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SOME WATER QUALITY ASPECTS IN A NASCENT IMPOUNDMENT IN CENTRAL ILLINOIS

V. Kothandaraman and Ralph L. Evans
Illinois State Water Survey
Water Quality Section, Box 717, Peoria 61601

ABSTRACT

A detailed 3-year study was performed to delineate the water quality aspects of the newly created Lake Evergreen. Some physical and chemical characteristics of the impoundment and its major tributary, Six-Mile Creek, are examined. An effort to detect significant relationships between the waters of a free-flowing stream and the impoundment of the waters was not productive. Dissolved oxygen stratification suggests that man-made impoundments may be 'old,' limnologically speaking, from the day of their creation.

INTRODUCTION

Impoundment as a water resources management tool is an age old process. With an increasing awareness of the importance of water quality aspects, quality and quantity considerations have become an integral part of water resources planning and management. Consequently, a knowledge of the physical, chemical, and biological changes which accompany an impoundment is invaluable. Limnological studies in large natural and man-made lakes and reservoirs have been extensive. However, systematic studies on small impoundments, particularly in their very early periods of existence have been very few. Lake Evergreen, situated in central Illinois, provided an opportunity to perform such an investigation.

LAKE EVERGREEN

The lake is located 10 miles north of Bloomington, Illinois. It was created by damming Six-Mile Creek where it flows northward into the Mackinaw River. The dam was closed in January 1971 and the impoundment reached the spillway level during the first week of January 1972. Trees and shrubs were cleared from the lake bottom but all of the herbaceous growth were disked under during the fall season preceding the closure of the dam.

The topography of the watershed is characterized by gently rolling uplands with slopes leading to the shoreline unlike the flat open farm land of the surrounding region. There are no industries in the watershed and the village of Hudson with a population of about 802 is the only community within the watershed. Household septic tanks are used for liquid waste disposal in this community.

TABLE 1. Physical Features of Lake Evergreen and Six-Mile Creek

Lake Evergreen	
Spillway elevation (*feet msl*)	715
Area at spillway level (*acres*)	700
Volume at spillway level (*in millions of gallons*)	3,950
Depth	
Maximum (*feet*)	48
Average (*feet*)	17
Theoretical detention time at mean flow (*days*)	172
Six-Mile Creek	
Total length of stream (*miles*)	15.0
Average velocity (*fps*)	0.1
Average depth (*feet*)	1.2
Discharge for years 1970-1973	
Minimum (*cfs*)	0.3
Maximum (*cfs*)	165.0
Mean (*cfs*)	35.5
Watershed	
Area (*square miles*)	40.2
Land use (*in percent*)	
Row crops	87
Small grains	1
Alfalfa	1
Pasture	2
Other	9

The impoundment is primarily a supplementary water supply reservoir for the city of Bloomington. The primary source, Lake Bloomington, is located about 6 miles directly east of Lake Evergreen. Other pertinent information on the lake, its major tributary, and the watershed are given in Table 1. Configuration of the lake and water sampling locations are shown in Figure 1.

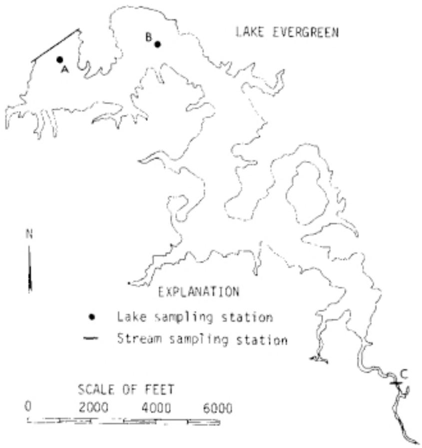

Figure 1. Lake Evergreen near Bloomington, Illinois.

FIELD AND LABORATORY PROCEDURES

Water samples were obtained once every two weeks from the three stations marked A, B, and C in Figure 1. At station A, the deepest portion of the lake, observations were made for dissolved oxygen (DO) and temperature. Samples were also obtained for mud-water interface examinations, but this aspect will not be discussed in this report. At station B (Lake Station), water samples were obtained at three locations (surface, mid-depth, and deep) for physical and chemical characterization and for algae identification and enumeration. Samples obtained at station C (Six-Mile Creek) were for assessing water quality under free-flowing conditions.

