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FLUCTUATIONS AND RELATIONSHIPS OF SELECTED PHYSICOCHEMICAL PARAMETERS IN DARDANELLE RESERVOIR, ARKANSAS, 1975-1982

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ABSTRACT

Annual and seasonal fluctuations and relationships are described for discharge, turbidity, chloride, total hardness, conductivity and suspended solids over an eight-year period in Dardanelle Reservoir. The parameters fluctuated rather widely primarily in response to seasonal patterns of rainfall. Chloride and conductivity were related and generally fluctuated together as did turbidity and suspended solids. Hardness appeared to vary independently of the others prior to 1979 then varied more closely with chloride after March 1979. Inherent differences between the Illinois Bayou arm and the main Arkansas River sections complicated the precise identification of any overall impact of power plant operation. No significant long term changes were seen, but chloride declined gradually whereas hardness and conductivity increased slightly. Suspended solids exhibited a significant rise in 1982.

INTRODUCTION

Dardanelle Reservoir is located in west-central Arkansas on the main stem of the Arkansas River near the city of Russellville. The reservoir was constructed approximately 20 years ago by the U.S. Army Corps of Engineers as a part of the Kerr-McClellan Arkansas River Navigation System. The lake has a surface area of approximately 13,720 ha, a shoreline of 510 km, a volume of 656 million m^3 and a mean depth of 4.3 m (range to 16.5 m). The normal pool level stands at 103.3 m (339 ft) above MSL, and the rate of fall is approximately 0.2 m/km. The mean long term river discharge (Q) at this point is 1103 cubic meters/sec (cms) making the average residence time 6.9 days. However, during this study period the average Q was 773.4 and 770.4 cms if calculated from monthly means and sample day means, respectively (USGS 1975-1982). The watershed of the reservoir proper comprises approximately 40,000 ha and contains a variety of natural and man-made environments including areas of mature hardwood, coniferous and mixed forest, row cropping, cattle farming, orchards, timber removal, light industry and limited urban development.

In the late 1960's Arkansas Power and Light Company began construction on a two-unit nuclear generating facility. In conjunction an environmental monitoring program was begun in 1969. Unit I, which began commercial operation in December 1974, utilizes an 875 megawatt dynamo which uses once-through circulation of lake water for condenser cooling at a rate exceeding 48 cms. The primary goal of this project was to identify and quantify any physicochemical or biological changes, especially those caused or accelerated by the operation of Unit I. Other than USGS Water Data (1975-1982), few literature sources are available that report general survey characteristics. Chittenden (1979, 1980) and Chittenden and McFadden (1978) reported on radionuclides, total dissolved solids and selected cations in Dardanelle Reservoir.

METHODS

Although there have been minor changes in procedures over the years, the general protocol of this project involved monthly sampling at stations 1 (discharge), 5 (mouth of discharge bay into the main part of the lake), 16 (intake) and 21 (upstream control) (Figure 1). The average depths at these stations were 3 m, 3 m, 3.5 m and 12 m, respectively. The water level fluctuated 0.3 m up or down in response to runoff and channel dredging. Water samples from 0.6 m and near the bottom at each station were tested. Turbidity was measured on site, whereas the others were measured in the laboratory. The samples were transported

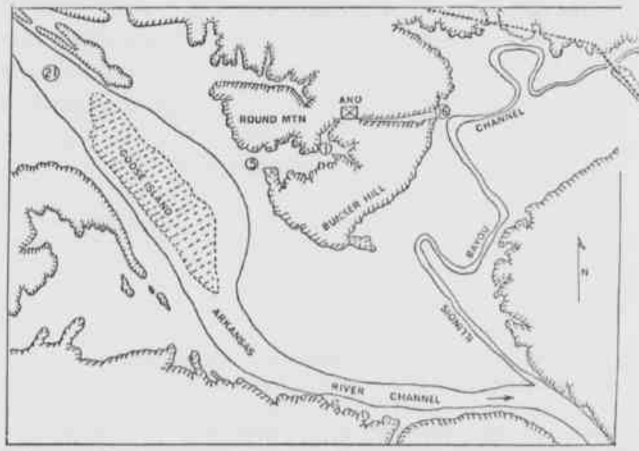

Figure 1. Outline map of Dardanelle Reservoir with key sampling stations, 1975-1982.

on ice and refrigerated continuously until analyzed within three days after collection. All chemical tests were performed according to methods recommended by Standard Methods (1975) as adapted by Hach Chemical Company.

