordinated with respect to the timing and location of sampling. Most of the agencies currently monitoring water quality in the reservoir will continue some level of effort. A management strategy should therefore seek to coordinate monitoring to standardize sampling methodologies, minimize duplication of effort, and foster information exchange. In addition, historical data bases should be assembled and critically examined to address the following questions:

1) Which water-quality monitoring agencies have useful historical information in existing data bases?
2) Are these data bases adequate to identify objectives of a local water-quality management organization?

Objectives

A water-quality monitoring program for Beaver Lake should have the following objectives:

1) Quantify long-term changes in reservoir water quality.
2) Identify areas of high nutrient input.
3) Evaluate the effects of nutrient removal, or assess the influx of nutrients from different levels of management.
4) Test for violations of state water-quality standards.
5) Identify regions in the reservoir that may require specific water-quality management actions.

Monitoring Strategy

Previous water quality studies on Beaver Lake have shown that rapid changes in concentratins of nutrients or pollutants are highly improbable, that concentrations of these materials lakewide will increase slowly, and that the greatest potential for problems will be in the uplake area where major tributaries enter the reservoir. The very slow movement of water through the reservoir permits the greatest loading in the least volume of water. This results in high biological activity near the tributaries, and a rapid decrease in nutrient concentrations and biological products downlake from these sites.

Development will continue in the watershed, and a deterioration of reservoir water quality through time will be difficult to prevent in uplake areas. Baseline or existing water quality conditions are adequately defined to illustrate the current trophic status of the reservoir. However, more accurate measurements of the rates of water-quality change are needed for planning purposes and to justify future management actions. A core program of data collection to quantify long-term trends in water quality could be conducted at a relatively small cost.

Short-term and local water-quality problems will continue to occur and will require specific actions by the NWA community. For example, sources of toxic substances that contaminate drinking water supplies or threaten human health must be located and eliminated. Detecting, quantifying, and eliminating these materials requires an entirely different sampling protocol than that needed to assess long-term trends in nutrients which influence water quality by stimulating biological production. With the exception of iron and manganese, natural levels of heavy metals and other toxic materials appear to be low in the Beaver Lake basin. High sampling and analytical costs make it difficult to justify a routine monitoring program for these substances. Existing monitoring for toxic materials at the Highway 45 Bridge by the DPC&E augmented with a lakewide survey once every 3 to 5 years, should detect significant new sources of these materials.

Monitoring Program

A systematic low-intensity monitoring program maintained for a period of 10 to 20 years will be required to accurately predict future trends in water quality of the reservoir. The program should be designed to minimize annual sampling effort and costs, while detecting significant changes in a limited number of important water-quality and biological parameters. It should incorporate known historical, seasonal and spatial trends in water quality. For example, biological production in aquatic communities is known to increase as temperature increases. Consequently, high nutrient concentrations stimulate biological production and cause water-quality problems mostly during summer. Although degradation in potable water quality may occur at any season, violations of water-quality standards usually occur during this period. Accordingly, a monitoring program should concentrate sampling during the warm seasons.

Beaver Lake experiences strong thermal stratification during the summer (National Reservoir Research Program, unpublished).

Stratification begins in April or May, and mixing occurs from September through November. The chemical and biological processes that occur during this time are predictable and can be used to optimize sampling times. Four sampling dates distributed evenly during reservoir stratification and one sampling during winter mixing would detect long-term trends in reservoir water quality. The following sampling dates are recommended, based on annual patterns of thermal stratification:

mid-February -- winter mixing

mid-April -- onset of stratification

mid-June -- early summer stratification

mid-August -- strong summer stratification

mid-October -- reservoir mixing

The greatest biological and chemical gradients in water quality occur in the headwaters of Beaver Lake, as most nutrients enter the reservoir from the White River and War Eagle Creek, and slow water movement permits substantial assimilation in the uplake area. The Beaver Water District's intake structure is located only 6 miles downlake from the confluence of these major tributaries. Conversely, the intake structure for the Boone-Carroll Water District is located downlake, where water quality is exceptional. Future trends in water quality in the uplake area of the reservoir will determine treatment costs and potential health problems for much of the NWA community. Water-quality monitoring should be concentrated in this area. The following recommended sampling stations (Figure 12) reflect this strategy:

Uplake, White River at Highway 68 Bridge (WR-68)

War Eagle Arm at Hickory Flat (WE)

Intake structure for Beaver Water District (BWD)

Midlake, Highway 12 Bridge (12-B)

Downlake, Rocky Branch area (RB)

These recommendations are based on assumptions that 1) the Beaver Water District and the Department of Pollution Control and Ecology will continue to monitor water quality at existing sites upstream (Wyman Bridge) and downstream (Highway 45 Bridge) of the Fayetteville Waste Treatment Plant; 2) the Game and Fish Commission will estimate standing crops of fish annually at presently sampled locations in the reservoir (Pine Creek, Coose Creek and Fords Creek); and 3) the Corps of Engineers will maintain the water-quality monitoring stations upstream and downstream from the dam.

