A Paleolimnological Study of the Water Quality Trends in Silver Lake, Waukesha County, Wisconsin

Written By

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This project was undertaken in cooperation with the Town of Summit and is one component of a comprehensive assessment of the water resources in the Upper Rock River Basin. Funding was provided by the Department of Natural Resources through the Wisconsin Lake Management Planning Grant Program and the Town of Summit.

Other lakes included in this assessment were Ashippun Lake, Druid Lake, Friess Lake, Fowler Lake, Moose Lake, Oconomowoc Lake, Okauchee Lake, Pike Lake and Pine Lake.

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Objective

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This study's objective was to determine the water quality trends in Silver Lake, dating back to presettlement times (early 1800's). A sediment core was collected dated using Lead-210 to determine sediment age and accumulation rate. Total carbon, organic carbon, organic nitrogen, total phosphorus, total iron and total manganese were also analyzed. Diatom frustules were identified in the core. Known changes in watershed landuse activities from early settlement to the present were correlated with changes in sedimentation rates, sediment chemistry and changes in water quality inferred from the changes in the diatom community composition.

Introduction

Silver Lake is located in the southwest portion of Waukesha County, in southeastern Wisconsin. It's a seepage lake, and is oligotrophic (slightly productive). It is 222 acres, 44 feet deep and has a drainage area is 1,154 acres resulting in a direct drainage area to lake area ratio of 5.2 to 1. The 1390 land use in the direct drainage area is summarized in table 1.

Table 1. 1990 Land use in the direct drainage area of Silver Lake, Waukesha County, Wisconsin.

Land Use Type	Percent	Acres
Developed	36.4	420
Agriculture/Open	33.8	390
Woodlands	5.7	77.3
Wetlands	5.4	73.8
Water	16.6	191.6

Background

Very little water quality information is currently available for Silver Lake. The Town of Summit has hired the United States, Department of the Interior, Geological Survey to collect water quality information on an annual basis. This work started in 1992 and is scheduled to continue through 1996. Insufficient data exists to determine long-term trends in water quality.

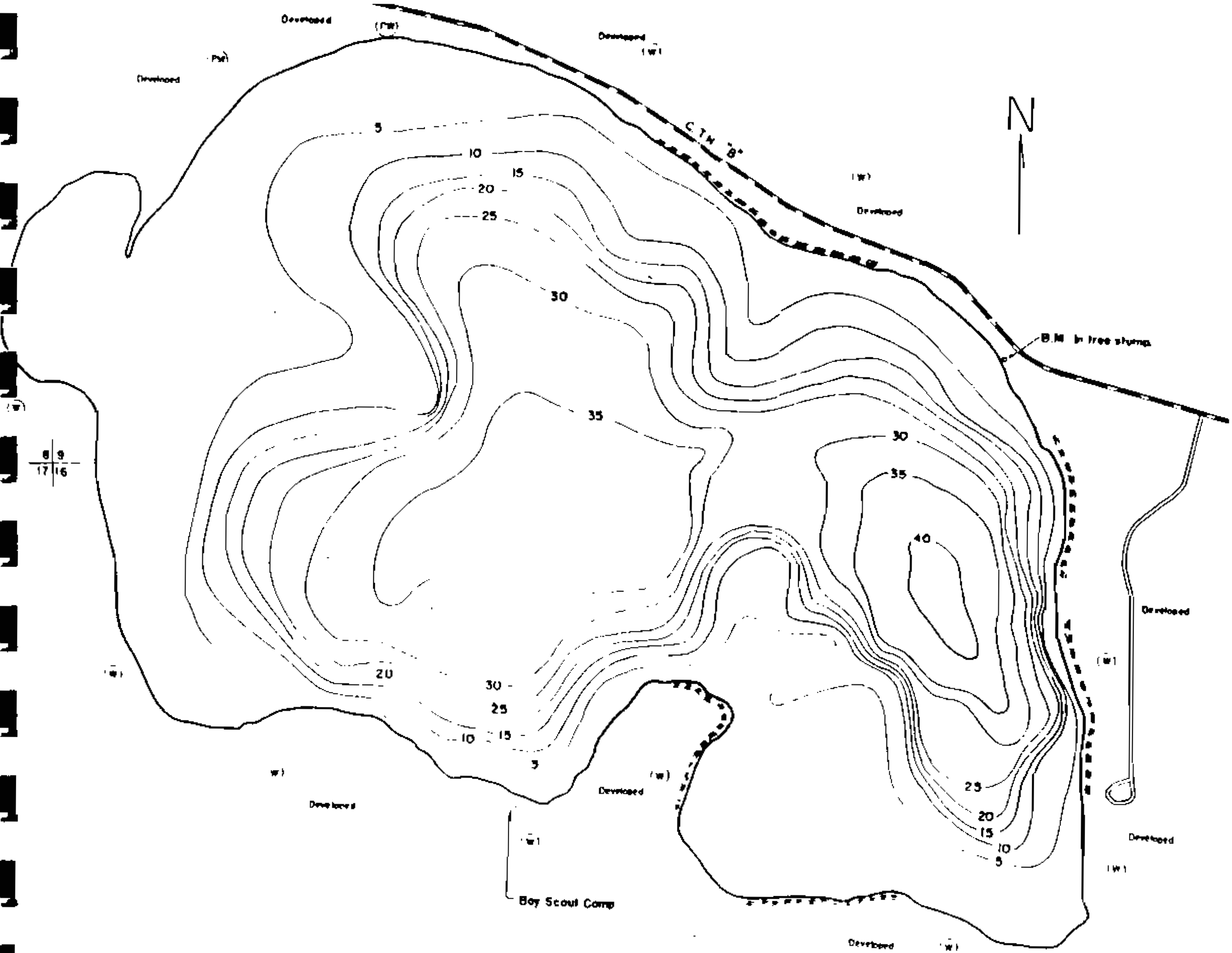


Figure 1. Silver Lake Map

Lead-210 (Aging Sediment Samples)

Geochronology with the naturally occurring Lead-210 is based on the principle that the isotope has been continuously delivered to the earth's surface and undergoes continuous radioactive decay following incorporation into steadily accumulating sediments. The activity of Lead-210 in a sediment sample was used to determine the age of the sample. Lead-210, a weak beta emitter with low activity and is not readily detected therefore, Polonium-210, is actuaily measured. Polonium-210 is the alpha emitting granddaughter of Lead-210, and can be used to represent the actual Lead-210 activity in each sample because the two isotopes are assumed to be in seqular equilibrium. The daughter is used because in an acidic solution it will spontaneously plate on to a copper disk, which can then be counted on a high resolution alpha spectrometry system. A yield monitor, Polonium-208, is added to each sample so that the exact activity of Polonium-210 can be determined. The activity of Lead-210 at the time of sediment sampling is calculated from the count rates corrected for counting background, growth and decay, counting efficiency and recovery of the yield monitor.