RESULTS AND DISCUSSION

The individual data collected during this project were too numerous to list in this report. After monthly means and ranges were determined for the six parameters, the months were ranked from highest to lowest by station and test, assigned a rank value from 1 to 12, and the rank values were summed (Tables 1-3). Our data compare favorably with periodic but incomplete readings of conductivity, turbidity and suspended solids reported at the USGS gauging station immediately below the Dardanelle Dam.

Discharge readings (Q) on sampling dates from USGS (1975-1982) data were averaged by month (Table 1). The years 1977 and 1981 experienced dry springs and wet autumns, whereas the other years followed the more expected trend of wet springs and dry autumns. Perhaps the most astonishing fluctuation occurred in 1975 between June and

Table 1. Monthly Means of Physicochemical Data, Dardanelle Reservoir, Arkansas, 1975-1982. Q is given in cubic meters/sec; conductivity in micromhos; others in mg/1.

Station	Q	Turb	Sus Sol	Chloride	Hard	Cond
JANUARY						
1	461	21.8	11.4	93.6	74.4	467.1
5		21.3	13.8	83.5	85.3	522.7
16		20.2	14	84.3	81	492.3
21		18.9	16	139.5	105.2	670.5
FEBRUARY						
1	688	37.1	25.4	77	71	384.9
5		27	17.2	110.1	95.2	517.9
16		26	22.7	81.9	71.3	475.1
21		23.7	33.4	136.6	94.6	597.1
MARCH						
1	1540	40.6	25.2	79.8	70.2	352.3
5		46.6	31	106.3	82.2	494
16		37.5	39.4	55.6	61.1	380.1
21		39.3	32.3	124.2	116.6	647.7
APRIL						
1	918	31.5	15.6	81.2	56.7	362.3
5		47.6	30.6	110.7	75.5	429.2
16		29.8	22.9	88.1	54.9	413.2
21		50.7	32.9	178.8	92.2	545.1
MAY						
1	1353	44.9	22	73.7	84	397.6
5		61.6	39.1	83.5	104.5	469.9
16		41.6	15.4	74.4	80.4	462.3
21		81	36.4	103.4	107.1	520.1
JUNE						
1	1361	32.5	16.4	172.1	93.6	669.2
5		49.9	29.7	192.2	100.9	718.6
16		29.6	12.4	92.2	94.1	540.4
21		49.9	30.1	226.4	116.1	843.7
JULY						
1	909	24.4	19.6	144.3	114.4	722.3
5		41.1	26.6	131.9	112.6	701.1
16		18.1	12.4	168.6	116.9	725.6
21		35.6	21.9	129.9	124.1	750.1
AUGUST						
1	432	20.1	13.6	148.2	127.8	681.4
5		28.8	16.4	157.4	119.8	704.1
16		18.4	12.7	109	118.4	764.4
21		29.9	18.8	190.7	130.5	715.4
SEPTEMBER						
1	244	18.6	11.3	164.5	122.5	762.2
5		29.6	21.5	163.8	128.5	744.3
16		17.2	18.1	139.8	124.8	852.7
21		21.4	14.4	162.6	142.6	761.8
OCTOBER						
1	235	29.7	25.2	144.4	119.4	739.1
5		31.1	21	147.4	118.1	723.3
16		22.7	16.8	169.9	115.2	804.7
21		31.9	20.2	144.8	120.8	713.6
NOVEMBER						
1	404	19.6	11.5	143.3	120	704.7
5		22.1	16.4	143.9	128.7	683.1
16		19.1	11.6	180.7	123	762.2
21		23.7	15.6	138.3	122.8	687.7
DECEMBER						
1	344	22.8	17.1	114.9	91.2	549.5
5		25.1	14.3	124.6	96.9	566.8
16		22.8	12.3	123	90.2	622.7
21		26.6	14.8	121.1	108.4	609.1

Table 2. Monthly Ranges of Physicochemical Data, Dardanelle Reservoir, Arkansas, 1975-1982. Q is given in cubic meters/sec; conductivity in micromhos; others in mg/1.