Changes in water quality can be detected by systematically measuring a relatively small number of chemical and biological parameters. Important indicators include dissolved oxygen concentration, indexes of primary and secondary production, and concentrations of selected nutrients. The amounts of dissolved oxygen present above and below the thermocline at different times during the summer provide a good index to the chemical and biological

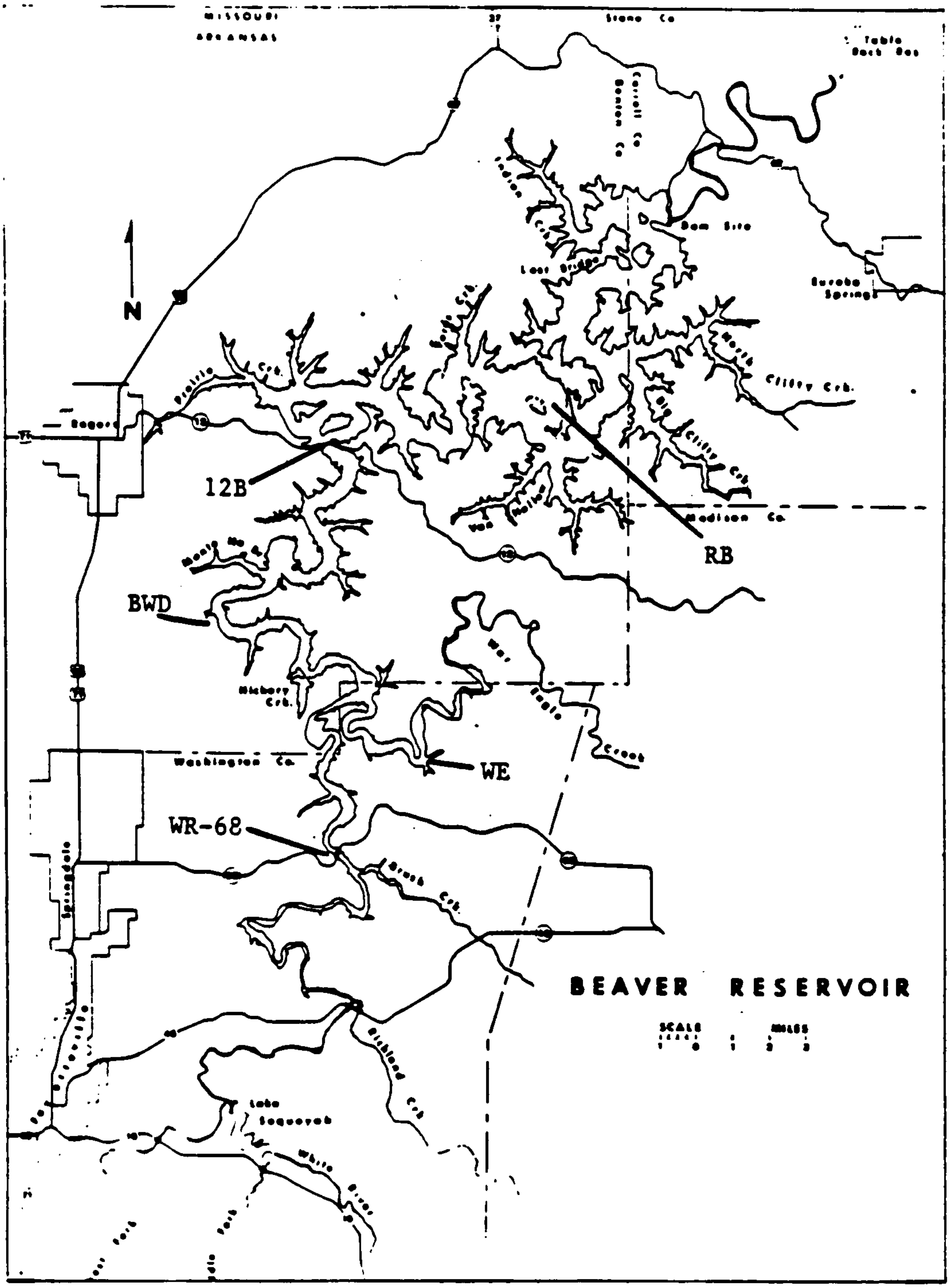

Figure 12. Map of Beaver Lake showing locations of proposed Monitoring Stations. (See legend on previous page.)

oxygen demand in Beaver Lake. Water transparency measured with a Secchi disk during summer provides an index to primary production, particularly if it is augmented with measures of chlorophyll *a*. Changes in the concentrations of nitrate nitrogen, total phosphorus, and orthophosphate would identify trends in major nutrient sources. The following measures represent a minimal sampling program for water quality monitoring.

1) Water temperature; measured at 3-m (= 10 ft.) intervals through the water column.
2) Dissolved oxygen; measured at the same intervals as temperature.
3) Water transparency; Secchi disk.
4) Chlorophyll *a*; phytophyton grab samples collected at 3 m, midpoint of the thermocline, and midpoint of the hypolimnion.
5) Nitrate nitrogen, total phosphorus, and orthophosphate; samples collected at each depth listed in item 4.

The program should incorporate strict quality control and a standard format for data collection and analysis. It should be reviewed frequently with the objectives of minimizing sampling effort, eliminating unproductive elements, and evaluating new management initiatives.

Localized water-quality problems or programs to evaluate specific management actions would require specific sampling design and expertise. For example, monitoring in areas around future commercial, industrial, or agricultural developments to detect increased nutrient concentrations or toxic materials should be viewed as separate problems, but coordinated within the core program whenever possible. These should be administered as separate problems, and specialists should be hired to conduct the work.

Important Data Gaps

Several broad data gaps presently limit development of a basinwide water-quality-management strategy. From an applied perspective, accurate measures of the relative contributions of the many point and nonpoint nutrient sources are needed (Ashworth and Mitchell, 1982). With upgrading of the effluent from the Fayetteville Waste Treatment Plant, much finer resolution of remaining point and nonpoint sources will be needed to justify and target future management actions.

An assessment of nutrient loading during storm events should be included in this effort. Future actions to improve or maintain water quality in Beaver Lake will be expensive. An understanding of the loading of certain nutrients (particularly phosphorus) during storms is essential, as this may reflect an uncontrollable input of nutrients which must be quantified if responses to reduced nutrient loading from known sources are to be evaluated.