Temperature and DO were measured *in situ* using a Yellow Springs Instrument Model 54. Turbidity was measured using an Evelin Colorimeter. Total and soluble iron were determined using the orthophenanthroline method. All other analyses were performed according to Standard Methods.[1]

Facilities for recording the streamflow of Six-Mile Creek on a routine basis did not exist. Stream discharges were estimated using concurrent daily flow records for the close-by Money Creek near Towanda and the East Branch of Panther Creek at El Paso.

The water quality data for Six-Mile Creek covers the 41-month period extending from June 30, 1970 to December 6, 1973; data for Lake Evergreen covers the 32-month period from March 31, 1971 to December 6, 1973.

RESULTS AND DISCUSSION

Temperature and Dissolved Oxygen. The temporal variations of temperature and dissolved oxygen in the free-flowing section of Six-Mile Creek are shown in Figure 2. Similar plots for the Lake Station at the surface, mid-depth, and deep locations are also shown in Figure 2. At all of these locations, the temporal variations in temperature exhibit an annual cyclic trend. Each plotted point represents a single observation obtained during the early part of the day instead of being an average of several observations during the day. This probably accounts for the scatter of the observed data from the usual sinusoidal fit. The scatter seems to be the greatest at the Six-Mile Creek location and progressively decreases at the Lake Station surface, mid-depth, and deep points of observation.

The temperature data for Six-Mile Creek and the Lake Station locations were subjected to a harmonic analysis, the mechanics of which can be found elsewhere.[2] The results are presented in Table 2. The results of similar analysis of temperature data for a water depth of 2 feet in Lake Bloomington[2] are also included.

The annual mean temperatures and the amplitude of annual cyclic variations are similar from year to year at corresponding locations.