Station	Q	Turb	S.S.	Chloride	Hard	Cond
JANUARY						
1	17-1543	8-52	2-28	37-195	25-176	268-805
5		8-44	2-55	8.5-148	14-170	316-1025
16		5-38	0-35	40-138	22-169	266-800
21		5-32	4-38	52-206	28-206	428-1198
FEBRUARY						
1	15-1594	6-140	4-93	21-126	30-150	164-705
5		4-72	5-42	56-180	51-152	359-710
16		3-80	6-50	38-125	36-145	326-695
21		10-44	4-40	57-300	48-142	420-832
MARCH						
1	148-3075	12-96	8-52	10-174	26-117	62-656
5		19-90	9-60	42-203	40-142	251-884
16		14-110	6-102	9-115	18-116	52-732
21		19-97	8-82	52-182	79-166	346-1115
APRIL						
1	80-2270	12-49	0-42	32-228	12-104	215-678
5		16-72	4-52	44-300	34-136	290-760
16		16-50	5-45	38-225	10-116	265-720
21		18-85	1-58	45-348	34-158	350-782
MAY						
1	84-2733	22-78	9-38	40-130	14-230	254-638
5		42-95	18-95	47-158	30-232	310-666
16		18-65	6-26	46-130	24-208	298-626
21		58-109	16-68	48-252	32-275	353-762
JUNE						
1	201-3401	20-70	7-30	47-450	63-150	345-1020
5		35-82	6-64	60-500	62-146	490-1015
16		14-50	4-22	44-180	62-131	338-852
21		35-79	14-70	68-455	62-162	605-1055
JULY						
1	329-2526	0-50	2-56	76-372	58-146	484-948
5		6-70	5-52	75-262	56-158	515-990
16		3-29	0-21	76-448	21-164	620-920
21		5-50	4-34	70-199	50-179	585-1174
AUGUST						
1	101-818	9-30	5-25	88-331	57-179	512-990
5		20-42	4-32	97-402	56-177	505-950
16		9-34	0-32	86-139	47-182	591-995
21		14-48	12-38	102-580	56-176	502-948
SEPTEMBER						
1	3.7-1156	9-30	0-22	98-420	42-176	560-885
5		20-50	4-42	94-420	45-180	550-870
16		10-22	8-40	104-188	38-174	700-958
21		13-42	5-32	98-405	76-194	590-892
OCTOBER						
1	26-643	15-75	2-56	94-318	42-176	545-806
5		23-58	2-32	92-312	42-174	540-873
16		12-46	5-35	102-312	36-184	670-916
21		16-60	1-45	92-300	44-171	560-938
NOVEMBER						
1	2.5-1411	8-38	0-22	103-288	36-189	355-860
5		6-46	2-32	74-324	34-235	358-915
16		12-35	1-32	104-278	34-192	605-930
21		4-59	0-40	94-302	35-172	368-889
DECEMBER						
1	113-649	6-60	0-60	24-180	30-174	178-862
5		10-60	0-44	30-185	30-172	264-870
16		12-59	0-42	38-178	29-172	224-890
21		8-56	1-44	55-180	30-180	414-902

September when Q declined from 3400 to 3.7 cms. Another sharp decline occurred in 1980 between May and November.

Turbidity and Q values were strongly correlated except during 1976, 1977 and 1981 (Table 4). Turbidity varied considerably among the stations, months and years, but May clearly gave the highest readings, whereas September showed the lowest readings by a slight margin under January and November. These fluctuations closely followed periods of abundant and sparse rainfall, respectively. Typically the Illinois Bayou arm contained less turbid water than the Arkansas River section, but rainfall created variations. A general heavy rain elevated the turbidity at all stations, whereas a local storm in the foothills north of Russellville would cause greater turbidity only in the Illinois Bayou arm. Several times a rainfall in part of the upper Arkansas River basin would strongly elevate turbidity in the main section of the lake. Using turbidity measurements we observed one aspect of mixing accomplished by passage through the plant. Station 5 typically showed a layering effect produced when the warmer, less turbid water from station 16 came from the discharge and flowed out over the top of the Arkansas River water.

Table 3. Cumulative Ranking Values for Months Listed from Highest to Lowest Physicochemical Concentrations, Dardanelle Reservoir, Arkansas, 1975-1982.