Information on patterns of sedimentation and nutrient assimilation within the reservoir is badly needed. The total quantities of sediments entering Beaver Lake are low compared to those entering many other reservoirs, but impacts on the NWA community may be significant because of the location of the Beaver Water District intake structure. The reservoir has a long theoretical retention time (1.5 years), and a disproportionate amount of the nutrients, sediments, and pollutants entering the impoundment are deposited in the upstream reaches. The intake structure for the Beaver Water District is located in this area, and only about 5 percent (60,000 acre feet) of the reservoir volume is contained uplake of the structure. If most sediment deposition takes place in the extreme uplake area, the volume of the reservoir upstream of the intake structure will decrease at a proportionally higher rate than that of the entire reservoir. Water quality problems in the uplake area will also worsen much more rapidly than for the entire reservoir.

Similarly, the chemical and biological effects of additional nutrient deposition in this area should be determined. Feeney (1971) reported that significant quantities of nitrogen and phosphorus were accumulating in sediments in uplake reaches of Beaver Lake soon after impoundment. The rapid improvement in water quality downlake confirms that a large portion of the inflowing nutrients are indeed assimilated in the extreme uplake reaches.

Knowledge of the distribution and concentration of nitrogen and phosphorus in sediments in this area of Beaver Lake would improve our understanding of nutrient assimilation by the reservoir. The Little Rock District, COE, conducted sediment sampling during the late summer of 1984 which will provide broader insight into the spatial distribution of primary nutrients in sediments. A detailed study to describe the biological and chemical processes that enable nutrients to reach the sediments and the ultimate fate of these materials is needed. It should be designed to show if the reservoir serves as an efficient long-term sink for nitrogen and phosphorus as has been suggested in many earlier studies, or if substantial recycling and mobilization of sedimented nutrients is occurring.

Seasonal and spatial production of algae remains poorly defined in Beaver Lake, particularly in upstream reaches where nutrient concentrations are highest. Mobilization of phosphorus and certain metals from sediments into anoxic hypolimnial waters occurs during summer stratification in many large storage impoundments. Relations between these increased concentrations of nutrients or pollutants and the production of algae in the reservoir is of immediate management concern for maintaining high-quality drinking water. If nutrients (particularly phosphorus) remain in the deeper areas (hypolimnion), they may contribute little to the overall production of algae in the reservoir (Taylor *et al.*, 1980). However, if they are transported to shallower (epilimnial) waters during late summer as the reservoir mixes, algal blooms with associated tastes and odors in drinking water may result.

Finally, the upgrading of the Fayetteville Waste Treatment Plant will have an undefined, but positive influence on water quality in Beaver Lake. Understanding how the reservoir responds to this major reduction of nutrients will provide valuable insight into the potential responses from future management actions and levels of management needed to significantly impact water quality. Describing changes in water quality of Beaver Lake after the plant begins operation should be an integral part of any monitoring strategy. The program outlined previously would detect significant improvements in water quality resulting from upgrading of the waste treatment facility.

Data Base Management

The historical data bases and numerous special studies on Beaver Lake provide valuable sources of information to address future water-quality problems in the basin. Published water-quality and biological studies are presently housed at the University of Arkansas Mullins Library, the Arkansas Water Resources Research Center, the Northwest Arkansas Regional Planning Commission, and The Fayetteville Public Library. Unpublished data are maintained by the different collecting agencies in variable formats. A continuing water-quality-management strategy should stress the collation and maintenance of published and raw data from the entire basin at one location. At a minimum, existing data should be retained in a standardized format, and a clearinghouse should be established to provide up-to-date water-quality information. The Northwest Arkansas Regional Planning Commission and the Arkansas Water Resources Research Center are centrally located with existing staffs and physical plants. With minimal staffing additions, these agencies could provide the needed user services to the NWA community.

Part 5. ORGANIZATIONAL ALTERNATIVES FOR MANAGING WATER QUALITY

Background

Developing a long-term water-quality management program for Beaver Lake will require that the leaders of the Northwest Arkansas (NWA) community work collectively to address resource problems in the entire watershed. The NWA area is fortunate that the quality of water in much of Beaver Lake is currently good when compared to that in other large reservoirs in the U.S. (see Part 1). This provides an opportunity for the community to consider long-term land use as a means of controlling water quality. How urban and agricultural development proceeds in the basin over the next ten to fifteen years will likely be the overriding factor determining future reservoir water quality. Planning activities by the governments of Benton, Carroll, Madison, and Washington counties and the municipalities of Fayetteville, Huntsville, Rogers, Springdale, and West Fork, with guidance from the Northwest Arkansas Regional Planning Commission will significantly influence future water quality in the reservoir. Therefore, it is appropriate that these county and municipal governments and organizations coordinate efforts (by active participation or by proxy) to assure wise land-use management.

A management program should recognize the broad range of potential pollutants from the watershed and provide for the systematic and quantitative evaluation of both point and nonpoint nutrient sources. Upgrading the effluent from the Fayetteville Waste Treatment Plant has been a major consideration of previous management efforts. Completion of the new facility will reduce nutrient loading from this major point source to the extent feasible with existing technology. Future management actions will therefore address diverse water-quality problems, as there will be few conspicuous point sources to control. Most actions will involve small gains, and those which promise a measurable economic benefit may be easiest to justify.

Conflicting water uses should be recognized and accommodated by long-range management programs. Economic development in NWA will be influenced by the availability and cost of high quality drinking water from Beaver Lake. Current water-quality management philosophies are designed to minimize nutrient loading, and this use will continue to be a high priority. The quantities of nutrients required to optimize water quality for drinking and primary-contact water activities are far lower than those needed to maintain large fish populations. Therefore, the organization should recognize that a water-quality strategy for one purpose may be detrimental to other competing uses, and that compromise may be necessary. For example, if recreational fishing is to be a primary long-term use of the reservoir, some trade-off between the quality of water needed to minimize treatment costs and that needed to maintain fish populations may be desirable, so long as no standards are violated.

