COMPARISON OF STUDY METHODS FOR THE EARLY DETECTION AND POSSIBLE CAUSES OF TASTE CAUSING ALGAL BLOOMS IN LARAMIE'S DRINKING WATER

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Comparison of Methods for the Early Detection and to Study Possible Causes of Taste Causing Algal Blooms in Laramie's Drinking Water

And

Algal Blooms Causing Tastes in Laramie's Drinking Water

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Abstract

The chlorophyll a concentration, the numbers of Asterionella, Anabaena and total algal count and various chemical and physical parameters were determined in Laramie's surface water source for a period of three summers. In addition, data were collected at various sites along the Laramie River and in Lake Sodergreen. Also, the presence of geosmin was monitored by Closed Loop Stripping-Gas Chromatography/Mass Spectrophotometry Analysis. All of this was done to determine the cause and to predict taste and odor causing algal blooms. No taste and odor causing algal blooms occurred during the three years of this study, thus these data may be used as background data for the future. It was determined that the lake was well mixed and that the raw water in the plant gave a reasonable estimate of the chemistry and microbiology of the lake. Geosmin was found in the raw water at various time and throughout the water plant. There is quite a problem in the reproducibility of the geosmin test.

Introduction

The first contact with city personnel concerning a taste in the city of Laramie's drinking water came in the fall of 1983, just before the water plant was shut down for the winter. Analysis of samples of the raw water taken at this time suggested that algae growing in the supply were responsible of the taste. During the winter of 1983-84 a proposal was written to and funded by the Wyoming Water Research Center in the amount of $3,000 to determine the cause(s) of the taste problems in Laramie's water should they occur during the summer of 1984. It was determined in 1984 that algal blooms of Asterionella and Anabaena caused a severe taste and odor problem.

To be able to solve, correct and/or prevent taste and odor problems one needs to have an early warning that the problem is developing. Two chemical compounds commonly thought to be responsible for tastes and odors are geosmin and 2 methyl isoborneol (9). A very sophisticated method for measuring the concentrations of these compounds has recently been developed and appears in the 16th edition of "Standard Methods" which entails the use of Gas Chromatography/Mass Spectrophotometry (2). This procedure is sensitive to the 2 ng/L level of geosmin and 2-methyl isoborneol while humans cannot detect these compounds until their concentration in water is 10-29 ng/L. Use of this method is said to allow treatment to commence in time to prevent distribution of water containing tastes and odors (15). The procedure is quite expensive. My estimate from two sources to perform the analysis runs $200-$250 per sample with instrument calibration being around $2,500 before the first sample can be processed. Instrumentation for this procedure starts at $80,000 and goes up. Obviously not all cities and most likely only very large cities will be able to routinely use this method of detection. During a recent audit of the city of Laramie's water treatment plant by Richard A. Arber Associates, it was suggested that chlorophyll in the raw water and the lake be monitored as a means of early detection. Although this method is substantially cheaper than the GC/MS method significant cost for the equipment is still involved. Potentially, refinements in the membrane filtration procedure could lead to a reliable, quick and cheap method for early detection of a taste problem and the establishment of an action level to initiate preventative treatment.

Methods to detect tastes and odors in water have until recently involved the use of taste panels or the culturing for actinomycetes in the raw water source (1,5). If actinomycetes were not the problem culturing for these organisms was not of use and if actinomycetes were the problem, it could take 1-2 weeks before the organisms were recognizable on agar plates. Taste panels are difficult and time consuming to employ. Further, their use usually tells one when the problem exists and does not warn one early enough to start treatment before "tasty" water is delivered to the consumer. It has been claimed, however, that certain people with extended training can detect odors early enough to start treatment to minimize problems (15).

Apparently a large number of compounds produced by algae and blue green bacteria (algae) are responsible for tastes and odors in water (9,10,11,12,16,17,22). The major products of <u>Anabaena cylindrica</u> have been shown to be dimethylallylic alcohol and mestiyloxide (11). The compounds produced by <u>Synura uvella</u> that impart a cod liver oil like flavor to water are trans, cis-deca - 2, 4, dienal and trans, cis hepta - 2, 4 dienal (10). Numerous volatile compounds have been identified in the water of a shallow eutrophic lake over a summers time (12). The last three studies have used gas chromatography which is a sensitive procedure that is suggested as being of value in the early detection of taste and odor compounds.

Numerous factors have been identified as reasons for algal blooms (18). The presence of blue green bacteria (algae) is said to indicate eutrophic water or a previous extensive diatom bloom (18). Low concentrations of silicates may limit the growth of diatoms (18). Low levels of nitrogen and phosphorus are thought to be the two most common limitation of algal growth (13,18) and, in fact, alum treatment has been used to precipitate phosphates from eutrophic recreational waters to prevent algal growth (3). In some cases phosphate can be regenerated internally, and other control measures are necessary (20,23). Manganese has been implicated as being responsible for algal blooms (7, Richard A. Arber, Associates personal communication). Also included as possible, controlling factors of algal growth have been iron, cobalt, dissolved oxygen, and pH (4). Clearly, one must determine the cause of an algal bloom in each particular case.

Requirements of Project

1. To compare membrane filtration and the counting of specific algae with the chlorophyll concentration in the water and with the quantification of geosmin and 2 methylisoborneol to determine the efficiency of each method as a predictor of a taste and odor problem as measured by complaints to the city water department.

2. To monitor selected chemical and physical factors in the water source to determine why algae blooms occur.

3. To grow taste and odor causing algae in laboratory culture and to study ways of eliminating or controlling their growth.

Materials and Methods

Algal cells were enumerated by a modification of the membrane filter nannoplankton filter method of Lind (14). The filter was counted at 100 magnification in a cross strip count without clearing the filter with oil. One hundred mls of water was routinely filtered. The counted filter was then dissolved in 5 mls of 90% acetone made with saturated magnesium carbonate solution. Chlorophyll was determined after centrifugation of the ice stored extract for 4 hours in a fluorometer (Turner Designs). During the last year of this study 6 mls of 90% acetone in a 13x100 mm screwcapped test tube was used to dissolve the filter. The filter was stored in a refrigerator for 24 hours before analysis which was done by placing the extraction tube with no centrifugation into the fluorometer. This procedure was done this last year as a matter of convenience for the water plant operator. Chlorophyll was determined against a standard curve of chlorophyll a from *Anacystis nidulans* (Sigma Chem. Co.). Membrane filters used were Millipore Corporations HA plain 0.45 micrometer poresize.

The analysis of geosmin and 2 methyl isoborneol was done by closed loop stripping of one liter of water with the trap temperature set at 45C, the line temperature was 56C, the sample temperature was 34C, the sp trap was 43C and the sp line was 54C. The stripping time was 3 hours. This was done in a Tekmar closed loop stripping CLS-1 apparatus. Samples were extracted from the 1.5mg activated carbon trap with 20-30µl of carbon disulfide. These extracts were given to Western Research Institute in Laramie for GC/MS analysis for the two target compounds.

The following analyses: Ammonia, nitrate, phosphorus, sulfate, silica, copper, manganese, iron, sulfide, and chemical oxygen demand were done using Hach Co. reagents according to Hach procedures (6). Alkalinity and actinomycetes enumeration were determined according to Standard Methods (1,2). Temperature was taken with a thermometer and pH was determined using a Beckman Phistol pH meter, an Orion pH meter or a pHep (pH electronic paper - Cole Parmer model 5941-00). Dissolved oxygen was determined using a YSI meter.

Samples were collected in appropriately acid cleaned bottles (1,2,6), iced, transported to the water plant and analysed. All samples were processed within eight hours of collection. Weekly samples were generally processed within 4 hours of collection. Samples were collected at weekly intervals at Woods Landing on the Laramie River, in 2-3 feet of water in Lake Sodergreen at the city intake structure, and at the raw water tap in the water treatment plant during the summers of 1985 and 1986. During 1987 triplicate samples at each site were taken once in June and then in July. Samples were taken on three different days in August. Also during the last year of this study alkalinity, temperature, pH, phosporus, nitrate, manganese, algal counts and chlorophyll were determined daily in the raw water. Due to a hasty and unexpected change in plant operators in early August the July data were lost.