	1975			1976			1977		
Variables	n	r	p	n	r	p	n	r	p
Q vs T	12	.899	.0001	12	.332	.1457	11	.135	.3467
Q vs SS	12	.581	.0228	12	.326	.1505	11	-.179	.3015
Q vs Cl	12	-.561	.0278	12	.271	.2015	11	.554	.0374
Q vs H	12	-.049	.4366	12	.103	.3735	11	.529	.0459
Q vs C	12	-.510	.0439	12	.107	.3697	11	.494	.0600
T vs SS	-	-	-	36	.842	.0001	29	.092	.3175
T vs Cl	37	-.572	.0002	36	.459	.0016	32	.030	.4356
T vs H	34	.136	.2260	36	.077	.3050	32	.285	.0305
T vs C	36	-.344	.0189	36	.254	.0554	28	.021	.4548
SS vs Cl	-	-	-	37	.471	.0018	32	-.150	.2190
SS vs H	-	-	-	36	.252	.0675	32	-.034	.4268
SS vs C	-	-	-	36	.405	.0068	28	-.044	.4056
Cl vs H	33	-.091	.3096	40	.138	.2024	32	.616	.0003
Cl vs C	38	.645	.0001	40	.727	.0001	28	.881	.0001
H vs C	34	.289	.0469	40	.431	.0028	28	.744	.0001
	1978			1979			1980		
Q vs T	11	.680	.0102	12	.925	.0001	12	.704	.0052
Q vs SS	11	.623	.0196	12	.973	.0001	12	.759	.0022
Q vs Cl	11	-.555	.0374	12	-.802	.0010	12	.050	.4358
Q vs H	11	-.475	.0688	12	-.877	.0002	12	-.569	.0257
Q vs C	11	-.658	.0134	11	-.884	.0003	12	-.413	.0901
T vs SS	34	.841	.0001	46	.890	.0001	48	.778	.0001
T vs Cl	34	-.406	.0081	46	-.690	.0001	48	.251	.0408
T vs H	43	.285	.0305	47	-.727	.0001	48	-.269	.0307
T vs C	31	-.366	.0204	42	-.738	.0001	48	-.094	.2651
SS vs Cl	34	-.116	.2593	46	-.599	.0001	48	.113	.2250
SS vs H	34	.179	.1554	46	-.646	.0001	48	-.221	.0637
SS vs C	31	-.162	.1974	42	-.673	.0001	48	-.118	.2158
Cl vs H	34	.249	.0759	45	.950	.0001	48	.406	.0022
Cl vs C	31	.737	.0001	42	.964	.0001	48	.661	.0001
H vs C	31	.315	.0404	42	.971	.0001	47	.759	.0001
	1981			1982					
Q vs T	12	.413	.0901	12	.592	.0205			
Q vs SS	12	.519	.0406	12	.366	.1202			
Q vs Cl	12	.268	.2047	12	-.394	.1016			
Q vs H	12	.044	.4432	12	-.398	.0989			
Q vs C	12	.146	.3265	12	-.339	.1403			
T vs SS	48	.434	.0012	48	.606	.0001			
T vs Cl	48	-.099	.2553	48	-.428	.0014			
T vs H	48	-.272	.0291	48	-.339	.0088			
T vs C	48	-.300	.0180	48	.051	.3648			
SS vs Cl	48	.179	.1103	48	-.202	.0828			
SS vs H	48	.272	.0290	48	-.408	.0021			
SS vs C	48	.073	.3147	48	-.302	.0173			
Cl vs H	48	.794	.0001	48	.704	.0001			
Cl vs C	48	.909	.0001	48	.918	.0001			
H vs C	48	.893	.0001	48	.789	.0001			

Table 4. Pearson Correlation Tests on Physicochemical Data, Dardanelle Reservoir, Arkansas, 1975-1982. Q = discharge; T = turbidity; SS = suspended solids; Cl = chloride; H = hardness; C = conductivity.