It will also be important to better understand how Beaver Lake processes nutrients and how the assimilative capacity of the reservoir might aid in controlling pollutants. The reservoir has a large, but poorly defined, assimilative capacity which has been given minimal consideration in the development of previous water-quality management plans. The strong nutrient and biological gradients observed from upstream to downstream reaches of Beaver Lake and other similar large storage reservoirs in Arkansas (see Part 1) suggest that a large percentage of the nutrients entering the reservoir are assimilated in the upstream reaches. Water quality in the main body of the reservoir has not changed measurably since the reservoir filled in 1968. This strongly suggests that the reservoir assimilates most of the current nutrient load and rapidly removes these materials from biological processes. Nitrogen, phosphorus, and other materials are apparently deposited in the upstream reaches of the reservoir. If these nutrients remain bound in the sediments, they may be removed indefinitely from biological processes.

The major data gaps identified in Part 4 represent important needs for future resource management. They are difficult questions and may require several integrated studies to solve.

For example, the study of algal growth potential conducted by Dr. Meyer (activity 1 of this report) was based on a perceived need for additional information about factors which influence algal production in the uplake area of Beaver Lake. This effort answered several important questions about how the reservoir processes nutrients, but raised new and equally important ones concerning other kinds of materials that influence production of algae in the reservoir. Similarly, a quantitative evaluation of nutrient loading during storms would do much to clarify the relations between point and nonpoint discharge of nutrients, and could drastically alter our perception of potential pollution sources in the basin. However, the work to better identify these sources might be required to justify specific management actions.

An approach to water-quality management wherein local governments pool talent and resources to collectively address water-quality problems is economically appealing. With a relatively small commitment of time and resources from each participating organization, community representatives from throughout the Beaver Lake watershed could meet to identify common water-quality concerns and take appropriate actions to quantify and determine the controllability of different point and nonpoint nutrient-source pollutants. The organization would serve the NWA area in the following ways:

1) Provide an open forum for community leaders and special interests to discuss water-quality problems in the upper White River basin.

2) Provide community administrators and policy-makers with a vehicle to collectively prioritize and address water-quality problems in the basin, seek acceptable solutions, and communicate these interests to the appropriate regulatory, management, or operational authorities.

3) Provide a mechanism for the NWA community to develop positions on issues involving state and federal water policy.

4) Develop a broad understanding of water-quality problems in the watershed based on an understanding of nutrient loadings from both urban and agricultural sources, and thereby offer a mechanism for incorporating important management considerations into community planning.

5) Provide a clearing house for published reports concerning Beaver Lake and maintain a data base of historical, chemical, and biological data.

6) Identify important data or information gaps, and focus the appropriate expertise and funds to effectively address these needs.

7) Maintain a cost-effective monitoring program to identify long-term trends in reservoir water quality and localized problem areas.

Initially, the function of a management organization should be to provide community leaders with an opportunity to discuss water-quality needs and possible management options from a basin-wide perspective. Specific problems will become apparent as perceptions of water-quality needs change and new legislative initiatives are developed. If future needs could be thoroughly reviewed and discussed by representatives of local governments and regulatory agencies, the wealth of engineering and scientific expertise available to the area could be focused very efficiently on the most pressing management and research problems.

A water-quality management organization should provide leadership to foster communication and cooperation between local governing bodies and the regulatory, management, and operating agencies. Residents of NWA have a vested interest in maintaining good water quality in Beaver Lake. It is therefore appropriate that a management organization made up of these local interests should assume the lead in identifying water-quality problems, setting priorities for management actions, and conveying these interests to appropriate regulatory or operating agencies.

Finally, a water-quality management strategy should recognize that NWA is made up of several communities with distinct interests and constituencies which will influence their water-quality needs, and that management actions may produce undesirable effects on nearby watersheds. Much of the Beaver Lake watershed lies in

Washington and Madison counties where agricultural activities are the major sources of reservoir nutrients. However, a large part of Washington County also lies in the Illinois River watershed where residents have divergent water-quality interests. Similarly, Madison and Carroll counties must accomodate interests with residents in the Kings River basin. Much of Beaver Lake, including most of the developed area around the lake, is in Benton County. Therefore, that county will bear most of the cost of enforcing and controlling urban development in the area immediately around Beaver Lake.

Fayetteville and Huntsville discharge treated effluents into the upper White River basin, whereas Springdale and Rogers discharge wastes into the Illinois River basin. Similarly, urban runoff from the different communities is not equally distributed in the basin. Huntsville and West Fork contribute surface runoff directly into the upper White River basin. With the exceptions of the runoff from the south and east parts of Fayetteville and the extreme eastern parts of Springdale and Rogers, urban runoff from the most heavily populated areas flows into the Illinois River. Drinking-water supply and recreational use are the common elements linking most NWA communities with respect to water-quality needs. These represent the primary uses for justifying future cooperative water-quality actions in the basin.

Existing Authorities for Regulating Point and Nonpoint Pollution Sources in Arkansas

Regardless of the management strategy adopted, the organization would have to work with or through several regulatory agencies to implement water-quality control in Beaver Lake. Several federal, state, and local regulatory and government agencies presently have legislative authority to regulate many actions related to water-quality management in the reservoir and the upper White River basin. These agencies tend to protect their authorities and should therefore be incorporated into future plans to regulate water quality at the community level.

Strategies and authorities for managing or regulating water quality of point sources of pollution differ substantially from those for nonpoint sources. This frequently complicates efforts to manage water quality and may result in more than one agency being involved in regulating a specific pollution source. Procedures for controlling point-source pollution are generally more clearly defined than for nonpoint sources, and it is therefore convenient to separate regulatory authorities on the basis of how they function relative to the two major classifications of nutrient sources. Much of the legislation governing pollution of surface waters has been implemented fairly recently, and strategies will continue to change. For example, the major regulatory agencies have recently become more interested in the significance of nonpoint pollution to surface waters. These interests may lead to legislative actions which place greater responsibility on local communities to control these diffuse pollution sources. The following agencies which have authority to regulate various aspects of water quality in the Beaver Lake basin.