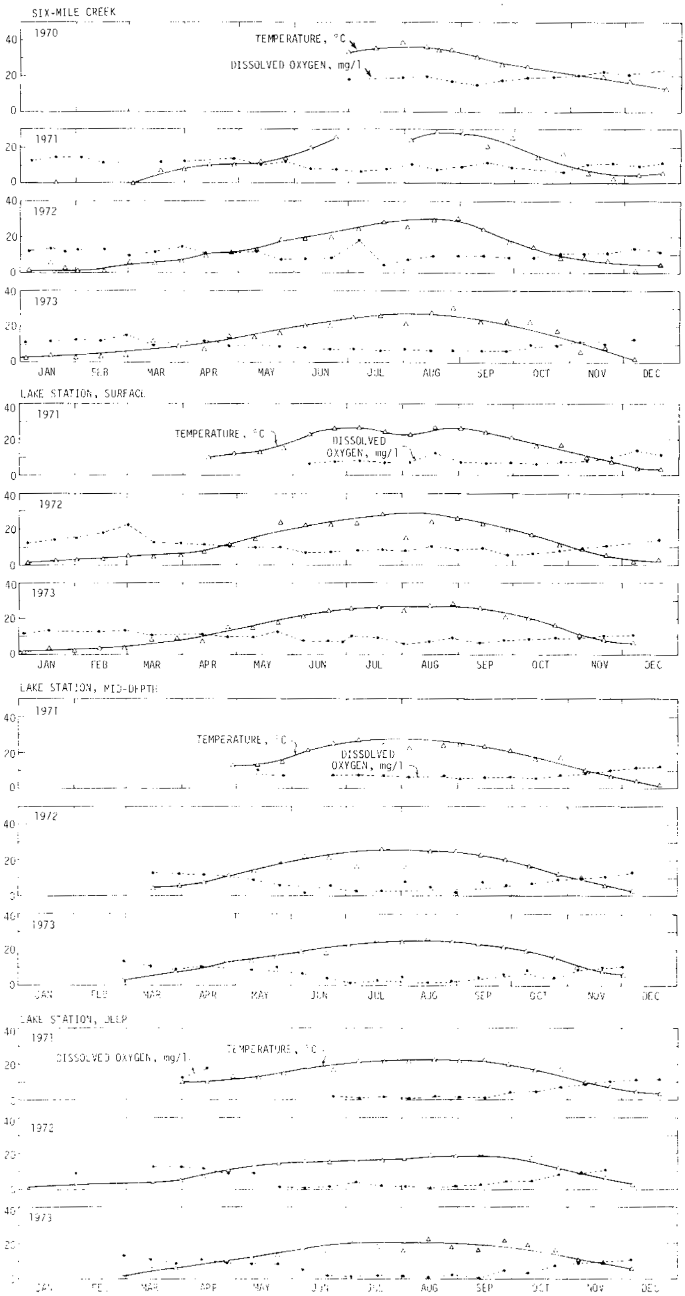

Figure 2. Temperature and DO variations in Six-Mile Creek and at the surface, mid-depth, and deep locations of Lake Station.

TABLE 2. Comparison of the Results of Harmonic Analysis of Temperature Data
(*temperature in degrees C*)

	Annual mean temperature	Amplitude	Standard error of estimate	Coefficient of correlation	Percent variance accounted for by first harmonic
Lake Station					
1972					
Surface	13.1	11.8	2.7	0.95	90.3
Mid-depth	12.5	11.0	2.6	0.95	90.3
Deep	11.0	8.7	1.9	0.96	92.2
1973					
Surface	15.3	12.3	1.7	0.98	96.0
Mid-depth	14.3	11.7	1.7	0.98	96.0
Deep	12.7	9.4	2.1	0.96	92.2
Six-Mile Creek					
1971	13.1	13.1	2.8	0.96	92.2
1972	13.9	12.7	3.0	0.95	90.3
1973	14.1	12.3	3.1	0.94	88.4
Lake Bloomington					
1966	13.2	12.3	1.8	0.98	94.6

The observed temperature data for Lake Bloomington gave a better fit with the teoretical sinusoidal curve compared with the surface and mid-depth data for Lake Evergreen as shown by the standard error of estimate. In the case of Lake Bloomington, even though each data point in the analysis represents a single observation for the day, there were twice as many observations in a year than for Lake Evergreen. This again confirms the general statistical axiom that the larger the sample size the better the results. For the same reason, the coefficient of correlation and percent of total variance in the temperature record accounted for by the annual harmonic cycle are higher for Lake Bloomington.

The annual mean temperatures in °C for the Lake Station at the surface, mid-depth, and deep locations for the year 1972 were 13.1, 12.5, and 11.0, respectively. Those for the year 1973 were 15.3, 14.3, and 12.7, respectively, showing a progressive decrease with increasing depth. A similar trend was observed for Lake Bloomington.[2]

Figure 3 shows the isotherms at the deep station for the years 1972 and 1973. The lake began to thermally stratify during the first week of May and became completely destratified by the middle of October. The stratification of the lake extended for a period of about 5 1/2 months. Isotherms at Station 1 of Lake Bloomington for the year 1966 had similar patterns that existed only for a period of 4 months, from early June until late September.