Q	Turb	S.S.	Chloride	Hard	Cond
Mar 12	May 48	Mar 42.5	Jun 42	Sep 46	Sep 47
Jun 11	Mar 40	May 40	Sep 40	Aug 43	Oct 41
May 10	Apr 39	Feb 38	Aug 38	Nov 42	Jul 36
Apr 9	Jun 39	Apr 36	Oct 37	Jul 35	Aug 36
Jul 8	Oct 27	Oct 30.5	Nov 33	Oct 34	Jun 35
Feb 7	Feb 25.5	Jun 26.5	Jul 29	Jun 26	Nov 32
Jan 6	Jul 24	Jul 26.5	Apr 24	Dec 22	Dec 23
Aug 5	Dec 20	Sep 18	Dec 22	May 20	Jan 21
Nov 4	Aug 17	Aug 17.5	Jan 17.5	Jan 15	Feb 14
Dec 3	Nov 11.5	Dec 13	Feb 14	Mar 13	Mar 10
Sep 2	Jan 11	Jan 13	Mar 10	Feb 12	May 9
Oct 1	Sep 10	Nov 10.5	May 5.5	Apr 4	Apr 8

The intensity of this layering was regulated by the volume of water pumped through the plant, the direction of wind and the discharge of the river (Rickett and Watson, 1982). Turbidity at station 21 was greater than at station 16 10 of 12 months by a mean of 12.9 FTU's. Turbidity at station 1 was greater than at station 16 all months by a mean of 3.2 FTU's, which was probably not caused by current disturbance of the bottom sediment. Shortly after the plant began commercial operation, we began experiencing great difficulty obtaining a benthos sample at station 1 because the current had scoured the loose silt away leaving hard gray clay.

The greatest average concentration of suspended solids was measured in March with May showing a close second, whereas November had the lowest (Table 1). The late winter and spring months had the highest values, while the late fall and winter months had the lowest. Again station 21 had larger values than station 16 10 of 12 months by a mean of 7.6 mg/1. There was no significant difference between stations 1 and 16 with respect to suspended solids. Pearson correlation analysis showed a strong positive correlation between turbidity and suspended solids (Table 4).

Chloride concentrations were highest in June and lowest in May, but there was much inconsistent variation month by month. Apparently the spring rainfall diluted the chloride concentration, which quickly recovered during the next month. There was more chloride at station 21 than 16, eight months out of 12 by a mean of 53.6 mg/1. There was no real difference between stations 16 and 1; the concentration was greater at station 1 five months out of 12 by a mean of 13.9 mg/1. Sinclair and Watson (1978) reported a somewhat stronger correlation between Q and chloride than our data, which show a weak positive correlation in 1976 and 1981, a significant positive correlation in 1977 and zero or negative correlations during the other years (Table 4). The location of a storm might help explain this fluctuating correlation. A localized heavy rain in western Arkansas should dilute the river water giving a negative correlation, whereas a rainfall in the major chloride source areas of eastern and northeastern Oklahoma would result in more chloride with the heavier discharge showing a positive correlation. The zero correlations would be observed with a generalized rainfall or a storm located in an intermediate area.

The greatest conductivity readings occurred in September, whereas the lowest values were obtained in April with May and March showing very low values. Conductivity values increased rather steadily between April and August and declined rather steadily between October and March. Station 21 had greater conductivity than 16 only seven months out of 12, but the mean difference was 109.4 micromhos. Station 16 had higher conductivity readings than station 1 during 11 of 12 months and was greater by a mean of 45.7 micromhos. Apparently the passage through the condenser circuit removed some of the ions. Pearson correlation tests showed a rather strong positive correlation between chloride and conductivity (Table 4). Generally minimum conductivity measurements were observed during the periods of greatest Q because of dilution, although the highest conductivity readings did not necessarily coincide with periods of lowest Q but occurred generally within two or three months following a peak Q reading.

Total hardness was also greatest in September and lowest in April, but the months between were arrayed differently than for conductivity. Station 21 showed higher values than station 16 11 of 12 months by a mean of 21.6 mg/1, but there was no significant difference between stations 1 and 16. Pearson correlations showed a moderate positive correlation between hardness and conductivity (Table 4).

Correlation may also be tested non-statistically using a rank matching technique. If two datasets are positively correlated perfectly, the rank-

Table 5. Ranking Match Correlations (z), Compared with Mean Pearson r values from Table 3. Physicochemical data from Dardanelle Reservoir, Arkansas, 1975-1982.