Point Sources

Environmental Protection Agency (EPA). The EPA is the principal federal agency responsible for providing guidance in the development of point and nonpoint source programs. It is a major funding agency for municipal water improvement. Under the National Pollutant Discharge Elimination System (NPDES) program, the DPC&E and EPA issue discharge permits jointly to municipalities.

Arkansas Department of Pollution Control and Ecology (DPC&E). As the principal agency entrusted with the administration of the water quality regulatory program in Arkansas, DPC&E is authorized to conduct the following water quality activities in the Beaver Lake watershed:

1) Administer and enforce all laws and regulations relating to pollution of any waters in the State.
2) Investigate and conduct surveys to identify pollution problems.
3) Set water-quality standards for waters in the State of Arkansas, establish use classifications, and regulate secondary treatment of discharge.

4) Permit and license waste-treatment facilities.

5) Require waste-treatment plans for subdivisions located less than 1/4 mile from a lake or reservoir.

Arkansas Department of Health. Arkansas acts 96, 302, and 402 created and modified responsibilities of the agency. The Department of Health exercises regulatory authority over sewer construction, design criteria, and operator training. The agency conducts inspections and approves the location, construction, operation, and maintenance of septic tanks and package plants for urban or agricultural development. It has authority to regulate improperly functioning units and impose penalties for violations.

Counties. The County Reorganization Act of 1977 gave counties a large share of regulatory control over point sources. The Act created the county planning boards. Responsibilities of these boards are listed in Arkansas Statute 17-1109. County planning boards may administer ordinances controlling the development of land with the approval of the Quorum Court.

Municipalities. Cities are authorized to construct, operate, and maintain waste treatment plants and all related support structures. They may contract for the disposal of sewage under Arkansas Statute 19-4116. First- or second-class cities are granted authority to zone development by Arkansas Statute 19-2804.

Suburban Improvement Districts. These districts are created by a petition from landowners with approval by the Quorum Court

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Suburban Improvement Districts. These districts are created by a petition from landowners with approval by the Quorum Court under Arkansas Statute 20-702.

Nonpoint Sources.

This area of water-quality management has developed primarily as a voluntary program. It deals primarily with agricultural and silviculture activities which have historically been addressed through education, training, and limited cost-sharing efforts.

EPA. The agency has national responsibility for oversight in the development of nonpoint source programs.

DPC&E. The agency has responsibilities for nonpoint nutrient control as detailed in Chapter 5 of the State of Arkansas Water Quality Management Plan (1982).

Arkansas Soil and Water Conservation Commission (SWCC). The agency was designated by the Governor as the management agency for implementation of the agricultural 208 water-quality management plan. The agency is responsible for state-level water planning as described under Arkansas Act 217, Arkansas statutes SS 21.1302-21.1332. The Commission cooperates in the development of water supplies associated with federal multipurpose reservoir projects.

County Soil and Water Conservation Districts. These organizations have responsibilities for nonpoint nutrient control as originally outlined in Act 197 of 1937 and modified by Act 14 of 1963. The Conservation Districts have an elected board, formulate long-range programs to govern the use of lands within the Districts, and develop annual work plans. They have a legal structure to obtain voluntary land-user participation. Activities of the Districts are coordinated through area representation. Ongoing nonpoint source programs include the following:

Agriculture Conservation Program

Forestry Incentive Program

Small Watershed Program

Resource Conservation and Development Program

Conservation Operations Program

Cooperative Extension Program

Soil and Water Loans

In addition, several management agencies work closely with Soil and Water Conservation Districts and the DPC&E to provide guidance in the control of nonpoint and agricultural point sources of pollution. These include the following organizations:

Soil Conservation Service

Agricultural Stabilization and Conservation Service

U.S. Forest Service (Management responsibilities are limited to federal lands.)

Arkansas Forestry Commission. The agency provides guidance on best management practices for forest resources and related silviculture practice and influences water quality through these recommendations.

Arkansas Transportation Commission. The agency has authority over toxic waste spills.

Arkansas State Highway Department. The agency influences water quality through road and design construction activities. Counties have responsibility for maintenance of county roads.

Arkansas Game and Fish Commission. Created by Constitutional Amendment No. 35, the agency is responsible for the management, restoration, conservation, and regulation of fish and wildlife resources in the state.

Organizational Structures and Representation

Solutions to most water-quality problems in Beaver Lake will involve the support of residents throughout the entire upper White River basin, as many future management actions will depend on voluntary participation and support by the public. Initially, emphasis should be placed on improving information transfer to increase public awareness of existing and future water-quality problems in the basin, providing accurate quantification of the many potential point and nonpoint pollution sources and the feasibility of the control, and fostering the cooperation of the various community interests and regulatory agencies. Substantive management decisions will not be possible until these actions are taken and the effect of reducing nutrient loading from the Fayetteville Waste Treatment Plant is ascertained. Otherwise, implementation of management actions will produce unknown benefits. The following organizational alternatives reflect different levels of community participation in managing future reservoir water-quality needs.