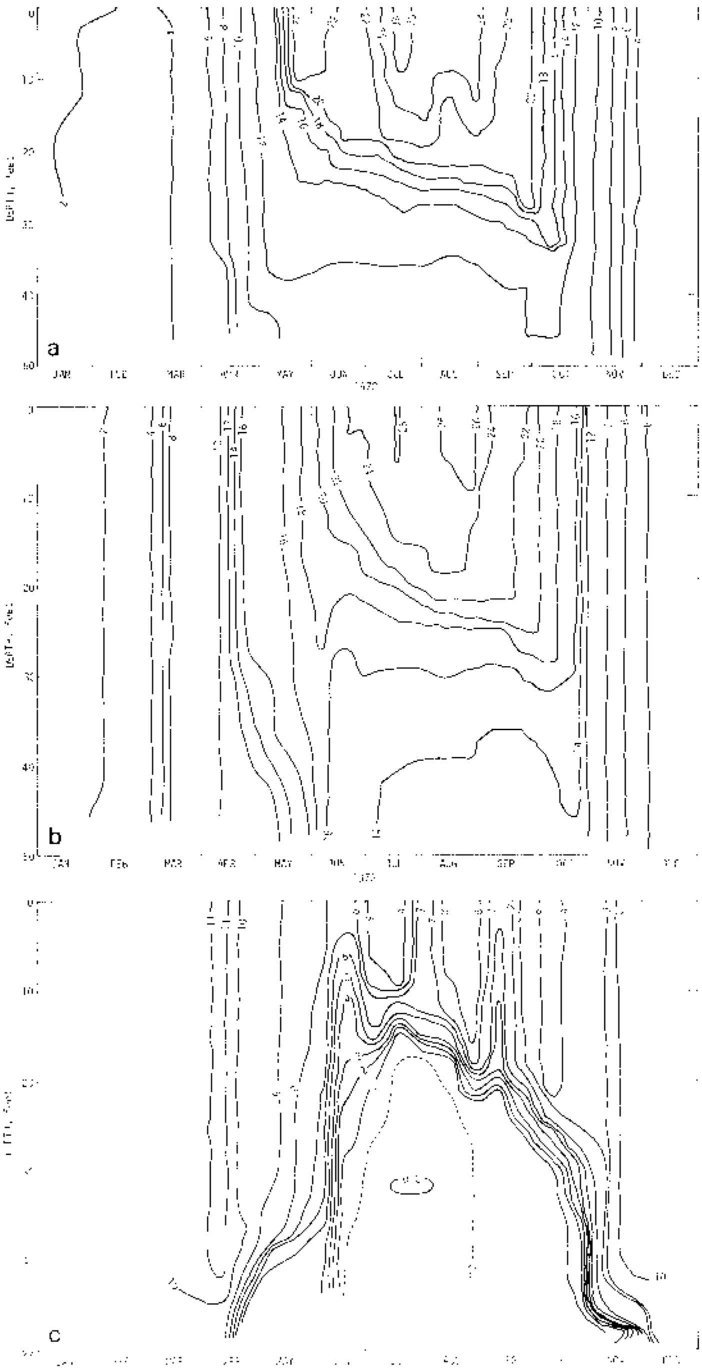

Figure 3. Lake Station (deep) isotherms for (a) 1972 and (b) 1973, and DO isopleths (c).

It has been found that the surface water temperatures of impoundments in similar geographical locations and subjected to similar meteorological conditions are comparable. Consequently, the temperature data in one impoundment can be successfully employed in another. A similar notion for free-flowing waters was suggested and substantiated by Kothandaraman.[3]

Figure 2 also shows the temporal variations of DO at the Six-Mile Creek and Lake Station locations. The DO level in the Six-Mile Creek was found to be high and often times supersaturated. Excluding 6 observations out of 60 with a percent saturation less than 80, other observations ranged from 80.4 to 216.6 percent. The DO levels at the surface of the Lake Station were also high and exhibited characteristics similar to that for Six-Mile Creek. However, the inverse relationship between temperature and DO is pronounced. Similar trends are obvious at the other two locations of the Lake Station.

Figure 3c shows DO isopleths for 1973. Surprisingly, dissolved oxygen was depleted in the hypolimnetic zone. For all practical purposes all waters of the lake below the 18 foot depth were devoid of oxygen during July and August. This is characteristic of old lakes suggesting that man-made lakes are eutrophic from their formation. Decaying vegetation on the floor of the impoundment is an important factor in the oxygen depletion during the very early life of the impoundment.

Turbidity. Because of the intensive farming in the drainage basin, turbidity in the Six-Mile Creek is usually high. Figure 4 shows the distribution of observed turbidities in Six-Mile Creek, Lake Station surface, and Lake Station deep. The median of the observed values for turbidity in the creek is about 34 compared to a value of 6 in the Lake Station surface and mid-depth locations and a value of about 10 in the Lake Station deep location. The benefits of impoundment from this aspect of water quality are marked.

Wang and Evans[4] reported an excellent correlation in linear relationships between turbidity and other chemical parameters like particulate iron, silica, and phosphate, for the Peoria Pool of the Illinois River. Correlation analysis between turbidity as the independent variable and total iron, silica, and manganese as dependent variables were carried out using the data for Six-Mile Creek, and the three Lake Station locations. Linear, exponential, and geometric forms of relationship were investigated. Significant correlation was found to exist only between turbidity and total iron. Linear relationship of the form $y = mx + c$ was found to give the best results. The results shown in Table 3 suggest that relationships between turbidity and total iron in Six-Mile Creek and Lake Station deep are well correlated.