The sediment accumulation rate is expressed as an accumulation of a mass of sediment (gm/cm2/yr) rather than as an accumulated depth. Since layers of sediment will become compacted by the addition of new sediment the depth can not be used to determine accumulation rates. Sediment mass is used to determine accumulation rates since no matter how compacted a layer becomes it's mass will remain.

The rate of sediment accumulation will vary depending on the sampling location in the lake. The greatest accumulation rate occurs at the maximum depth because of the lateral movement of sediment from shallow depths towards the deepest part of the lake !sediment focusing).

Total Iron and Total Manganese Analysis

Analysis of the Total Iron, and Total Manganese in the sediment was done using a acid digestion followed by analysis with a Atomic Absorption Analyzer. A known quantity of dried and ground sediment was digestrd using nitric acid and hydrogen peroxide. Following heated digestion the solution is filtered, and brought up to a known volume This solution is then analyzed for iron and manganese.

The ratio of iron to manganese is used to assess the presence of oxygen in the hypolimnion of a lake. In addition the ratio of iron to phosphorus can be used to indicate periods of erosion in the watershed.

Carbon and Nitrogen Analysis

Total carbon, organic nitrogen and organic carbon are measured in a Carlo Erba Elemental Analyzer 1106. The technique used is flash combustion. The samples are held in a lightweight tin container and dropped at preset intervals of time into a vertical quartz tube, maintained at 1,030 degrees celsius (°C), through which a constant flow of helium is run. When the samples are introduced, the helium stream is temporarily enriched with pure oxygen. Flash combustion takes place, primed by the oxidation of the container. The individual components are then separated and eluted as N_2, CO_2, and H_2O. They are measured by a thermal conductivity detector, whose signal is fed into an integrator with digital printout of peak area. The instrument is calibrated by combustion of standards of known elemental compositicn, A sediment sample of known composition is also included in each sample run. The inorganic carbon is determined by subtracting the organic carbon from the total carbon in the sample.

The total carbon accumulation rate is a combination of organic and inorganic carbon (carbonates) sources. Organic carbon accumulation rates are used to infer overall lake productivity. Productive lakes have more algae, and aquatic plants and the sediment organic carbon is higher. Inorganic carbon accumulation rates are useful in determining the overall water quality and the source of sediment. The accumulation of inorganic carbon is typically found in hardwater or marl lakes which tend to be less productive.

Total Phosphorus

A known amount of dried, ground sediment is digested with nitric and sulfuric acids. Following digestion the solution is filtered, diluted and analyzed with a spectrophotometer.

The iron to phosphorus ratio is used as a surrogate to watershed erosion. As erosion in the watershed increases the ratio of iron to phosphorus also tends to increase. The phosphorus accumulation rate can be used alone as an indicator of water nutrient levels. The sediment/water interactions regulating phosphorus are complex and can make the interpretation of the profile difficult. Therefore, the phosphorus accumulation rate is generally used as supportive evidence with other sediment parameters.

Diatoms

A known amount of wet sediment is digested with a known amount of hydrogen peroxide and potassium dichromate. Following digestion the residue is washed with distilled water at least four times. A known amount of glass microspheres is added to the sample to more accurately determine diatom concentrations in the sample. A portion of the diatom suspension is dried on a coverslip and samples arc mounted in Hyrax. A minimum of 100 frustules were identified and counted under oil immersion objectives (1400X).

All partial valves containing unique features such as identifiable central areas, or ends were tabulated. Counts were made continuously along randomly selected transects and all identifiable fragments were included in the count. When a fragment or frustule could not be identified, it was recorded as unknown and included in the total count. When valve ends were tabular-ed, the number recorded was divided by the number of ends a complete frustule would possess. Frustules and fragments were counted if they were completely in the field of view or in the case when only a portion of the frustule was visible, when the appropriate characteristic was visible in the right half of the field of view.

The diatom accumulation rate is used as a surrogate to lake productivity. As a lake becomes more nutrient rich and productive the diatom accumulation rate also increases. Changes in the diatom community within a core can also be used to indicate periods of changing water quality. The species also indicate the relative water quality. Since the relationship between certain species of diatoms and general water quality conditions is known, they provide an excellent tool to determine the historical water quality changes,

Results

The results are presented as accumulation rates rather than concentration for a particular period of time, with the exception of porosity and chemical ratios. The accumulation rate is calculated by multiplying the parameter concentration at a particular sediment depth with the corresponding calculated instantaneous sediment accumulation rate. The rate of accumulation gives the most accurate picture of changing lake conditions. An analogy is a small river flowing into Silver Lake. The conrentration of phosphorus in the water may be very high but if there is little flow in the river the total quantity reaching the lake is small, however if the concentration of phosphorus is low but the river is in flood stage then the total amount of phosphorus entering the lake may be very high. While the concentration is important it is the load to the lake or sediment that is critical to measure.

Appendix 1 graphically summarizes tne sediment core results and appendix 2 contains the sediment chsmistry concentrations for future reference. Appendix 3 summarizes the sediment accumulation results. The sediment core results are truncated at the early 1800's since the lead-210 sediment dating technique is accurate for the last 150 years. Prior to the early 1800's the dates are only marginally accurate.

Lead-210 (Sedimentation Rate)

Between 1800 and 1900 the sedimentation rate was nearly constant (0.016 gm/cm^2/yr) (Figure 2). Since 1900 the sedimentation rate increased to a peak of 0.064 gm/cm^2/yr in the 1940's. The rate then decreased in the 1950's to 0.044 gm/cm^2/yr then increased to a secondary peak of 0.056 gm/cm^2/yr between the 1960's and 1970's Following the 1970's the sedimentation rate decreased to the present rate of 0.028 gm/cm^2/yr.