A) Committee of Representatives from Major Governing, Regulatory, and Operating Agencies. The least complex and most easily implemented organizational structure for addressing water-quality needs would be a standing committee made up of representatives from the various municipal and county governments, agricultural interests, and the major regulatory and operating agencies. It could be established under the Interlocal Cooperation Act (Arkansas Statute No. 14,901-908). Initially, the committee would provide information transfer concerning various water-quality problems in the basin, elevate community awareness of important long-term water-quality problems, and identify workable solutions to existing and new water-quality concerns. It would not have regulatory authority. The committee would be made up of the following representatives:

Elected members and local user groups

1) Four county governments, County judges or appointees
2) Four to six city governments, mayors or appointees
3) Soil and Water Conservation District, area representative
4) Beaver Lake Water District, Director or appointee
5) Boone-Carroll Water District, Director or appointee
6) Northwest Arkansas Regional Planning Commission, Director

Public service representatives

1) Corps of Engineers, Resident Engineer

2) Soil Conservation Service, one representative

3) Arkansas Water Resources Research Center, Director

4) Department of Health

5) Department of Pollution Control and Ecology

6) Game and Fish Commission

B) An Expanded or Modified Beaver Lake Citizens Advisory Committee. The Beaver Lake Citizens Advisory Committee was formed to advise the Department of Pollution Control and Ecology on water-quality needs in the upper White River basin. It has been successful in encouraging the upgrading of Fayetteville's waste treatment facility and has obtained a high level of media visibility in the NWA community. The committee does not receive funding or have legal or regulatory authority, but it presently has representation from several of the organizations listed in Alternative A.

C) An Upper White River Basin Commission or Water Management District. Conceptually, the most efficient long-term organizational structure to address water-quality needs in the upper White River basin would be one in which a small working body (either elected or appointed) would have oversite responsibility to develop water policy and regulate land use in the basin. With upgrading of the Fayetteville facility and the lack of high-visibility water-quality problems, it will be difficult to gain support for a commission or water management district.

Continued agricultural, urban, and industrial growth in the watershed is certain. Therefore, a gradual deterioration of water quality in the tributary streams and at their confluences with Beaver Lake can be expected over the next 10 to 20 years. The NWA community would benefit by formulating strategies to deal with this development. Several local governments presently have regulatory authority for planning and zoning within the watershed. The Northwest Arkansas Regional Planning Commission has developed extensive land use guidance which includes areawide use plans. This agency could serve an important role in coordinating activities.

As water-quality problems intensify, the development of a Commission or Management District with regulatory powers may become more appealing. The development of a centralized authority would require local governments and regulatory agencies to relinquish some of their existing functions. This appears highly unlikely at present. A viable alternative would be to establish a commission or Water Management District with no regulatory authority. The function of the organization would be similar to that outlined for Alternative A. As community leaders and the general public broadened their understanding of the long-term water-quality needs in the basin, the acquisition of appropriate regulatory authority would be possible. This could be accomplished through a series of legislative actions and would require the cooperation or consent of city and county governments in the basin, inasmuch as they would be forfeiting some of their regulatory authorities.

Director

Hiring a qualified individual to serve as a Director is critical to the long-term success of any of the organizational alternatives described previously. Municipal and county governments provide varied services, and elected officials must deal with problems on the basis of their constituencies' interests and needs. These extend far beyond water quality and result in changing priorities. Maintaining continuity would be essential to developing a sound water-quality-management program. The most efficient way to accomplish this is by assigning a salaried individual (Director) the responsibility of permanently administering the program.

The Director should have strong technical skills in the area of water-quality management and planning, and proven ability to communicate effectively in both technical and lay terminology. Salary should be commensurate with qualifications and experience to insure obtaining and holding a qualified individual. Based on perceived needs for the program, a Director could be employed full-time or part-time to perform the following duties:

1) Coordinate meetings and information transfer within the management organization.

2) Act as liaison with other governing bodies, regulatory and operating agencies, special interest groups, and the general public to address pertinent water-quality problems and control information exchange.

3) Oversee, or conduct, a program to monitor water quality in Beaver Lake; conduct, or contract for, appropriate statistical analyses of water quality data; and collate and disseminate this information to interested parties.

4) Research areas of water-quality concern as identified by the management organization, locate expertise to address specific problem areas, and assist in developing sound proposals and obtaining funds for needed work.

5) Conduct appropriate administrative functions as required to insure sound fiscal operation of the organization.

Financial and Legal Considerations

Obtaining a legal identity and a stable financial base is essential to the formation of a water-quality-management organization. Initially, financial needs would be limited to those required to pay a Director and support staff and provide a modest operating budget. Legal considerations would vary with the type of organizational structure recommended by this committee and would change dramatically if the organization acquired regulatory authority. It is probable that a long-term water-quality-management strategy would evolve or change, inasmuch as a simple committee structure where community leaders gathered to exchange information could progress through several stages and culminate in a commission or management district authority with regulatory and enforcement powers.

Several sources of potential funding should be explored. Both the Beaver and Boone-Carroll water districts would benefit substantially from an expanded community initiative to control water quality in Beaver Lake. A small water surcharge to users in both districts could provide a significant part of the funding needed to maintain a small staff and conduct monitoring and data analysis with a minimum of administration. Participating counties and municipalities in the basin might also provide some fraction of the operating cost. This would require that Quorum courts and City boards first be apprised of the functions and benefits from a basinwide approach to water-quality management. A series of presentations to summarize these needs and benefits to the respective communities, followed up with periodic updating of accomplishments would be essential to maintain needed support for a management organization. In addition, appropriate formulas to assess each community's costs relative to the services provided would have to be factored into a management plan. A sales tax should also be explored, as most of the NWA area benefits from water supply and recreation. Finally, working agreements with regulatory or management agencies to provide cost sharing and coordination of ongoing monitoring programs should be included. Initial funding would provide for the following activities:

1) Salary and fringe benefits for a Director and limited support staff.
2) Office space, utilities, office supplies, and transportation.
3) Funds to conduct or oversee a monitoring program as outlined in Part 3.
4) Funds to maintain a clearinghouse for data and published reports on the Beaver Lake watershed.
5) A small contingency fund to address specific water quality or future needs.

Estimated annual cost of the above program should range between $50,000 and $100,000, depending on the level of monitoring desired and the amount of coordination possible with ongoing monitoring programs. However, $50,000-60,000 annually would support a minimal effort.