On occasion samples were taken around the lake and at various depths in the lake. These were collected using a van Dorn water sampler and from a boat. These samples were generally taken between 8-11 AM in order to avoid windy conditions which were common from noon into the evening.

Samples were also taken at various points along the Laramie River to obtain information concerning the addition of nutrients to the river. Seven sample sites were established. Site 7 was at Woods Landing. Site 6 was a fishing access 2.3 miles above Woods Landing. Site 5 was a fishing access in Colorado 14.2 miles from Woods Landing. Site 4 was a picnic area 26.2 miles above Woods Landing. Sites 3, 2, and 1 were 35.1, 35.8 and 37.9 miles above Woods Landing respectively.

It was attempted to grow Anabaena sp in laboratory culture. This was done by inoculating various media ASM 1, ASN III, BGII, Kratz & Meyers medium C and Mn with lake water containing Anabaena or by adding filters through which lake water had been filtered. The media formulations were obtained from George Izaquirre, The Metropolitan Water District of Southern California. Media formulations are given in the appendix. Incubation in the light was at room temperature and 15C. Also the addition of cow manure, Plants Tabs brand plant food, $MgSO_4$, NH_4Cl, KNO_3, $MnSO_4$, and KH_2PO_4 to 200 mls of lake water was tried in an effort to grow Anabaena. Incubation was in the light at room temperature.

Data were analysed by correlation analysis, Analysis of Variance and Duncans New Multiple Range Test.

Results

Presented in Table 1 are the results of correlation analysis of data collected in 1985 for the parameters of ammonia, phosphorus, sulfate, sulfide, silica, manganese and chlorophyll for the three sampling sites of the river, at Woods Landing, Lake Sodergreen and the raw water in the water plant. Very little was highly correlated to anything. There was a 0.9409 correlation between the sulfate in the lake and that in the raw water. A O.9130 correlation existed between the manganese in the raw water and the chlorophyll in the lake. There was a correlation value of 0.8796 between the manganese in the lake and the chlorophyll in the raw water. Some high correlations existed for ammonia concentrations. Between ammonia in the lake and chlorophyll in the lake the value was 0.8766. Correlation values between the lake and the raw water and between the river and the lake for ammonia were 0.7996 and 0.9235, respectively. The correlation between phosphorus in the river and phosphorus in the raw water was 0.7951. Also, there was a negative correlation between sulfate in the lake and the chlorophyll in the lake. This value was -.8094.

In 1986 actinomycetes were enumerated in addition to the previously stated parameters. The correlation values for the data obtained in 1986 are given in Table 2. The correlation values for sulfate between the river and the lake was 0.9204 and between the lake and the raw water was 0.9883. These values for the number of actinomycetes were 0.9053 and 0.9211 respectively. This indicated that sulfate and actinomycetes went almost directly from the river through the lake to the water plant. Also the same two values for ammonia were 0.8699 and 0.7613 respectively. When manganese in the lake was compared to manganese in the raw water the value was

Table 1. Correlation of Various Parameters Between Sample Sites in 1985

		Ammonia			Phosphorus			Sulfate			Sulfide			Silica			Manganese			Chlorophyll		
		River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw
Ammonia	River	1.0000																				
	Lake	.9235	1.0000																			
	Raw	.7996	.7217	1.0000																		
Phos-phorus	River	.4690	-.0074	.6129	1.0000																	
	Lake	.2093	.3712	.2403	.1586	1.0000																
	Raw	.4023	.7217	.1256	.7951	.4637	1.0000															
Sulfate	River	.4655	.1543	.4888	.0515	-.1993	-.1016	1.0000														
	Lake	.0820	-.1583	.1073	-.1534	-.5755	-.0869	.6353	1.0000													
	Raw	.2606	-.0328	.1423	.0778	-.0869	-.0160	.6753	.9409	1.0000												
Sulfide	River	.5450	.6230	.5629	-.0263	.0243	-.2166	.0870	-.0655	-.1707	1.0000											
	Lake	.3630	.2592	.1453	.1253	.2095	-.2193	.1499	.2357	.2095	.1457	1.0000										
	Raw	.3882	.6713	.6141	-.0170	.3403	-.0039	.1636	-.2278	-.1941	.6761	.3703	1.0000									
Silica	River	.4125	.3512	.4459	-.0580	-.3408	.2034	.3378	.2057	.2557	.2923	.0744	.3147	1.0000								
	Lake	.0434	-.0618	.2851	.3514	-.0682	.2321	.3739	.1939	.1817	-.1418	.0101	-.0259	.6350	1.0000							
	Raw	.5976	.4885	.6280	.5764	.2519	.4563	.4167	.0103	.1757	.0199	.1035	.2489	.6179	.5328	1.0000						
Man-ganese	River	.2769	.3031	-.1179	-.0416	.7632	.6523	-.0964	-.2203	-.2609	.0693	.2362	.2444	-.4954	.-2615	-.3738	1.0000					
	Lake	-.0005	-.3026	.0104	-.2010	-.4872	-.4105	.3595	.6753	.5144	.1812	.3939	-.0564	-.0484	-.1399	-.5997	.0780	1.0000				
	Raw	.5511	.0143	-.0740	.6173	-.5362	-.3805	.1971	.0334	.1366	-.0378	-.1588	-.2251	.5045	.2827	.3492	-.7665	-.2846	1.0000			
Chloro-phyll	River	.6315	.3796	.4229	-.2313	.3110	-.0774	-.5119	.2479	.2362	-.6631	.1467	.1368	.1137	.2607	.1571	.5975	.1602	-.1306	1.0000		
	Lake	.2191	.8766	.0566	-.1926	.0231	-.4060	.5835	-.8094	.2059	-.0377	-2007	-.3003	.2374	.8802	.3193	-.4844	.8796	.9130	.1532	1.0000	
	Raw	.5332	.3856	.0859	-.2269	.2916	-.3268	.6369	.2254	.3303	.1415	.0779	.1699	-.0277	-.0899	.0461	.6634	.1903	-.0282	.6154	.3521	1.0000