Chloride, Sulfate, Hardness, and Total Dissolved Solids. The temporal variations of chloride and sulfate in Six-Mile Creek are shown in Figure 5. There is no discernable pattern of variations, either seasonal or otherwise for these constituents. They can be visualized as varying randomly about a mean value. Fluctuations of sulfate are moderate

TABLE 3. Results of Correlation Analysis between Turbidity and Total Iron

	Ordinate intercept	Slope	Coefficient of correlation
Six-Mile Creek	1.425	0.0244	0.86
Lake Station			
Surface	0.134	0.0395	0.61
Mid-depth	0.428	0.0010	0.07
Deep	0.118	0.0420	0.92

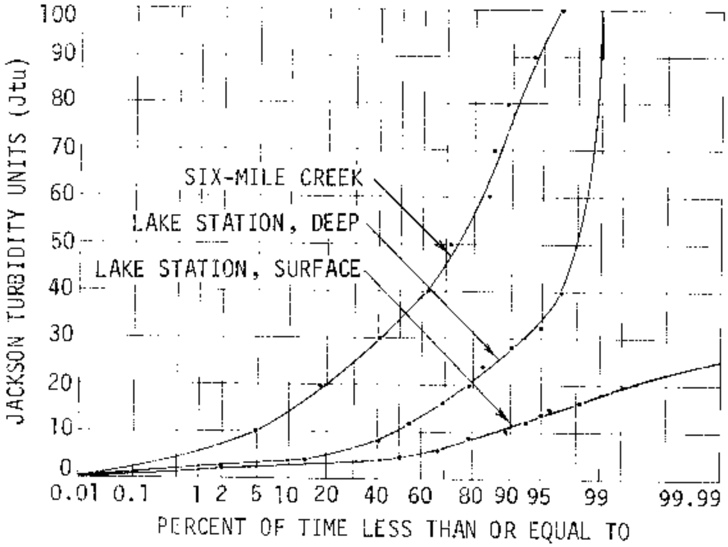

Figure 4. Cumulative probability distribution of turbidity in Six-Mile Creek and Lake Station (surface and deep).

compared to chloride. Two unusually high peaks were observed for chloride in the year 1971. Two similar peaks, though not of same magnitude, were again observed for chloride in the years 1972 and 1973. The flow in the creek when these peaks occurred was essentially a baseflow with a rate of about 0.5 cfs in 1971 and about 1.5 cfs in 1972. These high chloride concentrations were drastically reduced immediately after rainfall when the streamflow increased. The high chloride concentrations are reflective of either the soil characteristics of the drainage basin or of some factor caused by agricultural activities, particularly in cattle raising where salt blocks are used extensively. Road salting operations cannot be the source for these elevated chloride concentrations in the creek. A comparison of the chloride and hardness determinations indicated an association did not exist thus suggesting the chloride source was sodium chloride.

The yearly mean and the range of values in each year for hardness, chloride, sulfate, and total dissolved solids (TDS) for Six-Mile Creek are shown in Table 4. The sulfate to chloride ratio failed to indicate

TABLE 4. Water Quality Data for Six-Mile Creek and the Three Lake Evergreen Station Locations