Part 6. SUMMARY

Beaver Lake is physically and chemically similar to several deep storage reservoirs in the southeastern United States which have large storage capacities relative to annual inflows. Nutrient concentrations in tributary streams may be high, but movement of water through these impoundments is slow, and nutrients are assimilated and deposited in uplake areas. This produces nutrient and biological gradients which are highest near sources of inflow. The reservoirs are efficient sinks for nitrogen, phosphorus, and many pollutants.

On average, water quality of Beaver Lake compares favorably with that of most other large reservoirs, although nutrient concentrations in the major tributaries (especially the White River) are much higher than desired. Consequently, the upstream area of the reservoir experiences the most significant water quality problems, while the main body of the impoundment maintains excellent water quality. The intake for the Beaver Water District is located far uplake, and it is in this area that long-term management actions must be directed.

The National Reservoir Research Program monitored dissolved oxygen, water transparency, and fish communities in the reservoir at monthly intervals from 1969 to 1980. These studies did not indicate a measurable deterioration in water quality throughout the period. There have been large year-to-year differences in water quality as a result of variations in runoff. However, water quality in the mid and lower reaches of the reservoir has remained good since it first reached power pool elevation in 1968. The responses to annual variations in surface runoff suggest that nonpoint nutrient sources may be more important to reservoir production than previously thought, and the reservoir has a large capacity for nutrient assimilation which occurs within a year, and probably within a growing season.

Water quality and biological features of Beaver Lake have been studied extensively since it began filling in early 1964. Most of these have been short-term in nature and have limited application for a water-quality-management strategy. Several fundamental data gaps still exist (see Section 4), and these pose significant limitations for efficient resource management. Measures of nutrient delivery from the many diverse point and nonpoint sources in the basin are poorly defined. An accurate nutrient budget is needed to insure that future management decisions target the primary nutrient sources. This should include an evaluation of nutrient runoff during storms. Recent studies on DeGray Lake, Arkansas, have shown that between 90 and 95 percent of the annual phosphorus load to that reservoir occurs during storm events. Similar findings for Beaver Lake would alter perceptions of the relative importance of different nutrient sources and permit targeting of the ones which have the greatest impact on reservoir water quality. With upgrading of the Fayetteville Waste Treatment Plant, much finer resolution of the remaining pollution sources will be needed.

Quantitative information on sedimentation and nutrient assimilation in the reservoir is also lacking. Studies to define the fate of sediments and nutrients in the reservoir and the levels of algal production associated with different nutrient loadings would provide needed information on the assimulative capacity of the reservoir.

Future land uses will strongly influence reservoir water quality and the amount of control that is feasible. Currently, about 62 percent of the watershed is forested, 32 percent is agricultural, and only about two percent is urban. Nutrient loading from forest lands is lower than that from agricultural and urban lands. Continued agricultural and urban growth will result in the conversion of forest land, and increased nutrient concentrations in inflowing waters will occur. The extent to which these may be offset by reductions from the upgrading of the Fayetteville Waste Treatment Plant or by assimilation in the reservoir presently are unknown.

Future water quality management will focus on nutrients and pollutants from diverse point and nonpoint sources widely distributed in the watershed. The most easily targeted of these will be septic tanks, small package plants, and small agricultural point sources. The amount of control possible from greater regulation of these sources may be limited, as other uses, such as the land application of animal wastes, may contribute much greater total quantities of nutrients. Recently completed studies by the Soil Conservation Service indicated that only about one-half the available pasture lands in the basin receive annual fertilizer applications, and that most of these are within accepted agricultural limits. These will not violate water-quality standards and may require actions through BMPs to collectively produce small improvements in water quality. Long-term commitments to planning, education and training, monetary support, and regulation are required to address these sources.

Several state and federal regulatory and management agencies are working actively to maintain and protect water quality in the basin. They have legislative authority to regulate many potential problems. Formation of a basinwide management organization with powers to regulate would require these agencies to divest themselves of their existing authorities. This action is highly unlikely, and involvement at the local level may be limited initially to an advisory capacity.

Development of a basinwide management program will be difficult because large multi-purpose projects like Beaver Lake affect many constituencies with diverse interests. At a minimum, a program would require the active participation of the four county governments, the larger municipalities, agricultural interests, and the primary water users. Several of these local governments have significant parts of their constituencies living outside the basin where water quality needs may be perceived differently. Selling a management plan will require the development of carefully designed programs to justify support by those residents who live outside the watershed. Municipal water supply, recreation, and the associated economic benefits are the primary factors which should link the NWA community to the reservoir. They provide the basis for future cooperation.

Residents of Northwest Arkansas are accustomed to very high-water quality, as the region was historically forested with high gradient streams. The rapid increase in population experienced by the Northwest Arkansas area since the 1950s will continue, and demands on Beaver Lake water will increase. Careful planning, a firm commitment of resources, and an understanding of scientific, economic, and legal constraints will be needed to insure that the water quality of Beaver Lake does not deteriorate. Currently, maintenance of good reservoir water quality has broad public support. However, the transition from cleaning up highly visible point sources to that of the many small nonpoint and point sources that will be ameliorated only through extensive management efforts may result in a rapid erosion of public interest.

Part 7. RECOMMENDATIONS

Water quality in the main body of Beaver Lake is presently good, and long-term monitoring studies by the former National Reservoir Research Program have not indicated a significant deterioration since impoundment. Upstream areas, and particularly the upper White River have experienced significant water-quality problems which have been linked to the effluent of the Fayetteville Waste Treatment Plant. With the solution to this problem, future management needs will center on small point and nonpoint sources in the basin. The Management Strategies Committee recognizes that a sustained commitment by the residents of Northwest Arkansas is needed to insure that the future quality of water in Beaver Lake remains suitable for recreation and water supply.

This report proposes a strategy for managing water quality in Beaver Lake which involves first quantifying contributions of nutrients from different land-use practices throughout the watershed. Those sources which have the greatest potential for degrading water quality would then be targeted for appropriate management actions. Future actions will address diverse small point and nonpoint sources. These efforts will require long-term commitments and will depend heavily on land-use management and voluntary programs sponsored by existing regulatory and management agencies.