Table 2. Correlation of Various Parameters Between Sample Sites in 1986

		Ammonia			Phosporus			Sulfate			Sulfide			Silica			Manganese			Chlorophyll			Actinomycetes		
		River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw	River	Lake	Raw
Ammo-	River	1.0000																							
nia	Lake	.8699	1.0000																						
	Raw	.8980	.7613	1.0000																					
Phos-	River	-.1194	-.0377	-.1215	1.0000																				
phorus	Lake	-.0681	.0150	.1162	.6945	1.0000																			
	Raw	-.0560	.0499	.1231	.1161	.4865	1.0000																		
Sulfate	River	-.1210	-.3181	-.3805	.0047	.0388	-.3460	1.0000																	
	Lake	-.2501	-.4352	-.5061	.1429	.1296	-.3200	.9204	1.0000																
	Raw	-.3243	-.5388	-.4437	.1879	-.0170	-.2852	.9358	.9883	1.0000															
Sulfide	River	-.6807	-.6539	-.5203	-.6807	.1274	-.0727	-.0358	.1820	.2251	1.0000														
	Lake	-.2726	-.3631	-.0842	-.0291	-.0697	.1498	.0529	.2336	.2636	.6328	1.0000													
	Raw	-.2905	-.1785	-.3000	.1630	-.1678	-.0995	.1051	.0910	.2134	.1998	.0910	1.0000												
Silica	River	-.4909	-.4826	-.1868	-.1766	-.1828	.1218	-0546	-.0172	.0792	.1768	-.0346	.0995	1.0000											
	Lake	-.0776	.0171	-.0071	-.1329	.1490	.4956	-.2533	-.2366	-.2322	-.0472	.1231	.0910	.3425	1.0000										
	Raw	-.2589	-.1028	.0239	-.2483	.0440	.2356	-.2986	-.1340	-.1608	.2262	-.1340	.0824	.7918	.6026	1.0000									
Man-	River	-.0379	.1121	.2680	.1395	.0264	.2427	-.7291	-.6708	-.6429	.0969	.0043	-.0196	.2853	.4125	.4501	1.0000								
ganese	Lake	.3911	.5041	.5181	-.0446	.0678	.3825	-.6810	-.6743	-.6707	.0710	.1365	-.2102	.0510	.3445	.4724	.6344	1.0000							
	Raw	.3043	.4498	.5448	-.1244	.2355	.4303	-.8032	-.3068	-.8100	-.0285	-.3068	-.0479	.0353	.3745	.3662	.7292	.8740	1.0000						
Chloro-	River	-.1818	-.1155	-.3441	.3813	-.1022	.0838	.0149	-.0272	.6524	.4811	-.2234	.0249	.5689	.2066	.1589	.4861	-.0674	.1230	1.0000					
phyll	Lake	-.1174	.1858	-.1606	-.1184	-.0199	.1496	-.0513	-.3099	-.3019	.0665	-.3457	.0319	-.1719	-.3058	-.3043	-.4318	-.0482	.1486	.1377	1.0000				
	Raw	-.2622	.1224	-.2365	-.0804	.1191	.3418	.2258	-.2504	-.2399	-.1632	-.0551	.3177	.0033	-.2670	.0030	-.1851	-.0693	.2581	.3220	.7070	1.0000			
Actino-	River	.7500	.8086	.7973	.1541	.0982	-.0021	-.4543	-.5813	-.5602	-.2926	-.1716	-.1912	.1078	.0252	.2701	.3874	.7212	.5584	-.1617	-.1430	-.1195	1.0000		
mycete	Lake	.7520	.7262	.9118	.0199	.1934	.1918	-.5160	-.5770	-.5386	-3045	-.1735	-.2872	-.4780	.1039	.4928	-.5662	.8771	.6948	-.3050	-.2658	.1195	.9053	1.0000	
	Raw	.6808	.7013	.0836	.1350	.2705	.3232	-.3956	-.6715	-.6565	-.6468	-.1976	-.3373	.0388	.1681	.3961	.7047	.9271	.7589	-.1679	-.2332	-.1703	.7514	.9211	1.000

0.8740. Also the correlation values for the comparisons of manganese in the lake to actinomycetes in the lake and to actinomycetes in the raw water were 0.8771 and 0.9271 respectively. There were negative correlations of -0.8100 for sulfate in the raw water compared with manganese in the raw water and 0.8032 for sulfate in the river compared with manganese in the raw water and -0.8032 for sulfate in the river compared with manganese in the raw water.

During 1987 the sampling plan was changed. It was decided not to sample the lake and the river very often but instead to take daily samples of the raw water. The results of correlation analysis of daily samples of the raw water appear in Table 3. Days were correlated with alkalinity (0.8305), alkalinity correlated to pH (0.8488). The correlation values for flow with temperature was 0.7128 and for days with nitrate was 0.7130. Over all three years no surprising correlations were seen.

Since part of this project was to compare chlorophyll, algal counts and geosmin, correlation analysis of chlorophyll and algal counts were done alone with the results shown in Tables 4 and 5. Geosmin was not included in these analyses because of questions concerning the reliability of the data. Anabaena counts in the lake had a correlation value of 0.8592 when compared to those in the raw water in 1985 (Table 4) and this value was 0.8690 in 1986 (Table 5). No other correlations were very high. Thus it appears that the determination of Anabaena numbers in the raw water would be reasonably representative of what is in the lake.

The chemical and microbiological data which had been analysed by correlation analysis plus some addition parameters were grouped by months over the two year period and the data reanalysed by

Table 3. Correlation values of Parameters assayed in the Raw Water on a Daily Basis during 1987

	Days	Alkalinity	Flow mgd	Raw Temperature	Raw pH	Nitrate	Phosphorus	Anabaena	Asterinella	Total Algal count	Ammonia	Chlorophyll	Manganese
Days	1.000												
Alkalinity	.8305	1.0000											
Flow mgd	.3348	.5655	1.0000										
Raw Temperature	.3691	.5904	.7128	1.0000									
Raw pH	.6961	.8488	.5169	.5144	1.0000								
Nitrate	.7130	.5721	.0555	.0127	.4154	1.0000							
Phosphorus	-.4107	-.4478	-.2447	-.2866	-.4458	-.1403	1.0000						
Anabaena	.0926	.2603	.2390	.5382	.3392	-.1162	-.1447	1.0000					
Asterionella	-.2240	.0049	.0745	.0733	-.1167	-.1429	.0361	-.0696	1.0000				
Total Algal count	-.6780	-.5083	-.0573	-.0723	-.4263	-.4994	.3267	.0780	.3088	1.0000			
Ammonia	-.2508	-.2511	.1420	.2111	-.0818	.2861	.1471	.0145	.0404	.2748	1.0000		
Chlorophyll	-.1917	-.3586	-.1717	-.3549	-.2331	-.1478	.3244	-.0363	-.2690	.1810	-.1603	1.0000	
Manganese	.1484	-.0241	-.1545	-.1835	-.0137	.2874	.3160	-.0754	-.0216	-.0122	.2988	.3831	1.0000

Table 4. Correlational of Chlorophyll and Anabaena Counts Between the Lake and the Raw Water in 1985.

			Lake		Raw	
		Days	Chlorophyll	Anabaena	Chlorophyll	Anabaena
	Days	10000				
Lake	Chlorophyll	-.4763	1.0000			
	Anabaena	-.1108	-.1295	1.0000		
Raw	Chlorophyll	-.1208	.3521	-.0561	1.0000	
	Anabaena	-.0973	-.2410	.8592	-.3285	1.0000

Table 5. Correlational Of Chlorophyll, Anabaena and Asterionella Counts Between the Lake and the Raw Water in 1986.

			Lake			Raw		
		Days	Chloro-phyll	Ana-baena	Asteri-onella	Chloro-phyll	Ana-baena	Aster-ionella
	Days	1.0000						
Lake	chlorophyll	-.2208	1.0000					
	Anabaena	.0975	.0145	1.0000				
	Asterionella	.5936	.0333	-.1486	1.0000			
Raw	Chlorophyll	-.4694	.7070	-.0323	-.2910	1.0000		
	Anabaena	.0921	-.0333	.8690	-.1055	.0076	1.0000	
	Asterionella	.3294	.0034	-.1756	.5335	-.1079	-.1534	1.0000

analysis of variance. The values for the river at Woods Landing are given in Table 6. Statistically significant differences (P>0.01) were seen for Ammonia, Sulfate, Silica, Dissolved Oxygen, Chlorophyll and Actinomycetes. Duncan's New Multiple Range test was used to determine what the differences were. It was found that the ammonia concentration in June 1986 was higher than all of the rest of the months. The chlorophyll concentration in May 1986 was greater than the concentration in October 1985, October 1986 or June 1986. The silica concentration was the lowest in June, August and September of 1985 while the concentrations of these parameter in May, July, August and October 1986 were higher than those of July 1985 and September of 1986. The sulfate concentrations were the highest in July 1985, May 1986 and June 1986 while the June 1985 concentration was significantly lower. The dissolved oxygen concentration was the lowest in July 1985 while the actinomycetes were most numerous in May and June of 1986, the only year they were enumerated.