Porosity

Sediment porosity increased slightly between 1800 and 1910's (Figure 3). Between 1910 and 1930 the porosity decreased to a minimum. After the 1930's the porosity remained unchanged until the 1960's when the porosity increased to the present (1995) value of 0.9580.

Carbon Accumulation Rates

The total carbon, organic carbon and inorganic carbon accumulation rate profiles are the same as the sediment accumulation rate profile (Figure 4). The carbon accumulation rate was nearly constant between presettlement and the early 1900's. After the early 1900's the carbon accumulation rate increased substantially to a peak in the 1340's. The rate then decreased in the 1950's followed by a secondary peak in the 1960's. Following the 1960's the carbon accumulation rate decreased to near presettlement levels.

Total Phosphorus

The phosphorus accumulation rate peaked in the early 1900's followed by smaller peaks in the 1920's, 1940's, 1960's and the 1980's (Figure 5).

Iron/Phosphorus Ratio

Between the early 1800's and the 1840's the iron to phosphorus ratio increased (Figure 6). Since the 1840's the ratio decreased to a minimum in the early 1900's. The ratio increased to two peaks one in the 1930's and the other in the 1950's. Following the 1950's the ratio decreased to the present (1995) level which *is* close to the minimum observed in the early 1900's.

Diatoms

Cyclotella michiganiana was found throughout the core and was one of the most abundant taxa found (Figure 7). Other species of interest include *Staurosira construens*, *Staurosira construens* var. *venter* and *Staurosira* pinnata which are present in the core until the mid 1930's. After the 1930's *Asterionella formosa*, *Fragilaria crotonensis*, *Aulacoseira ambigua* and *Cyclotella glomerata* increased in abundance and are present at the top of the core (1995).

The diatom accumulation rate is shown in figure 8 and shows several major peaks since the 1910's. Peaks occurred in the 1920's, 1940's, 1960's and 1980's. The peaks occurred at the same time as the phosphorus accumulation rate peaks, with the exception of the phosphorus peak in the 1310's (See discussion above).

Discussion

The follcwing discussion will first focus on the watershed activites which were taking place at known periods of time. This will then be related to the sediment core results to show the impact land use activites had on the water quality of Silver Lake.

Initial settlement of southeastern Wisconsin started in the 1830's and continued through the 1850's. German farmers settled the area and cultivated predominately wheat and lesser amounts of corn, oats and hay. Around the 1880's wheat farming declined and farmers turned to ccrn, oats, hay and began to develop dairy herds. By the 1930's agriculture was beginning to grow rapidly, and was becoming mechanized. Through the 1380's dairy farms were numerous in southeastern Wisconsin. In the early 1990's dairy farming has declined and cash cropping which require less labor but can also result in greater soil loss has increased.

From the 1940's to the 1960's there was a tremendous increase in the population, especially around the lakes in the Washington, Waukesha County areas. Lake shorelines that were once farmed were being sold for seasonal homes. By 1970 the majority of the shoreline had been developed with seasonal homes.

Continued urbanization of the watershed contributes increased stormwater inputs to the lakes and rivers. Stormwater is the source of nutrients and other pollutants which are conveyed in stcrmsewers directly to the surface waters rather than being filtered in vegetated drainage ways.

The results of the sediment analysis will be broken into time periods which reflect either a period of status quo or periods of substantial change. These periods can then be compared to watershed activities to see how the activity on the Land influenced the lake. Table 2 summarizes the watershed activities and corresponding sediment core results,

Time Period	Watershed Activity	Sediment Core Results
1800 - 1920	Presettlement through early settlement conditions Major changes in agriculture during this period (wheat farming changing to corn, hay, oats and dairy)	Low sedimentation rate 0.017 gm/cm²/yr Diatom community indicate excellent water clarity, low nutrients
1920 - 1935	Agriculture becoming mechanized High agric. yields being demanded	Increase in sedimentation rate, carbon accumulation, iron to phcsphorus ratio and diatom accumulation rate Uiatom taxa indicative cf increasing nutrient levels
1935 - 1970	Intensive agricultural activity dairy farming booming Intensive shoreline development	Peak sedimentation rate Diatom indicators suggest elevated nutrient levels
1970 - 1995	Rapid population growth Dairy farming and cash crops still widespread	Low sedimentation rate Porosity increasing suggesting decreasing sediment load Carbon accumuiation rate decreasing Diatom taxa suggest improving water quality

1800 - 1920

Presettlement water quality conditions for Silver Lake were excellent. The lake experienced a very low sedimentation rate of 0.017 gm/cm²/yr and had diatom taxa which were indicative of excellent water clarity and low nutrient levels. Conditions remained very good until the 1920's when a increase in the sedimentation rate, a decrease in the porosity and an increase in the iron to phosphorus ratio suggests an increase in the erosion of the watershed, probably due to human activity.

1920 - 1935

Wany of the sediment chemistry parameters show a steady increase in accumulation rates during this period. The most important change observed was in the diatom community between the 1920's and 1935. A significant decrease in the number of species which indicated good water clarity and low nutrient levels, and an increase in species indicative of elevated nutrient levels. The abruptness of this change was also seen in Moose Lake. The other study lakes had a more gradual transition between water quality changes.

1935 - 1970

Between 1935 and the 1970's the sedimentation rate was the highest corresponding to the period of maximum agricultural activity. The decrease in the 1950's is unexplainable since all of the accumulation rates show a similar pattern during this decade, however the porosity profile does not show any significant divergence from it's trend.

1970 - Present

After the 1970's several parameters have decreasing accumulation rates or values. The sedimentation rate decreases to near presettlement levels, the porosity begins to increase suggesting the accumulation of fine grained material and the accumulation rate of carbon also decreases during this period. These trends suggest decreasing sediment load and primary productivity. During the 1970's one of the diatom species (*Cyclotella michiganiana*) indicative of good water clarity begins to increase dramatically while other species (*Aulacoseria ambigua* and *Fragilaria crotonensis*) indicative of elevated nutrient levels, decrease. The sediment chemistry and diatom community changes during this period suggesting that the water quality of Silver Lake may be improving.

Conclusions

Sedimentation rates, sediment chemistry and diatom indicators suggest that presettlement water quality ccnditions of Silver Lake was very *good.* Increased agricultural activity and urban development resulted in a steady increase in the sedimentation rate and nutrient level until the 1970's when the sedimentation rate decreased. The diatom community also indicates there has been a decrease in the nutrient level in Silver Lake by an increase of species indicative of good water clarity and a reduction of species indicative of higher nutrient levels.