Data Gaps and Water Quality Monitoring

Many short-term water-quality and biological studies have been conducted on Beaver Lake and its major tributaries, and a large base of historical and environmental data exists. Unfortunately, these data have not been thoroughly evaluated. Most studies have addressed specific problems with different sampling protocols, and this limits their value for targeting management needs from a basinwide perspective. The following information needs should be evaluated as a basis for a water-quality-management program.

1) Collate all historical water quality and biological information and establish a central repository to maintain and disseminate this information. Conduct a thorough analysis of existing data to define historical water-quality and biological features of the reservoir, to determine rates at which changes in future water quality are likely to occur, and to establish specific water quality standards for Beaver Lake based on historical data.

2) Develop an accurate nutrient budget for Beaver Lake. This should quantify loadings of nutrients or pollutants which enter the reservoir from major point and nonpoint sources and define the role of storm runoff in delivery of nutrients and other pollutants to the reservoir.

3) Conduct a study of patterns of sediment deposition, concentrations of primary nutrients and potential toxic materials, and algal production paths in the reservoir. This study would

provide much needed information on the assimilative capacity of the reservoir and the fate of imflowing nutrients.

4) Initiate a water-quality-monitoring program, as detailed on pages 62-66. This program should be designed to detect important changes in reservoir water quality and to assess the effects of the upgrading of the Fayetteville Waste Treatment Plant. Professional staff is needed to insure continuity and quality control for a monitoring program. Field sampling should therefore be conducted by a private contractor, University personnel, or an existing management agency.

Best Management Practices

Over the long term, water quality in Beaver Lake will be a function of land uses in the basin. County and municipal planning commissions currently have the authority to regulate urban growth, and the Northwest Arkansas Regional Planning Commission provides planning assistance for many communities in the basin. Increased coordination among these planning elements to insure that environmental needs receive high priority is suggested.

Collectively, agricultural activities are a primary source of nutrient loading to the reservoir. The basin is not well suited for row cropping, and animal wastes are the major agricultural nutrient sources. Ongoing programs for BMP administered by the Soil Conservation Service, the Soil and Water Conservation Commission, county Soil and Water Conservation districts, and the

Arkansas Forestry Commission warrant continued support, as they have been effective in controlling the delivery of sediments and agricultural nutrients into the reservoir. These voluntary programs stress site-specific BMP for agricultural and silvicultural activities in the basin. They are predicated on a close working relationship with individual landowners and the development of site-specific BMP. Incentives to promote broader participation in these voluntary programs should be supported.

The Committee recognizes that long-term reductions in agricultural wastes will depend on continued development of new technologies to provide alternate uses for waste materials. Ongoing or new research programs by the University of Arkansas Agricultural Experiment Station and nearby federal agencies which address alternate uses for poultry and livestock wastes or wiser management of forest resources should be supported.

Future development of the Beaver Lake basin will result in an increased number of septic or on-site treatment plants. Presently, the total quantity of effluent produced by these sources is unknown, but it is probably small when compared to total nutrient input from other land uses. An inventory should be made to accurately determine the number of existing on-site units in the basin. Future development should be monitored to identify future problem areas. Procedures to insure that new systems are properly inspected and approved by the Department of Health are recommended. A cooperative arrangement wherein a utility company delays hook-up of services until proof of inspection by the Health Department is provided should be explored.

Control measures for urban runoff are difficult to implement. The quantities of primary nutrients and pollutants entering the reservoir from urban runoff should be determined as part of a nutrient-budget study for the reservoir. Guidlines to minimize erosion losses during construction activities should be developed. This could be based on existing guidelines developed by the Soil Conservation Service.

Lake Management Organization

Authorization for regulating water quality in Beaver Lake currently rests with several federal, state, and local agencies and governments. A management strategy should not attempt to usurp these authorities, but it should assume the role of coordinating management and regulatory actions as described on pages 77 and 78 of this report. Environmental needs of the Northwest Arkansas community could best be served through a lake-management body. However, the area is made up of many communities with different water-use needs. The development of a lake-management organization with regulatory functions will likely require several years to implement, and it will probably require enabling legislation at the state or federal levels. A management strategy of the type developed in Wisconsin does not appear feasible for Beaver Lake, as these large federally funded projects present much more complex regulatory and operational responsibilities.

A lake-management body as described in organizational alternative A (pages 87-88) could be established with minimal effort. However, it should be viewed as an interim step in which local governments, water users, and operating agencies in the basin would continue to meet to discuss common interests and needs and to explore working relationships of the many diverse interests.

Administration and Funding

A full- or part-time director is crucial to the success of any long-term management organization. Hiring should be based on the individual's demonstrated ability to perform duties as detailed in Part 5 of this report.

A minimal base level of local funding in the amount of $50,000-$60,000 would be required annually to fund a full-time or part-time director and support staff, provide a repository for reservoir water-quality and biological data, and maintain a limited water-quality-monitoring program. This represents an essential element in the development of any water-quality-management plan. The following potential sources of funding should be explored.

1) An annual assessment from each participating municipal or county government to insure that these organizations maintain a vested interest in the activities of the lake-management body.

2) A small surcharge on residential, commercial, and industrial water users supplied by the Beaver Water District

and the Boone-Carroll Water District. A surcharge of $1.00 per year for residential users and $5.00 per year for commercial and industrial users could provide most of the funding needed to finance a lake management organization, a center for reservoir data, and a water quality monitoring program.

3) Non-cash contributions from regulatory or management agencies. These could include sample analysis for a monitoring program or evaluation of special problems.

4) A minimal sales tax. A small fraction of one percent on sales in the four county area would be adequate to fund a management program but might be difficult and costly to implement.

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