The analysed data for Lake Sodergreen is presented in Table 7. The number of actinomycetes and the dissolved oxygen were highest in May and June (P>0.01). The ammonia concentration in June 1986 was the highest (P>0.01). The chlorophyll concentration in July 1985 was higher than the rest of the months except for July and September 1986 (P>0.01). The silica concentration in August of 1985 was significantly lower than the rest of the months except for June and September of 1985 (P>0.01). The values of silica in May and July 1986 were significantly higher than any values found in 1985 (P>0.01). The phosphorus concentration was higher in June 1985 than all of the other values except July 1985 (P>0.01). The sulfate in August 1985 was significantly higher than all the rest except July 1985. Also, the values in May, June and July 1986 and June 1985 were the lowest (P>0.01). _Anabaena_

Table 6. Monthly Means of Various Parameters in the River at Woods Landing for 1985-1986

Parameter	Concentration	June 1985	July 1985	Aug 1985	Sept 1985	Oct 1985	May 1986	June 1986	July 1986	Aug 1986	Sept 1986	Oct 1986	F value	Level of Significance
Ammonia	mg/L	0.14	0.18	0.14	0.07	0.13	0.09	0.42	0.23	0.19	0.18	0.19	9.2217	0.01
Nitrate	mg/L	0.00	0.05	0.13	0.08	0.01	0.00	0.00	0.01	0.00	0.02	0.00	1.2189	None
Sulfide	µg/L	3.0	3.9	3.9	2.0	10.0	4.8	0.0	0.0	3.0	8.4	7.0	0.9694	None
Sulfate	mg/L	7.6	70.8	53.6	46.8	31.8	8.2	6.9	22.5	44.5	29.8	30.1	19.6199	0.01
Silica	mg/L	8.2	10.2	8.6	8.8	--	13.3	11.2	11.8	12.0	11.1	13.5	12.8367	0.01
Phosphorus	mg/L	0.15	0.17	0.08	0.13	0.13	0.11	0.10	0.10	0.14	0.01	0.10	1.5869	None
Manganese	mg/L	0.040	0.042	0.026	0.021	0.000	0.067	0.061	0.030	0.027	0.034	0.031	1.8818	None
Copper	µg/L	0.01	0.03	0.01	0.00	0.00	0.05	0.00	0.05	0.00	0.03	0.02	0.5875	None
Iron	mg/L	0.005	0.004	0.010	--	--	--	--	--	--	--	--	0.4485	None
Dissolved Oxygen	mg/L	7.9	7.0	7.3	--	--	--	--	--	--	--	---	7.0843	0.01
Chemical Oxygen Demand	mg/L	--	--	--	--	--	--	--	--	15.1	12.1	5.3	0.4154	None
Chlorophyll	µg/L	--	15.5	14.8	11.9	7.4	27.9	11.5	16.2	22.6	18.4	8.4	3.2958	0.01
Anabaena Sp.	cells	--	--	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.6821	None
Actinomycetes	cells/ml	--	--	--	--	--	19	44.3	9.7	4.2	8.4	8.0	5.1523	0.01

Table 7. Monthly Means of Various Parameters in Lake Sodergreen for 1985-1986

Parameter	Concen-tration	June 1985	July 1985	Aug. 1985	Sept 1985	Oct 1985	May 1986	June 1986	July 1986	Aug 1986	Sept 1986	Oct 1986	F value	Level of Significance
Ammonia	mg/L	0.13	0.16	0.13	0.09	0.16	0.14	0.47	0.30	0.20	0.20	0.16	8.4584	0.01
Nitrate	mg/L	0.01	0.14	0.08	0.13	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.9486	None
Sulfide	µg/L	1.5	1.8	5.1	5.0	10.3	3.3	0.8	0.6	3.0	6.6	7.0	0.8161	None
Sulfate	mg/L	7.2	50.7	59.2	45.8	26.6	11.5	6.9	17.0	41.1	36.9	28.7	44.4275	0.01
Silica	mg/L	8.3	9.4	8.5	8.8	--	12.6	11.5	11.4	11.2	10.9	11.1	7.5644	0.01
Phosphorus	mg/L	0.28	0.19	0.05	0.09	0.10	0.08	0.08	0.09	0.10	0.01	0.04	2.6480	0.05
Manganese	mg/L	0.000	0.144	0.036	0.028	0.035	0.051	0.061	0.036	0.030	0.024	0.027	0.3934	None
Copper	µg/L	0.00	0.02	0.01	0.00	0.00	0.04	0.01	0.05	0.04	0.02	0.02	0.9528	None
Iron	mg/L	0.005	0.012	0.013	--	--	--	--	--	--	--	--	1.1428	None
Dissolved Oxygen	mg/L	7.5	7.4	7.2	--	--	--	--	--	--	--	--	5.6987	0.05
Chemical Oxygen Demand	mg/L	--	--	--	--	--	--	--	--	14.3	12.5	7.5	0.2004	None
Chlorophyll	µg/L	--	49.4	29.5	24.5	21.5	24.7	19.2	30.6	20.7	14.7	15.1	3.9665	0.01
Anabaena Sp.	cells	--	3.5	47.0	24.3	1.3	1.8	0.00	0.4	40.8	3.6	0.0	3.6028	0.01
Actinomycetes	cell/ml	--	--	--	--	--	19.7	29.4	5.3	2.8	3.8	3.3	5.7621	0.01

numbers in August 1985 were higher than the rest except for July 1985 and August 1986 (P>0.01).

The data for the raw water are given in Table 8. The ammonia concentration in June 1986 was the highest (P>0.01). Silica had the highest concentration in May of 1986 and August and September of that year yielded the lowest concentrations (P>0.01). The sulfide concentration in September 1985 was higher than all of the rest of the months except for August 1986 (P>0.05). For sulfate the highest values were seen in July and August of 1985 (P>0.01). The value in July of 1986 was significantly lower than those found in September or October 1985 and August, September and October 1986 (P>0.01). The lowest values were found in June 1985, May 1985 and June 1986. The highest nitrate concentration was found in September 1985 (P>0.05). The numbers of Anabaena in August 1985 were significantly higher than those found the rest of the months except for September 1985 and August 1986 (P>0.01). The highest concentrations of iron was found in June 1985 (P>0.05) and of Actinomycetes in May and June 1986 (P>0.01). The lowest dissolved oxygen was found in July (P>0.01).

Given in Table 9 are the results of 3 samples taken at the three sites for June, July and August 1987. All of the statements made in this paragraph are significant at P>0.05. For ammonia the lowest values at all three sites were found in June while the highest were found in August. Also the value found in the lake was higher than that found in the river in July. The nitrate concentration in the river and the raw water in August and in the lake and the raw water in July were significantly higher than all three sites in June. The silica concentration in the lake and the raw water in June were significantly lower than the river in June or all three sites in July. The phosphorus concentration in the

Table 8. Monthly Means of Various Parameters in the Raw Water in the Plant for 1985-1986

Parameter	Concen-tration	June 1985	July 1985	Aug. 1985	Sept 1985	Oct 1985	May 1986	June 1986	July 1986	Aug 1986	Sept 1986	Oct 1986	F value	Level of Significance
Ammonia	mg/L	0.13	0.19	0.15	0.13	0.14	0.13	0.55	0.27	0.13	0.22	0.21	6.4125	0.01
Nitrate	mg/L	0.00	0.03	0.10	0.35	0.03	0.02	0.00	0.00	0.00	0.01	0.00	2.5168	0.05
Sulfide	µg/L	4.5	2.7	2.1	0.0	14.0	4.0	0.0	1.8	7.5	6.0	1.5	2.6479	0.05
Sulfate	mg/L	5.0	54.2	57.2	34.0	32.3	11.8	6.7	16.4	39.9	32.2	26.7	37.3188	0.01
Silica	mg/L	8.8	10.1	8.0	8.0	--	14.3	12.1	11.7	11.9	10.9	11.4	14.0781	0.01
Phosphorus	mg/L	0.12	0.17	0.04	0.13	0.07	0.11	0.07	0.08	0.04	0.04	0.02	1.7881	None
Manganese	mg/L	0.020	0.096	0.036	0.025	0.034	0.052	0.053	0.041	0.027	0.023	0.023	1.9942	None
Copper	µg/L	0.02	0.03	0.01	--	0.00	0.07	0.01	0.04	0.03	0.03	0.02	1.6213	None
Iron	mg/L	0.035	0.006	0.012	--	--	--	--	--	--	--	--	6.4412	0.05
Dissolved Oxygen	mg/L	7.3	6.2	6.8	--	--	--	- - -		-- - -	- - -		9.8850	0.01
Chemical Oxygen Demand	mg/L	--	--	--	--	--	--	--	--	14.2	11.7	4.3	0.4420	None
Chlorophyll	µg/L	--	32.5	23.0	16.6	20.3	24.9	17.1	22.0	19.6	13.7	8.3	1.7954	None
Anabaena Sp.	cells	--	6.8	39.3	6.5	0.5	1.8	0.5	0.6	23.3	2.8	0.5	4.3492	0.01
Actinomycetes	cells/ml	--	--	--	--	--	18.0	26.1	6.1	1.3	3.6	3.0	8.9535	0.01

Table 9. Chemical Data Collected at Three Sites During 1987.