	Temperature (°C)	DO (mg/l)	Hardness (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	TDS (mg/l)
Six-Mile Creek						
1970*						
Mean	17.7	9.1	351	29.7	84.9	481
Range	2.6-28.7	5.0-13.5	274-410	21.8-490	74.0-109	378-526
1971						
Mean	14.4	10.5	377	84.1	76.8	548
Range	0.2-28.5	6.3-14.3	295-448	16.0-223	55.7-177	422-825
1972						
Mean	11.4	10.8	342	27.4	70.4	429
Range	0.3-29.5	4.1-15.4	212-460	13.0-60.8	45.5-83.5	260-500
1973						
Mean	14.9	9.5	322	19.8	63.6	418
Range	1.4-30.7	5.9-15.4	212-393	12.0-75.5	45.5-77.8	260-532
Flow weighted average for entire record			343	26.5	71.4	458
Lake Station, surface						
1971**						
Mean	15.7	8.8	264	21.8	57.9	336
Range	3.4-26.9	6.5-13.9	244-296	20.1-23.0	53.1-68.3	293-383
1972						
Mean	13.0	9.8	265	21.4	60.2	328
Range	1.5-28.0	6.2-15.3	236-328	19.7-23.2	52.2-64.2	268-380
1973						
Mean	14.9	9.7	245	14.6	49.7	288
Range	1.2-28.2	5.5-13.7	138-298	9.8-19.6	30.8-60.1	183-360
Lake Station, mid-depth						
1971**						
Mean	17.1	8.2	264	21.6	57.8	341
Range	3.1-26.3	5.1-12.7	252-295	20.1-24.0	39.1-66.0	306-397
1972						
Mean	11.9	8.2	268	21.0	59.7	329
Range	1.5-26.0	1.6-13.7	240-304	16.8-23.2	52.2-64.0	275-369
1973						
Mean	15.7	7.4	252	14.8	50.3	295
Range	1.9-26.2	1.3-13.7	216-304	11.2-19.6	43.5-63.7	239-360
Lake Station, deep						
1971**						
Mean	15.1	6.3	265	21.5	54.5	322
Range	3.1-22.4	0.5-17.4	251-291	19.0-24.0	49.6-65.8	293-391
1972						
Mean	10.6	5.8	277	21.1	58.2	338
Range	1.5-19.8	0.4-12.9	250-314	19.7-22.6	53.5-62.3	289-386
1973						
Mean	14.1	6.1	253	14.2	49.2	297
Range	2.0-23.2	0.6-13.8	227-300	10.2-20.0	37.8-60.3	262-363