The management implications of this work clearly point to the need to manage nutrient loading to Silver Lake. Since Silver Lake is phosphorus limited every effort should be made to reduce the phosphorus load. Sediment appears to be less of a problem than phosphorus at the present time.

Acknowledgments

The author would like to acknowledge the assistance of Mr. Paul Garrison and Molli MacDonald from the Department of Natural Resources for completion of the diatom profiles and interpretation of the sediment profiles. Mr. Pat Anderson from the Center for Great Lakes Studies for his assistance in sediment chemistry analysis and interpretation. Mike Bruch from the Department of Natural Resources for his assistance in collection of the sediment core. The Southeastern Wisconsin Regional Planning Commission was very helpful in providing information on the soils, land use and extent of urban development within the watershed. Dan Helsel was extremely helpful in reviewing drafts of this report and providing constructive comments on organization and content. The author also wishes to acknowledge the participation of the Town of Summit for participating in this study. The results provide a valuable amount of information regarding the importance of proper land management and should provide the District with added information to influence property owners to be conscious of their activities.

Sediment Accumulation Rate

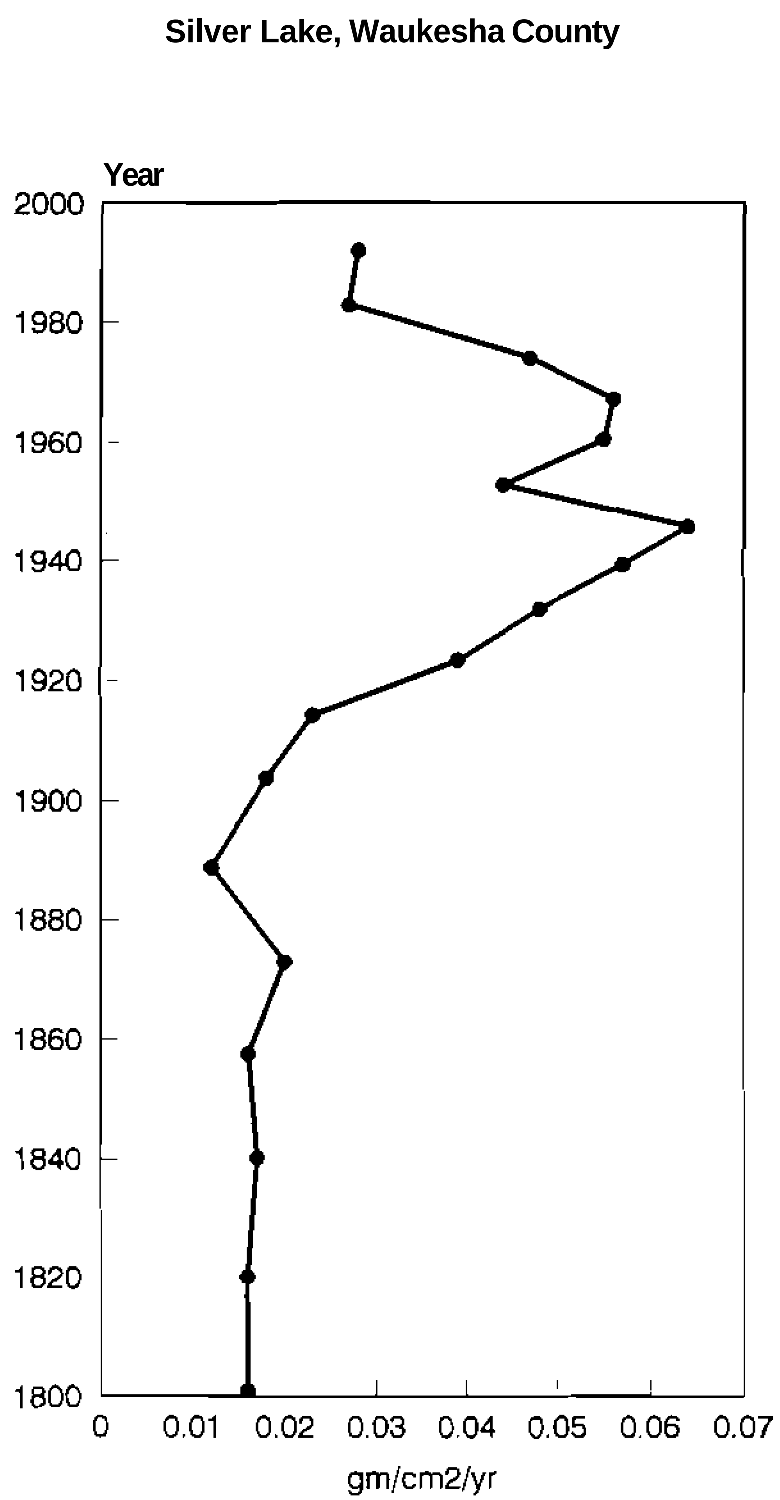


Figure **2.** 1995 Upper Rock River Basin Assessment

Porosity

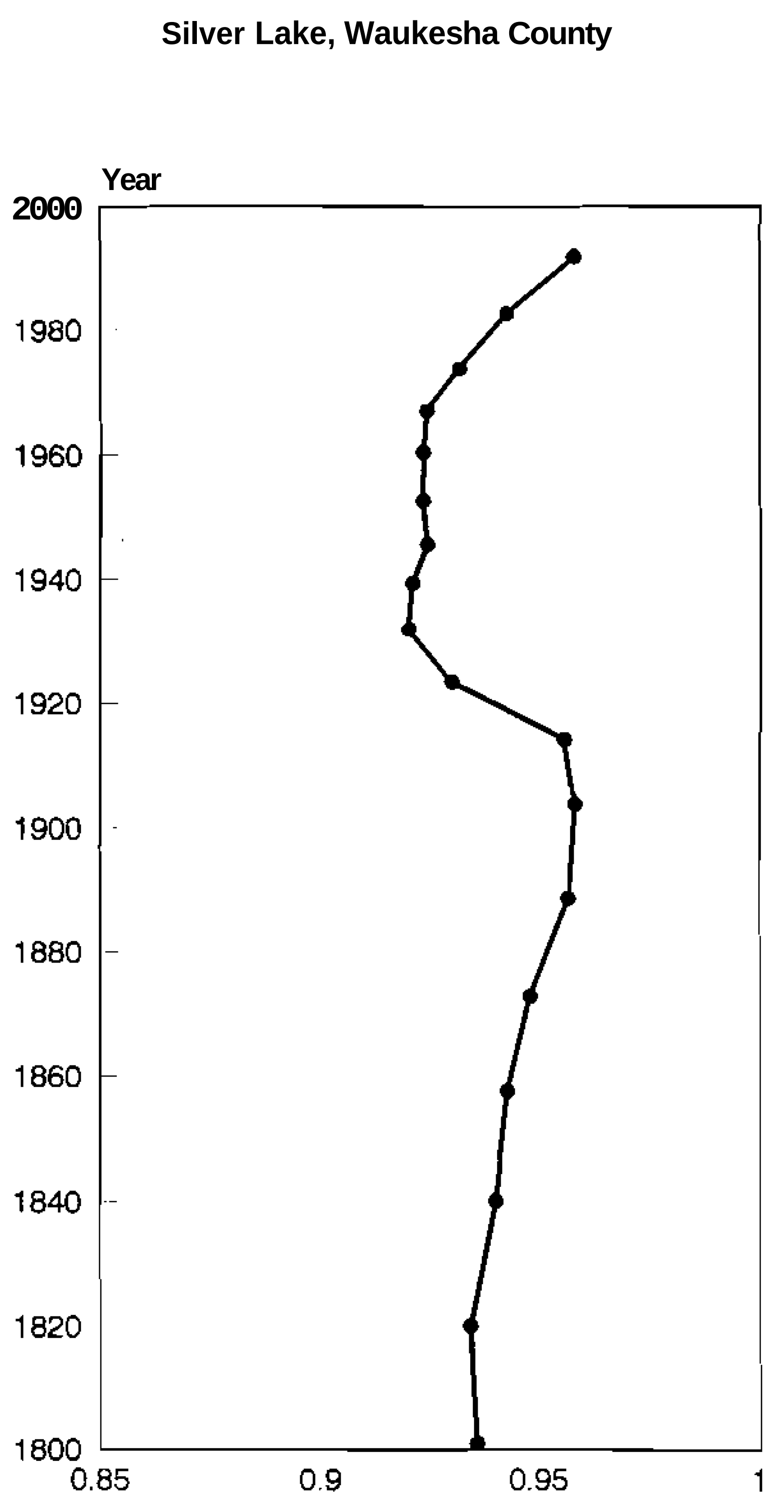


Figure 3. 1995 Upper **Rock** River Basin Assessment

Carbon Accumulation Rate

Silver Lake, Waukesha County

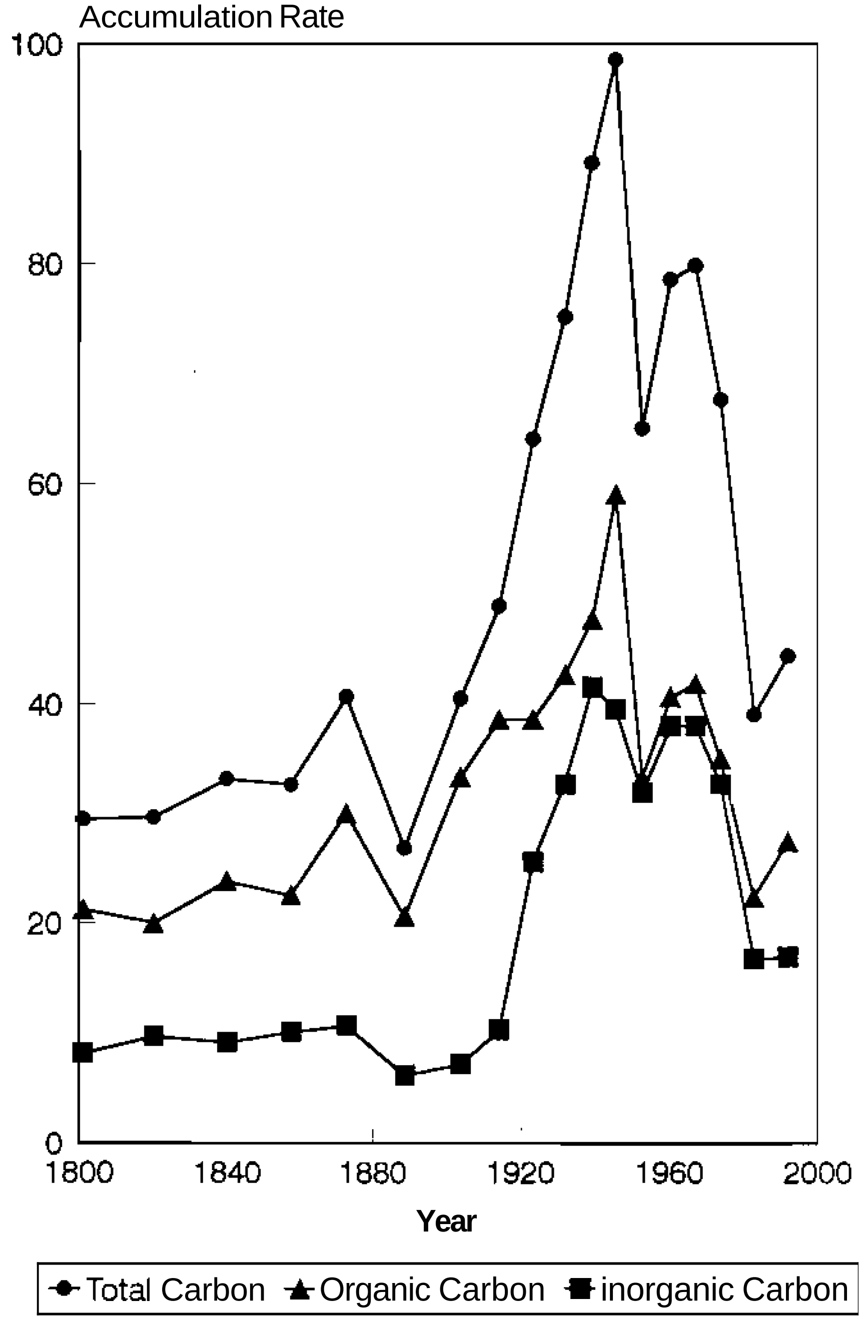


Figure 4. 1995 Upper Rock River Basin Assessment

Iron/Phosphorus Ratio

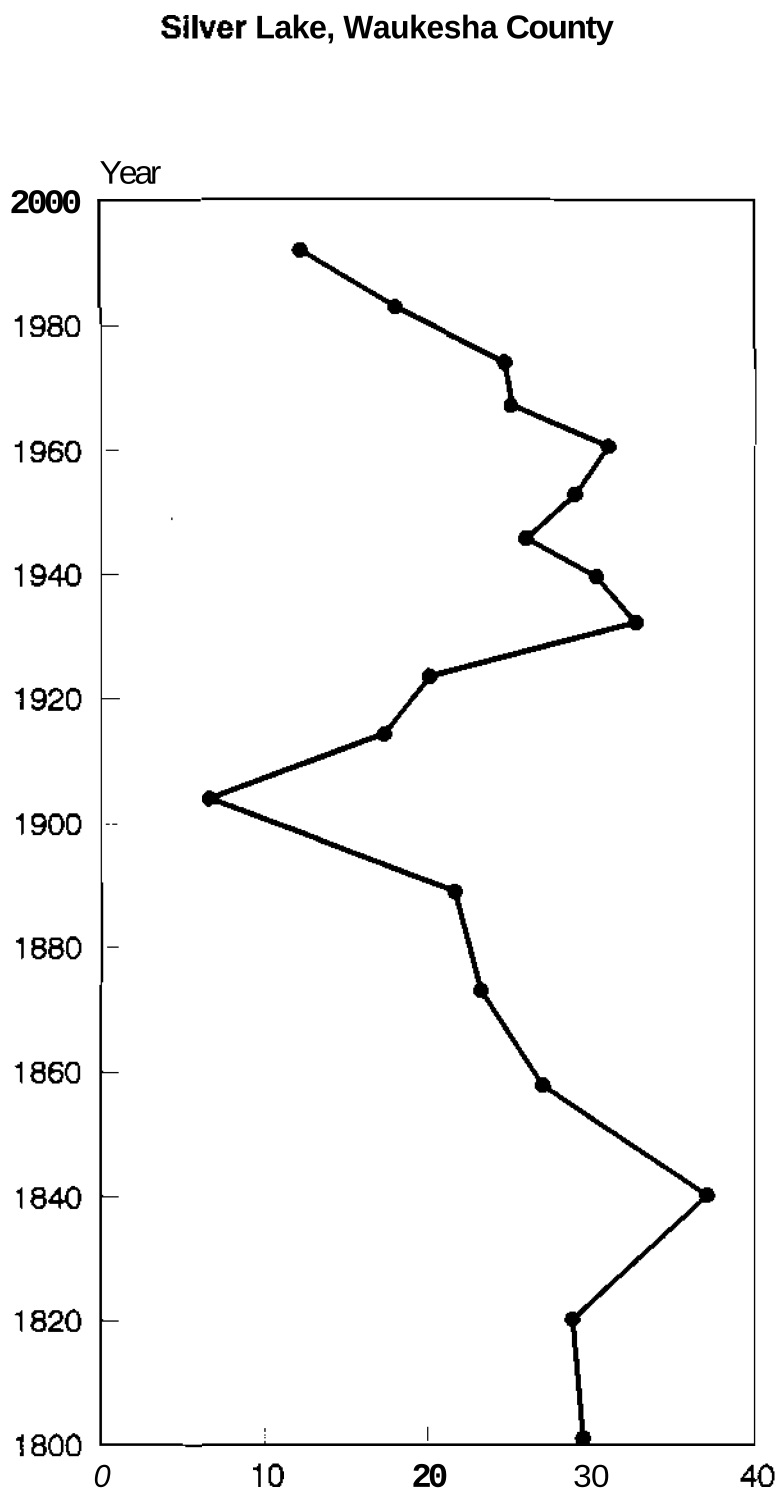
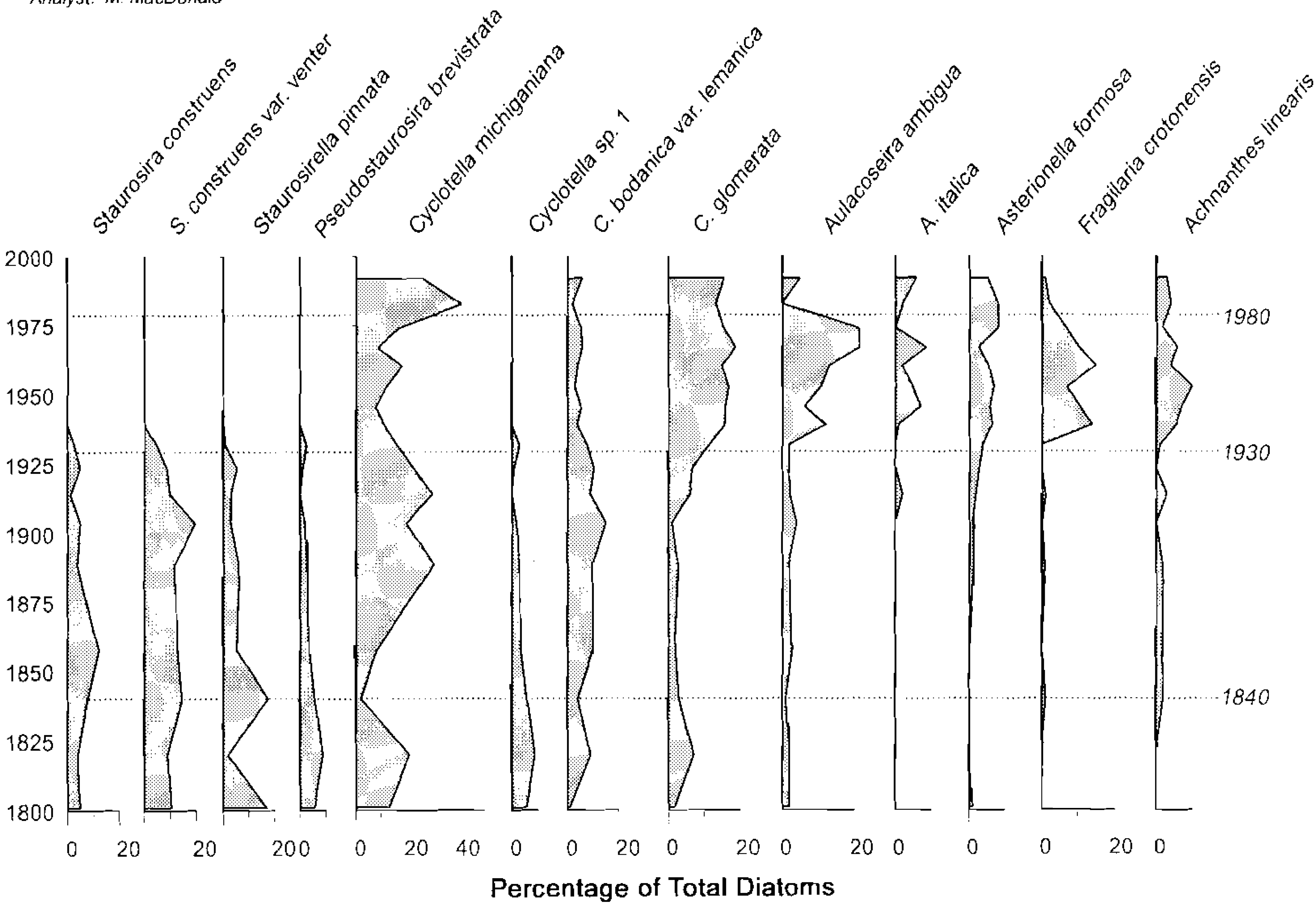