Month	Site	Value Presented	Ammonia mg/L	Nitrate mg/L	Silica mg/L	Phosphorus mg/L	Sulfate mg/L	Sulfide µg/L
June	River	mean	.15	0.00	11.6	.05	24.1	26.0
	Lake	mean	.17	0.00	9.1	.00	19.3	21.0
	Raw	mean	.13	0.00	10.1	.10	21.2	20.0
July	River	mean	.30	.06	11.7	.03	76.9	18.0
	Lake	mean	.40	.11	12.1	.07	76.9	31.0
	Raw	mean	.38	.12	12.1	.05	77.7	17.0
August	River	mean	.66	.14		.02	71.6	32.0
	Lake	mean	.62	.06		.06	65.8	33.0
	Raw	mean	.59	.14		.03	64.0	33.3

raw water in June was significantly higher than that in the river in July, the lake in June or the raw water or river in August. The sulfide concentrations in the river in June, the lake in July and all three sites in August were significantly higher than the lake and raw water in June and the river and raw water in July. Finally, for sulfide the concentration in the river in August was significantly higher than in the lake or raw water this month. All three sites had higher concentrations in July than June or August with no differences between sites. The lowest values were found in June with no differences between sites.

Present in Table 10 are the mean values for data collected at seven sample sites along the Laramie River The silica concentration at the diversion of the Laramie River back to the Cache LaPoudre River was significantly lower than at any of the other six sampling sites ($P>0.05$). The only other parameter to be significantly different was sulfate ($P>0.05$). The value at the fishing access in Colorado was higher than the four upstream sites and the two furthest downstream sites had significantly higher concentrations than the five upstream sites.

The perimeter of the lake was surveyed to see if any particular part of the lake was different than any other part. The results of this study are presented in Table 11. The pH at 3 meters depth in the northeast corner was significantly different from the pH at 3 meters of the inlet, the middle east, the southwest corner and the southeast corner ($P>0.05$). The only other difference found was that the manganese concentration in the southwest corner at 2 meters depth was significantly higher than at all of the rest of the sampling sites ($P>0.01$). Thus for most tests a sample anywhere around the lake should be representative of the lake.

Table 10. Mean Values for Various Parameters in the Laramie River

Parameters	Concen-tration	Sample Site* 1	2	3	4	5	6	7	F Value	Level of Significance
Ammonia	mg/L	0.13	0.12	0.14	0.15	0.16	0.17	0.15	0.2348	None
Nitrate	mg/L	0.00	0.02	0.02	0.01	0.06	0.00	5 reps	no statistics run	
Sulfide	µg/L	3.7	3.8	1.5	0.4	0.8	0.4	4 reps	no statistics run	
Sulfate	mg/L	1.1	1.2	0.5	2.0	13.6	37.3	36.5	25.5265	0.01
Phosphorus	mg/L	0.16	0.18	0.10	0.13	0.18	0.21	0.15	1.0626	None
Chemical Oxygen Demand	mg/L	6.3	2.5	3.8	6.3	9.1	6.2	3 reps	no statistics run	
Chlorophyll	µg/L	8.7	11.2	9.9	10.1	13.1	14.4	18.0	1.3015	None
Actinomycetes	cells/ml	9.3	4.8	3.7	9.3	12.5	15.2	3 reps	no statistics run	
Manganese	mg/L	0.024	0.025	0.019	0.033	0.024	0.057	0.032	1.7178	None

* Sample Site	Miles Above Woods Landing
1	37.9
2	35.8
3	35.1
4	26.2
5	14.2
6	2.3
7	0

Table 11. Mean Values for Various Parameters around the Perimeter of Lake Sodergreen

Parameters	Concentration	NCenter	N East Corner		Outlet	Inlet	S West Corner		SCenter	SECenter	ECenter	F Value	Level of Significance
		3meters deep	2meters deep	3meters deep	3meters deep	3meters deep	2meters deep	3meters deep	3meters deep	3meters deep	3meters deep		
Ammonia	mg/L	0.13	0.14	0.11	0.14	0.14	0.17	0.16	0.13	0.12	0.14	0.2349	None
Nitrate	mg/L	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.07	0.01	0.02	no statistics run	
Sulfide	µg/L	7.5	--	0.0	6.0	7.4	3.0	0.0	8.2	7.9	1.5	no statistics run	
Sulfate	mg/L	42.2	42.0	39.6	41.8	41.3	40.1	43.5	41.5	41.8	39.8	0.9916	None
Silica	mg/L	11.2	10.8	10.9	11.1	11.4	10.7	10.8	--	11.9	10.8	1.5904	None
Phosphorus	mg/L	0.14	0.11	0.22	0.17	0.18	0.08	0.61	0.20	0.11	0.13	1.2507	None
Manganese	mg/L	0.032	--	0.042	0.030	0.036	0.031	0.072	0.037	0.032	0.035	7.8222	0.01
Chemical Oxygen Demand	mg/L	18.7	--	44.4	11.3	18.7	--	--	--	11.3	11.3	no statistics run	
Copper	µg/L	0.07	--	0.05	0.04	0.04	0.08	0.26	0.01	0.03	0.02	2.12	None
Temperature	°C	16.5	16.5	16.6	16.5	16.3	16.1	16.0	16.0	16.5	16.5	0.3930	None
pH	units	8.2	8.2	8.3	8.2	8.1	8.2	8.1	8.2	8.1	8.1	no statistics run	
Secchi disc	feet	7.0	8.5	--	7.0	8.0	8.0	--	6.5	8.1	8.0	no statistics run	
Chlorophyll	µg/L	16.8	15.7	22.9	29.3	21.5	20.9	37.5	24.9	20.9	17.9	1.0012	None
Anabaena	cells	14.3	27.0	31.3	31.0	19.8	22.8	19.8	33.3	23.8	42.0	0.9390	None
Asterionella	cells	1.5	0.0	1.0	1.0	5.5	2.0	2.3	0.0	2.5	2.3	0.6591	None

* One determination only.

A series of samples was also taken at one meter intervals from top to bottom at the center of the lake. The data which were analysed by analysis of variance are shown in Table 12. Chlorophyll and Manganese concentrations were significantly higher at 10 meters depth than at any other depth ($P>0.05$). This was probably due to the inclusion of some sedimented material into this sample. No other differences were found which indicated that the lake is well mixed.

Given in Table 13 are the results of trying to grow *Anabaena* sp. in the laboratory by supplementing lake water which had cells of *Anabaena* in it with various chemical compounds. Incubation was at room temperature in the presence of light. No *Anabaena* were ever cultured even after one years incubation. This experiment was done both years.

Shown in Table 14 are the results of trying to grow *Anabaena* in various laboratory media. Inoculations were made by adding lake water or filters which had had 100ml of lake water filtered through them to the laboratory media. *Anabaena* was never grown however geosmin was produced in some cultures when the inoculum was taken from growth attached to the sediment basin. This production was due to the growth of what probably was an *Aphanizomenon* sp.. Since *Anabaena* was never grown in the laboratory, studies on how to control it could not be done.

Presented in Table 15 are the results of closed loop stripping followed by GC/MS analysis for geosmin when a known amount of geosmin had been added to geosmin free water. When 40 ng/L geosmin was added the recovery was between 19 and 103 percent of the added amount. When 20 ng/L was added the recovery was 26%. This problem was never solved during this project.