**Data collection commenced on 6/30/70*

***Impoundment closed January 1971; reached spillway level January 1972*

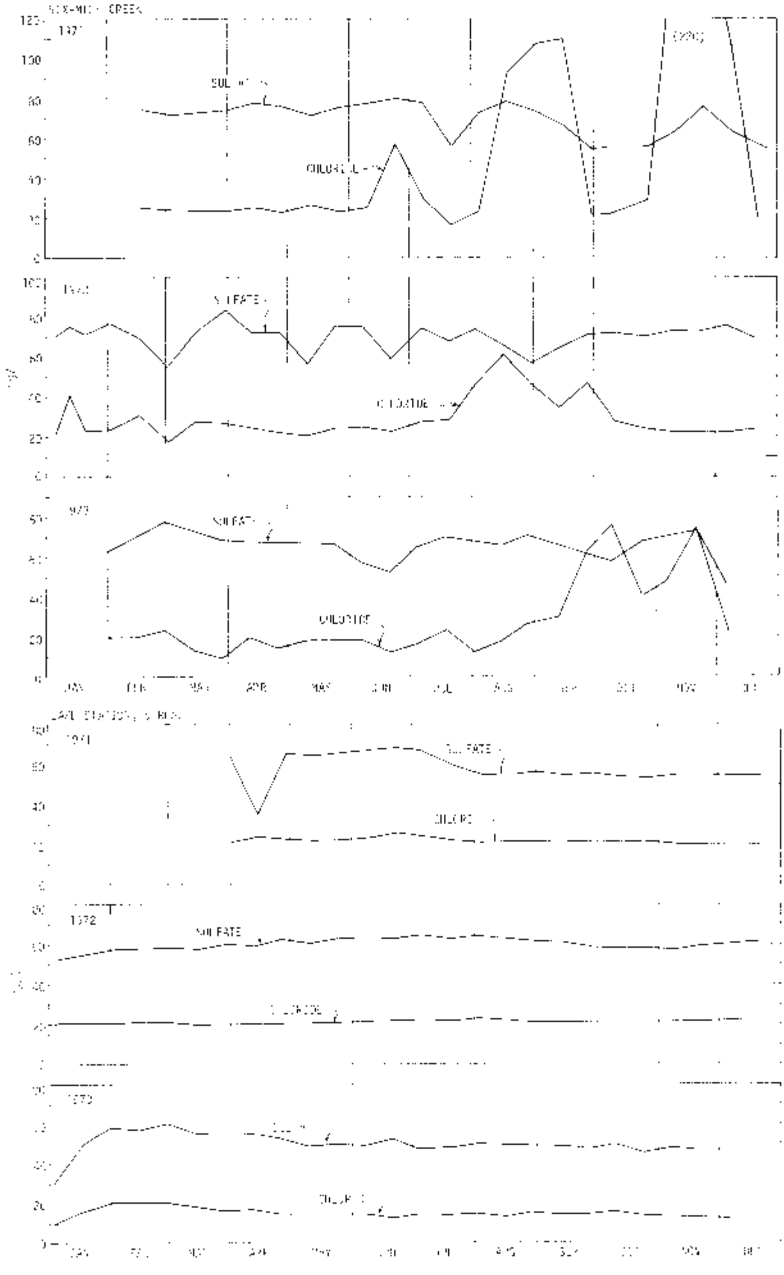

Figure 6. Chloride and sulfate variations in Six-Mile Creek and Lake Station (surface).

any trend in the mineral quality variations. The flow weighted average for hardness, sulfate, and total dissolved solids compare well with the yearly arithmetic mean values of the observed concentrations. That is not the case for chloride. Simple correlation analyses were run with streamflow rates in cubic feet per second (cfs) as the independent variable (X) and chloride, sulfate, hardness, and total dissolved solids as dependent variables (Y). No functional relationship was discernable between flow rates and either sulfate, hardness, or total dissolved solids. The relationship between streamflow and chloride (in mg/l) was found to be inverse of the form $Y = ax^b$ with a correlation coefficient of -0.75. The values of the coefficients were, a = 70.66 and b = -0.31.

A simple linear correlation analysis was also carried out among the four variables chloride, sulfate, hardness, and total dissolved solids. The only significant correlations noted were between total dissolved solids and hardness, and between total dissolved solids and chloride. The correlation coefficients in these cases were 0.71 and 0.85, respectively.

The temporal variations in chloride and sulfate at the three Lake Station locations were similar. Observations for the surface of the Lake Station (Figure 5) is typical of the other locations. Except for one observation for sulfate, in all of these locations at the very early stages of the filling of the impoundment, the chloride and sulfate concentrations did not fluctuate much. The moderating effect of the impoundment on wide fluctuations in chloride and sulfate concentrations in the creek is readily apparent by examination of Figure 5.

Mineral quality characteristics, dissolved oxygen, and temperature data for the three Lake Station sampling locations are presented in Table 4. The mean values from year to year at each location and among the three locations themselves are very nearly the same. The range of values of these parameters is also moderate compared to the corresponding values for the free-flowing waters in the Six-Mile Creek.

An attempt was made to correlate the mineral quality parameters in Six-Mile Creek with the corresponding mineral quality parameters of the Lake Station surface. Linear, exponential, and geometric forms of relationship were tried treating the Six-Mile Creek values as independent variables. There was practically no correlation between the Six-Mile Creek values and the lake surface observations. The concept of predicting the likelihood of the water quality of impounded waters from knowledge of water quality data of a free-flowing stream is not supported here.

An anomalous situation in Lake Evergreen should be pointed out here. The mean values of chloride, sulfate, hardness, and total dissolved solids for the Lake Station are all less than the corresponding mean values and the flow weighted average values for Six-Mile Creek. Direct rain and snow precipitation on the lake surface is not considered significant. The effect of snowmelt should have equal bearing on streamflow as on the impounded waters. No rational explanation for this phenomenon is apparent at this time.

SUMMARY

Some water quality aspects of Lake Evergreen, which is in the early phase of its existence, were examined and reported here. Dissolved oxygen and temperature variations have annual cyclic trends. The annual temperature variations of Lake Evergreen surface waters are similar to those for Lake Bloomington, located about 6 miles east of Lake Evergreen. Concentrations of several of the chemical quality parameters like chloride, sulfate, iron, hardness, total dissolved minerals, etc., were found to be less in the lake than the average values of the same parameters under free-flowing conditions. For Six-Mile Creek, flow was found to be reasonably well correlated with chloride and turbidity in the creek and lake samples were highly correlated with total iron.

The development of dissolved oxygen stratification to the point where an anoxic hypolimnion is created is a classic demonstration of an aging, eutrophic lake system. Such a development during the first year of Lake Evergreen's existence suggests that the limnological principles applied to natural systems may not be applicable to man-made impoundments.

ACKNOWLEDGMENTS

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