Figure *6.* 1995 Upper Rock River Basin Assessment

Silver Lake

Waukesha County

Analyst: M. MacDonald



Diatom Accumulation Rate

Silver Lake, Waukesha County

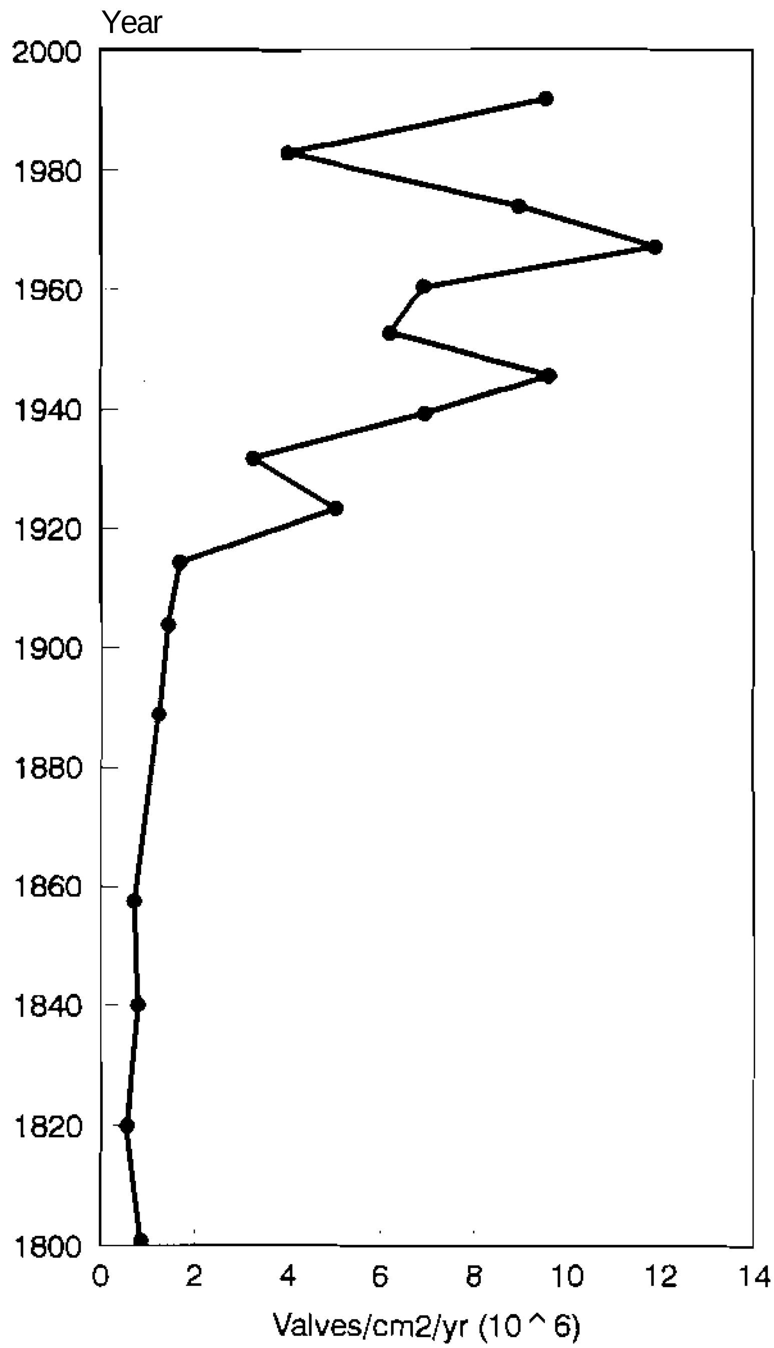


Figure 8. 1995 Upper Rock **River** Basin Assessment

Silver Lake, Waukesha County sediment chemistry results.

SEDIMENT DEPTH	POROSITY	TOTAL PHOSPHORUS	TOTAL CARBON	TOTAL NITROGEN	TOTAL, ORGANIC CARBON	IRON Fe	MANGANESE Mn	YEAH (MID)
cm		ug/gm	WT. %	WT. %	WT. %	ug/gm	ug/gm	
0-2	0.95803	675	15.79	1.04	9.76	8243	432	1991.[illegible]
2-4	0.94245	481	14.70	0.82	8.40	9698	440	1982.6
4-6	0.93164	358	14.32	0.70	7.41	8904	426	1973.9
6-8	0.92427	335	14.14	0.68	7.41	8485	424	1967.1
5-10	0.92342	282	14.37	0.70	7.43	8789	410	1960.4
10-12	0.92341	354	14.69	0.74	7.50	10345	412	1952.7
15-14	0.92443	368	15.30	0.79	9.17	9645	409	1945.6
14-16	0.92106	258	15.51	0.79	8.29	7861	379	1939.3
16-18	0.92016	239	15.70	0.85	8.69	7860	479	1931.9
18-20	0.93004	479	16.52	1.05	9.94	9664	251	1923.4
20-22	0.95569	672	21.28	1.78	16.81	11719	293	1914.2
22-24	0.95806	2004	22.02	1.83	18.11	17756	296	1903.8
24-26	0.95653	637	23.07	1.89	17.74	13659	298	1898.8
26-28	0.94796	564	2b 65	1.55	15.21	13202	381	1872.9
28-30	0.94275	532	20.12	1.43	13.10	14462	786	1857.6
30-32	0.93990	429	18.96	1.34	13.67	15890	380	1840.1

Silver Lake, Waukesha County sediment chemistry results (Con't).