Variable	z	1/z	Mean r
Q vs turbidity	2.00	.500	.585
Q vs susp. solids	2.33	.429	.496
Q vs chloride	4.83	.207	.146
Q vs hardness	5.50	.182	-.212
Q vs conductivity	5.33	.188	-.257
turbidity vs sus. solids	1.33	.752	.640
turbidity vs chloride	4.67	.214	-.182
turbidity vs hardness	5.17	.193	-.018
turbidity vs cond.	5.17	.183	-.190
sus. solids vs chloride	5.00	.200	-.043
sus. solids vs hardness	5.17	.193	-.087
sus. solids vs cond.	5.42	.184	-.117
chloride vs hardness	2.00	.500	.471
chloride vs conductivity	1.83	.546	.805
hardness vs conductivity	1.33	.752	.640

ing of items (months, in this case) should match perfectly. If the correlation is less than perfect and the two ranked lists (Table 3) are compared side by side, the number of positions each entry in the second list must be moved to match its counterpart in the first list should be an indication of the lack of correlation. The total number of positions the entries in the second list must be moved divided by the number of entries in the list yields the average number of positions moved per entry. This was done for each of the 15 possible correlation pairs. These values (z) may be inverted and compared with the Pearson correlation r values (Table 5). Inverted z values could range from zero to one, smaller decimals representing less correlation. While the Pearson r values may be negative (inverse correlation), inspection indicates z values less than about 0.2 show a beginning negative correlation. This shows turbidity and suspended solids and hardness and conductivity to be strongly correlated with a value of 0.752 each. Chloride and conductivity were moderately correlated at a value of 0.546, whereas chloride and hardness and Q and turbidity were correlated at a value of 0.500, each, and Q and suspended solids were correlated at 0.429.

Bi-annual means of Q declined from 904 to 660 cms, whereas the bi-annual means for chloride declined from 170 to 101 mg/1. Bi-annual means for hardness and conductivity increased from 94.4 to 133 mg/1 and from 520 to 676 micromhos, respectively. Hardness showed one fluctuation, while the others exhibited uniform trends. Turbidity showed no long term tendency to change, and neither did suspended solids, except in 1982, which revealed a sharp rise.

T-tests (Table 6) showed no significant differences between stations 16 (intake) and 1 (discharge), although turbidity had a near-significant value of 0.1771. However there were significant differences between stations 16 and 21. All parameters except conductivity were significant at $p = 0.05$ or below, and even conductivity had a lower p value than any test between stations 16 and 1.

Table 6. T-test results for Significant Differences Using Monthly Means of Physicochemical Data, Dardanelle Reservoir, Arkansas, 1975-1982.

Parameter	Sta 16 vs 21 t	Sta 16 vs 21 p	Sta 16 vs 1 t	Sta 16 vs 1 p
turbidity	1.940	.0312	0.986	.1771
sus. solids	1.897	.0340	0.108	.4558
chloride	2.282	.0154	0.359	.3616
hardness	2.496	.0097	0.114	.4529
conductivity	1.154	.1301	0.621	.2738

Compared with eutrophic Big Bear Lake (California) (Siegfried, et al., 1982) total hardness was lower and conductivity higher in Dardanelle Reservoir. Holland, et al. (1983) determined that suspended solids, total dissolved solids, organic carbon and pH had minor effects on the rotifer community, whereas temperature and dissolved oxygen were more important. Rickett and Watson (1982, 1983) determined these two parameters were normal and that the rotifer community was abundant and diverse in Dardanelle Reservoir. Arruda, et al. (1983) determined that a heavy suspended solids load (up to 100 mg/1) reduced algal carbon filtering and ingestion by *Daphnia* to near a starvation level. At higher concentrations, though, *Daphnia* were apparently starved to filtering sediment particles to which organic particles had adsorbed and therefore survived. We occasionally measured suspended solid concentrations exceeding 100 mg/1, but the mean was much lower.

CONCLUSIONS

Fears that an operating generating station would ruin the lake environment have been largely unjustified. Minor changes have occurred, but at this time, they are limited to a local warm water dispersal pattern (Rickett and Watson, 1982), a shift in the dominant taxa of rotifers (Rickett and Watson, 1983), a gradual decline of Q and chloride and a slight increase of hardness and conductivity. These fluctuations may include a minor component of plant operation impact, but so far we have been unable to separate or positively identify the components. However, it is important to be watchful for signs of advanced eutrophication and changes in physicochemical characteristics.

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