Table 12. Mean Values for Various Parameters at One Meters Intervals In Depth at the Center of Lake Sodergreen

Parameters	Concen-tration	Meters Deep from the Surface 1	2	3	4	5	6	7	8	9	10	F Value	Level of Significance
Ammonia	mg/L	0.20	0.18	0.18	0.17	0.18	0.17	0.17	0.18	0.18	0.17	0.1900	None
Nitrate	mg/L	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.01	0.00	no statistics run	
Sulfide	µg/L	1.5	5.1	2.3	4.1	0.4	3.0	2.1	2.6	3.9	2.0	0.9950	None
Sulfate	mg/L	38.4	35.2	36.3	35.8	135.4	35.0	35.1	36.4	34.4	38.1	0.2877	None
Phosphate	mg/L	0.16	0.13	0.10	0.11	0.13	0.10	0.17	0.15	0.14	0.32	1.7839	None
Silica	mg/L	11.9	11.5	11.5	11.5	11.8	11.8	11.7	11.5	11.9	12.4	0.5586	None
Copper	µg/L	0.08	0.02	0.04	0.03	0.05	0.04	0.03	0.04	0.07	0.11	1.1731	None
Chemical Oxygen Demand	mg/L	18.8	16.6	10.0	11.2	9.6	19.2	19.2	13.4	25.1	0.0	no statistics run	
Temperature	°C	17.8	14.5	14.7	14.6	14.1	14.1	14.1	14.2	14.1	14.6	0.2884	None
pH	units	8.2	8.0	8.1	8.0	8.0	8.0	8.0	7.9	7.9	7.7	1.4477	None
Anabaena	cells	13.8	7.9	15.4	12.2	5.4	5.1	3.9	4.3	6.8	5.4	1.0509	None
Asterionella	cells	3.6	1.9	2.0	1.5	3.0	1.0	2.3	0.9	0.3	0.0	no statistics run	
Chlorophyll	µg/L	14.0	15.7	16.8	14.2	14.4	12.4	15.2	20.6	18.3	40.5	2.7853	0.01
Manganese	mg/L	0.031	0.028	0.057	0.026	0.030	0.030	0.034	0.046	0.062	0.131	3.8689	0.01

Table 13. Growth of Algae in Supplemented Lake Water Incubated at Room Temperature

Addendum	Milligrams Added per 200 ml	Algal Growth	Growth of Anabaena	Geosmin Produced
Cow Manure	100	+	-	-
	200	+	-	-
Plantables 11-15-20 Aquarium Plant Food	8	+	-	-
	16	+	-	-
	24	+	-	-
$MgSO_4.7H_2O$	.191	+	-	-
	.382	+	-	-
NH_4Cl	.068	+	-	-
KNO_3	.15	+	-	-
	.30	+	-	-
$MnSO_4$	.191	+	-	-
	.382	+	-	-
KH_2PO_4	.09	+	-	-
	.18	+	-	-
	.36	+	-	-
$KH_2PO_4 + KNO_3$	.09 + .15	+	-	-
	.18 + .30	+	-	-
	.18 + .60	+	-	-
$KH_2PO_4 + MnSO_4$	.09 + .191	+	-	-
	.18 + .191	+	-	-
	.18 + .302	+	-	-
Material from Sediment Basin	0.1 ml	+	-	-
None		-	-	-

+ means growth or production

- means no growth or no production

Table 14. Growth of Algae in complete media incubated at 15°C

Medium	Algal Growth	Growth of Anabaena	Geosmin Produced
ASN3	+	-	-
ASM1	+	-	+
BG11	+	-	+
Manganese	+	-	-
Kratz and Meyer's Medium C	+	-	+

+ means growth or production
- means no growth or no production

Table 15. Stripping Efficiency of Geosmin

Concentration added ng/L	Concentration recovered ng/L	mean	standard deviation
40	41.1, 9.6, 7.5, 30.6	22.20	16.36
20	4.8, 5.	5.10	0.42

Shown in Table 16 are the results of geosmin determinations in the raw water in 1986 and 1987. Geosmin was found in August of 1986, July and August of 1987 and sporadically at other times. The amounts which were recovered varied quite a bit. This probably was due to the techniques more than what was actually in the water. Low levels of geosmin (1-2 ng/L) were detectable. No increasing levels of geosmin were noted and 2 methyl isoborneol was never found.

Presented in Table 17 are the results of looking for geosmin at various locations within the treatment plant. Geosmin was found throughout the plant. There were no significant differences between any site whether all three dates were lumped together or analysed individually ($P>0.05$). A problem developed during the July analysis which was never solved in this project. Six samples were being processed by closed loop stripping and after sample four the air pump of the closed loop stripping instrument quit. It had to be taken apart and cleaned, then it functioned again. As can be seen from the data very large variations in recovery of geosmin occurred. One sample from the south sediment basin which was stripped just before the pump quit had a recovery of 0.0 while the recovery in the duplicate sample which was stripped after the pump was worked on recovered 51.8 ng/L of geosmin. This leads one to wonder how much efficiency is lost between samples in any run series. A standard compound needs to be added to each sample to be able to calculate recovery. This was not done in this project.

The results of two experiments to see if ozonation can be used to remove geosmin from the water are given in Table 18. Twelve liters of raw water were spiked with 40 ng/L of geosmin. Samples were then taken for geosmin recovery. The remaining water was

Table 16. Geosmin In the Raw Water of the Laramie Water Treatment Plant

Date	Concentration ng/L	Mean	Standard Deviation
1986:			
7-2	0.00		
7-23	0.00		
8-6	0.14		
8-13	0.00		
8-20	3.30, 10.20, 13.80	9.10	5.34
8-30	4.20		
9-20	2.00		
1987:			
5-14	5.70, 0.00	2.85	4.03
6-5	0.00		
6-24	0.00		
6-30	3.60		
7-10	15.40		
7-14	8.10, 37.40	22.75	20.72
7-17	15.30		
7-21	0.00		
8-24	2.20, 1.00	1.60	0.85
9-29	3.60, 3.60	3.60	0.00

Table 17. Geosmin in Various Locations within Laramie's Water Treatment Plant in 1987.

Date	Location and Condition	Concentration Recovered (ng/L)	mean	Standard deviation	F* Value	Level of Significance
7-14	South sediment basin cleaned	0.0, 51.8	25.9	36.6	1.3729	None
7-14	North sediment basin dirty	20.4, 51.8	36.1	22.2		
7-14	Raw Water	8.1, 37.4	22.8	20.7		
8-24	New filter effluent	0.0, 4.0	2.0	2.8		
8-24	Old filter effluent	1.8, 2.6	2.2	0.6		
8-24	Raw Water	2.2, 1.0	1.6	0.8		
9-29	New filter used 6 weeks	4.8, 3.8	4.3	0.7		
9-29	New filter used 1 week	3.6, 4.0	3.8	0.3		
9-29	Raw water	3.6, 3.6	3.6	0.0		
9-29	North sediment basin dirty	2.2				
9-29	Spiked 40 ng/L	30.6				

*The F value for just the 8-24 data was 0.0619 and for the 9-29 data was 1.3448, neither of which was significant.

Table 18. Effect of Ozonation Upon Geosmin in Raw Water

Condition	Concentration Recovered	Mean	Standard Deviation	F value
raw + 40 ng/L geosmin	10.5, 7.8	9.15	1.91	
spiked as above then bubbled at 3 L/ min with air	11.2, 7.8	9.50	2.40	6.5607
ozonated - 3 L/min at 3 amp setting	4.2, 2.7	3.45*	1.06	

*Significantly lower P > 0.05

bubbled with air at a flow rate of 3 L/min. After 10 min of bubbling samples were taken again for geosmin analysis. Then the water was ozonated for 10 min at a flow rate of 3 L/Min at a 3 amp setting on the ozonation. The ozone residual after 10 minutes was 2.0 (Hach DPD procedure). The value of geosmin left after ozonation was significantly lower than after either spiking with geosmin or bubbling with air ($P>0.05$). No work was done to determine the optimum conditions of ozonation.