SEDIMENT DEPTH	POROSITY	TOTAL PHOSPHORUS	TOTAL CARBON	TOTAL NITROGEN	TOTAL ORGANIC CARBON	IRON Fe	MANGANESE Mn	YEAR (MID)
cm		ug/gm	WT. %	WT. %	WT. %	ug/gm	ug/gm	
32-34	0.93427	506	18.53	1.29	12.49	14706	338	1820
34-36	0.93585	549	18.38	1.32	13.26	16235	329	1801
36-38	0.94378	580	20.31	1.60	14.17	14731	277	1783
38-40	0.92928	495	17.98	1.16	11.39	12113	315	1762
40-42	0.94298	593	19.75	1.48	14.40	11987	273	1745
42-44	0.92760	509	18.20	1.16	11.16	9789	335	1722
44-46	0.90523	386	16.61	0.89	8.92	7277	369	1694

Silver Lake, Waukesha County sediment chemistry results.

SEDIMENT DEPTH	Fe:Mn	Fe:P	YEAR (MID)	SEDIMENT ACCUM. RATE	TOTAL DIATOMS
cm				gm/cm2/yr	valves/g dry wt.
0-2	19.1	12.2	1991.9	0.028	3.41e+08
2-4	19.8	18.1	1982.8	0.027	1.52e+08
4-6	20.9	24.9	1973.9	0.047	1.90e+08
6-8	20.0	25.3	1967.1	0.056	2.11e+08
8-10	21.4	31.2	1960.4	0.055	1.27e+08
10-12	25.1	29.2	1952.7	0.044	1.41e+08
12-14	23.6	26.2	1945.6	0.064	1.49e+08
14-16	20.8	30.5	1939.3	0.057	1.21e+08
16-18	18.4	32.9	1931.9	0.048	6.81e+07
18-20	26.8	20.2	1923.4	0.039	1.30e+08
20-22	40.0	17.4	1914.2	0.023	7.38e+07
22-24	44.8	6.6	1903.8	0.018	7.85e+07
24-26	46.5	21.8	1888.8	0.012	1.07e+08
26-28	34.6	23.4	1872.9	0.020	
28-30	37.5	27.2	1857.6	0.016	4.45e+07
30-32	41.8	37.1	1840.1	0.017	4.61e+07

Silver Lake, Waukesha County sediment chemistry results ('t).

SEDIMENT DEPTH	Fe:Mn	Fe:P	YEAR (MID)	SEDIMENT ACCUM. RATE	TOTAL DIATOMS
cm				gm/cm2/yr	valves/g dry wt.
32-34	43.5	29.0	1820	0.016	3.46e+07
34-36	49.4	29.6	1801	0.016	5.30e+07
36-38	53.1	25.4	1783	0.016	6.04e+07
38-40	38.4	24.5	1762	0.016	1.08e+08
40-42	43.1	20.2	1745	0.016	1.38e+08
42-44	29.1	19.2	1722	0.016	1.81e+08
44-46	19.7	18.9	1694	0.016	6.56e+07

Silver Lake, Waukesha County sediment chemistry accumulation results.

YEAR	TOTAL PHOSPHORUS	TOTAL NITROGEN	TOTAL CARBON	TOTAL ORGANIC CARBON	INORGANIC CARBON	IRON Fe	MANGANESE Mn	TOTAL DIATOMS
	ug/cm2/yr					ug/cm2/yr	ug/cm2/yr	valves/cm2/yr *10^6
1991.9	0.19	2.9	44.3	27.4	16.9	2.31	0.12	9.57
1982.8	0.13	2.2	39.0	22.3	16.7	1.31	C.12	4.03
1973.9	0.17	3.3	67.6	34.4	32.6	4.20	0.20	8.98
1967.1	0.19	3.8	79.8	41.8	38.0	4.79	0.24	11.90
1960.4	0.15	3.8	78.5	40.6	37.9	4.80	0.22	6.93
1052.7	0.16	3.3	65.D	33.2	31.8	4.58	0.18	6.22
1945.6	0.24	5.1	98.5	59.0	39.5	6.21	0.26	9.63
1939.3	0.15	4.6	89.1	47.6	41.5	4.52	0.22	6.97
1931.9	0.11	4.1	75.2	42.6	32.6	3.78	0.21	3.26
1923.4	0.19	4.1	64.1	38.6	25.5	3.75	0.14	5.05
1014.2	0.15	4.1	48.8	38.6	10.3	2.69	0.07	1.69
1903.8	0.37	3.4	40.5	33.3	7.2	2.44	0.05	1.44
1888.8	0.07	2.2	26.8	20.6	6.2	1.61	0.03	1.24
1872.9	0.11	3.1	40.7	30.0	10.7	2.60	0.08	
1857.[illegible]	0.09	[illegible]	32.6	22.5	10.1	2.34	0.0[illegible]	[illegible]
1840.2	0.07	2.3	33.1	23.8	9.2	2.77	0.07	[illegible]
1820	0.08	2.1	29.6	20.0	9.7	2.35	0.05	0.55
1831	0.09	2.1	29.4	21.2	8.2	2.60	0.05	0.85
1783	0.09	2.6	32.5	22.7	9.8	2.36	0.04	0.97
1762	0.08	1.3	28.8	18.2	10.5	1.93	0.05	1.73
1745	0.09	2.4	31.6	23.0	3.6	1.92	0.04	2.21
1722	0.08	1.9	29.1	17.9	11.3	1.57	0.05	2.89
1694	0.06	1.4	26.6	14.3	12.3	1.16	0.06	1.05