Conclusions

1. There were no *Anabaena* or any other taste and odor causing algal blooms during the three years of this study. Therefore the data in this report should be considered background data against which to compare future data.

2. *Anabaena* could not be grown in the laboratory therefore experiments on how to limit growth could not be done.

3. There were very few highly correlated parameters for both years at the three sites. Those that did occur generally showed that the river was connected to the lake which was connected to the water plant. There was a 0.85 correlation between the *Anabaena* in the lake and the *Anabaena* in the raw water, thus counts in the raw water should representative of what is in the lake.

4. The lake is well mixed and a sample at any location or depth likely will produce results representative of the lake in general. The one possible exception is that manganese concentration in the southwest corner was significantly higher than all of the other sites. If manganese concentrations is a predictor of algal growth to come, it would be wise to sample this location occasionally.

5. Some chemicals and bacteria are washed into the water with spring snow melt, others are diluted at this time and still others become more concentrated as the summer progresses. None of this is new information.

6. Geosmin was found throughout the water plant upon occasion and may be produced by organisms which were growing in the sediment basins.

7. It appeared that ozonation may be used to eliminate geosmin from the water, however much more work needs to be done to determine the optimum conditions of ozonation.

Recommendations

1. The city should continue a monitoring program so as to have data to compare to these should a bloom of taste causing algae occur again.

2. Samples should be taken occasionally of the lake and in particular the southwest corner just to see that the raw water is representative of the lake.

3. Geosmin determinations should not be pursued unless a large number of samples can be run which will cost considerable money.

References

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APPENDIX

RAW DATA

COLLECTED DURING

THE STUDY

Appendix A. Raw Data Collected in 1985-1986.[a]

1985 Date	Ammonia	Nitrate	Phosphorus	Sulfate	Sulfide	Silica	Manganese	River Chlorophyll	Copper	Temperature	pH	Actinomycetes	Anabaena	Asterionella	Iron	Dissolved oxygen	COD
5-24											5.8					7.7	
5-30	.03	0	.31	3.4,8.5						8.0	6.8						
6-4										8.5	7.1					8.3	
6-12	.24	0	.05	9.2	3	9.4	.060		0	8.0	7.3				.0	7.7	
6-19	.15	0	.09	9.2	3	6.9	.060		.02	13.0	7.4				.01	7.7	
6-27 .	.12	0	.14			- -	.000			13.0	7.6					7.7	
7-5 .	.13	0	.11	59.7	0	11.3	.060	12.2		14.5	7.8						
7-10	.14	.28	.35	65.9	4.5	11.1	.120	8.8.		18.0	7.9						
7-12	.15	0	.09	65.4	3	10.5	.000	12.2	.02	19.5	7.8				0		
7-15 .	.28	0	.38	54.8	- -	9.8	.000	11.2	.02	18.5	8.4				.01	6.6	
7-24	.19	.03	.08,.07	69.6	3	9.0	.037	23.6	0								
7-29	.21	0	.17,.11	109.6	9	9.4	.040	25.0	.04	14.5	7.8.				.01	7.4	
8-1	.13	0	.13	61.5	3	9.0	.034	27.0	0	17.0							
8-5	.17	0	.03,.13	56.3	6	8.0	.031	15.6	0	15.0	7.2			0	0	7.1	
8-9	.12	.07	.02	63.4	12	7.6	.031	17.0	0								
8-14	.12	.23	.02	47.3	0	10.5	.021	1.0	.02	19.0	8.3			1	0	7.4	
8-20	.15	.07	.07	59.7	0	8.0	.021	17.4	0	12.0	8.6			0	0	.7.3	
8-22	.10	0	.16	43.4	0	8.3	.018	8.2		18.0	8.0			0	.03	.7.5	
8-26	.21	.51	.06	43.4	6	- -	.027	17.4		13.0	7.3			0	.02	7.4	
9-3	.12	0	.09	76.6	3	- -	- -	11.8		17.5	8.2			0			
9-12	.06	.25	.18	38.2	3	9.0	.021	15.4		12.0	7.8			0			
9-19	.03	0	.13	25.5	0	6.9	.021	8.4		14.0	7.6						
10-1	.21	.05	.11	30.1	21	10.5	- -	11.2		1.0	7.5						
10-3	.05	0	.29	35.5	- -		- -	5.8		10.0	7.2						
10-10	.13	0	.09	36.3	9		- -	- -		7.0	7.0			0			
10-24	.17	0	.08	31.8	0		- -	6.8		2.0	7.5			0			
10-29	.10	.02	.07	25.5	- -		- -	5.6		7.0	- -						

Appendix A. Continued

1986 Date	Ammonia	Nitrate	Phosphorus	Sulfate	Sulfide	Silica	Manganese	Chlorophyll	Copper	Temperature	pH	Actinomycetes	Anabaena	Asterionella	Iron	Dissolved oxygen	COD
								River									
4-30	.00	0	.11	12.7	6	13.8	.065	37.1									
5-6	.00	0	.11	9.2	12	11.7	.054	24.2	.02	2.0	6.6						
5-15	.13	0	.07	5.9	3	14.3	.061	26.6	.11	5.0	7.2	5.5	0				
5-20	.13	0	.06	6.5	0	13.8	.087	23.5	.02	10.0	7.3	24.5	0				
5-30	.19	0	.18	6.6	3	13.0	.068	- -	0	8.0	7.4	27.0	0				
6-4	.30	0	.20	5.3	0	11.7	.095	17.4	- -	10.0	6.9	20.0	0				
6-12	.52	0	.09	10.6	0	12.5	.065	7.4	0	9.0	6.8	65.0	0				
6-18										11.0	6.9	70.0	0				
6-19	.43	0	.05	4.6	0	10.5	.037	9.3	- -								
6-25	.43	0	.07	7.2	0	10.1	.047	12.0	- -	10.0	7.0	22.0	1				
7-2	.24	0	.16	14.9	0	11.3	.044	22.6	- -	12.5	7.0	24.0	0				
7-9	.22	0	.07	14.4	0	12.1	.037	19.7	.05	13.0	7.0	12.0	0				
7-16	.24	0	.02	22.8	0	12.1	.024	19.1	- -	15.0	6.9	35.0	0				
7-23	.22	.03	.03	31.8	0	13.0	.024	11.6	- -	14.0	8.1	4.5	0				
7-30	.21	.03	.20	28.6	0	10.9	.021	8.1	- -	15.5	7.9	4.5	0				41.4
8-5	.24	0	.03	56.7	- -	12.6	.024	11.6	- -	17.0	8.2	0	0				0
8-13	.22	0	.27	42.9	3	11.4	.024	31.3	- -	17.0	8.3	6.5	0				11.3
8-20	.19	0	.16	42.3	3	10.6	.034	23.2	- -	15.5	8.6	6.0	0				7.5
8-26	.12	0	.09	35.9	- -	13.5	.024	24.3	- -								
9-2	.15	.10	.00	34.4	6	11.2	- -	13.9	- -	11.0	8.1	5.5	0				35.3
9-11	.08	0	.02	28.8	0	11.0	.--	17.0	- -	8.0	7.9	8.0	0				0
9-18	.24	0	.00	31.4	15	10.3	.034	38.2	.07	9.0	7.9	13.0	0				14
9-22	.26	0	.00	29.4	0	11.0	- -	12.5	0	9.0	7.8	5.5	0				3.7
9-30	.19	0	.00	25.2	21	12.2	- -	10.2	.02	5.0	7.9	10.0	0				7.5
10-9	.21	0	.13	25.2	0	12.6	- -	6.5		10.0	8.0	- -	0				1.0
10-14	.19	0	.13	29.4	28	14.3	- -	10.2	0	1.5	7.6	9.0	0				7.5
10-21	.21	0	.13	32.9	0	13.5	.031	7.4	.04	5.0	7.9	4.0	0				
10-28	.13	0	.02	32.9	0	13.5	- -	9.3	.02	4	7.9	11.0	0				7.5

Appendix A. Continued

								Lake									
1985 Date	Ammo-nia	Nit-rate	Phos-phorus	Sul-fate	Sul-fide	Silica	Man-ganese	Chlor-ophyll	Copper	Temper-ature	pH	Actino-mycetes	Ana-baena	Asteri-onella	Iron	Dissolved oxygen	COD
5-24										6.1						8.0	
5-30	.01	0	.44	4.0						11.0	7.0					8.2	
6-4										11.0	7.4					7.8	
6-12	.22	0	.06	7.2	0	8.7	0		0	13.0	7.4				.01	7.5	
6-19	.17	0	.57	5.9	3	8.0	0		0	20.0	7.8				0	7.3	
6-27	.13	.03	.05	12.0			0			17.0	7.9					7.7	
7-5	.15	0	.05	39.2	0	8.7	0	33.2	.04	19.0	7.5				.02	7.5	
7-10	.19	.02	.35	51.7	0	8.7	0	17.0	0	21.5	7.2				.01		
7-12	.15	.03	.02	46.0	0	9.8	0	84.0	.04	20.5	8.0		6.0		.02		
7-15	.15	.75	.43	58.9		10.7	1.005	35.6		19.5	8.4		1.0		.01	7.0	
7-24	.17	.03	.14,.13	58.0	3	9.0	.037	49.6	.02,.04								
7-29	.17	0	.13,.29	50.1	6	9.4	.031,.037	74.0	0,.02	17.0	8.2				0	7.7	
8-1	.13	0	.07	69.6	0	9.4	.040	52.8,39.0	0	19.0			38.0				
8-5	.17	0	0,.03	67.4	15	8.3	.047	41.4	0	17.0	7.6		24.0		.01	6.9	
8-9	.12	.10	.05	63.4	0	7.6	.054	34.0	0								
8-14	.12	0	0	56.3	6	9.0	.040	22.0	0	19.0	8.2	13,16			.01	6.9	
8-20	.13	.05	.08	54.7	0	8.0	.031	27.6	.02	15.0	8.1		106		.01	7.3	
8-22	.13	.02	.04	44.7	0		.024	17.6		18.0	8.0		44		.02	7.1	
8-26	.13	.42	.11	58.0	15		.018	24.8		16.0	7.5		88		.02	7.6	
9-3	.10	0	.05	54.7	12		.027	36.6	0	17.5	8.1		62		.01		
9-12	.10	.23	.16	47.3	3	10.1	.031	5.8		14.0	7.9		11				
9-19	.08	.15	.05	35.3	0	8.0	.027	31.2		13.0	8.1		0				
10-1	.21	0	.08	33.5	3	8.3	.027	22.8		5.0	7.5		1				
10-3	.05	0	.25	27.8	- -		.044	24.0		7.0	7.4		2				
10-10	.19	0	.09	32.7	3					8.5	- -		1				
10-24	.15	0	.03	29.3	25		.034	22.0	0	4.0	7.4		1				
10-29	.20	0	.05	24.8				17.2		7.5	7.5		- -				

Appendix A. Continued

Lake

1986 Date	Ammo- nia	Nit- rate	Phos- phorus	Sul- fate	Sul- fide	Silica	Man- ganese	Chlor- ophyll	Copper	Temper- ature	pH	Actino- mycetes	Ana- baena	Asteri- onella	Iron	Dissolved oxygen	COD
4-30	0	0	.13	12.7	0	10.5	.044	33.3									
5-6	0	0	.07	17.5	9	11.3	.054	27.0	.02	6.0	6.8		2				
5-15	.15	0	.09	12.0	3	14.7	.047	28.4	.10	8.0	7.2	8.0	3				
5-20	.28	0	.06	7.9	0	14.3	.051	10.0	.02	12.0	7.4	18.0	2				
5-30	.26	0	.05	7.6	4.5	12.3	.061		0	9.0	7.3	33.0	1				
6-4	.34	0	.10	5.3	0	12.5	.051	10.0	.02	14.0	6.9	18.5	0	0			
6-12	.52	0	.11	10.6	3	11.7	.087	6.5	0	11.0	7.0	55.0	0	0			
6-19	.54	0	.03	5.3	0	11.7	.051	23.2	.02	14.0	6.9	30.0	0	1			
6-25	.49	0	.07	6.5	0	10.1	0.54	37.1	.01	14.0	7.0	14.0	0	3			
7-2	.49	0	.11	10.6	0	10.1	.031	36.5	.16	15.0	7.0	11.0	1	0			
7-9	.32	0	.03	7.2	0	10.5	.044	40.5	.02	16.0	7.0	6.5	1	9			
7-16	.19	0	.07	15.9	0	12.1	.044	27.8	0	17.0	8.2	2.5	0	14			
7-23	.22	0	.05	24.1	3	12.5	.034	30.7	.01	17.5	- -	4.0	0	0			
7-30	.26	0	.19	27.0	0	11.7	.027	17.4	.07	17.0	8.0	2.5	0	0			38.4
8-5	.24	0	.03	38.4	- -	12.2	.031	23.2	0	17.5	8.2	2.5	2	1			0
8-13	.24	0	.22	42.9	3	11.8	.034	23.2	.07	17.5	8.4	3.5	16	0			11.3
8-20	.15	0	.08	38.2	3	10.6	.031	19.7	0	17.0	8.4		98	5			
8-26	.15	0	.05	44.8	- -	10.3	.024	16.7	.09			2.5	47	0			7.5
9-2	.15	.08	.01	41.0	0	10.3	- -	18.5	.03	- -	- -	4.0	16	0			39.9
9-11	.13	0	.02	36.7	12	11.4	.021	17.4	.05	12.0	8.0	4.0	1	0			11.3
9-18	.26	0	0	32.8	0	11.0	.027	13.9	.02	12.0	8.0	1.0	1	0			2.0
9-22	.24	0	.02	30.7	6	11.0	.024	12.3	0	11.0	8.1	3.5	0	19			7.5
9-30	.24	0	0	28.1	15	11.0	.023	11.6	0	8.0	8.0	6.5	0	16			2.0
10-9	.17	0	0	32.1	3	11.8		15.3		11.5	8.2		0				7.5
10-14	.20	0	.13	26.4	25	11.8	.034	14.1	.04	4.0	7.7	4.0	0	0			11.3
10-21	.10	0	0	27.5	0	8.8	.021	8.8	.01	6.0	- -	2.5	0	4			
10-28	.15	0	.01	28.8	0	12.2	.027	22.0	0	5.5	8.1	3.5	0	45			3.7

Appendix A. Continued

1986 Date	Ammonia	Nitrate	Phosphorus	Sulfate	Sulfide	Silica	Manganese	Chlorophyll	Copper	Temperature	pH	Actinomycetes	Anabaena	Asterionella	Iron	Dissolved oxygen	COD
								Raw Water									
4-30	- -	0	.13	- -	- -	- -	- -	- -	- -								
5-6	0	0	.09	14.9	0	13.0	.051	27.0	.02	6.0	7.2		3				
5-15	.18	0	.17	11.3	12	14.7	.054	31.3	.13	8.0	7.4	8.0	0				
5-20	.21	0	.05	9.2	0	15.2	.051	16.4	.02	12.0	7.2	22.5	4				
5-30	- -	.08	.10	- -	- -	- -	- -	- -	.11	9.0	- -	23.5	0				
6-4	.32	0	.10	3.4	0	12.1	.057	12.3	0	14.0	7.0	23.5	0	0			
6-12	.95	0	.09	12.0	0	14.3	.065	15.1	.01	11.0	7.0	45.0	1	0			
6-19	.47	0	.03	5.3	0	11.7	.047	19.3	0	14.0	7.1	15.0	0	3			
6-25	.45	0	.06	5.9	0	10.1	.044	31.3		14.0	7.0	21.0	1	2			
7-2	.26	0	.06	11.3	9	10.9	.047	33.6	.05	15.0	7.0	8.5	1	0			
7-9	.32	0	.07	7.9	0	11.3	.044	15.6	0	16.0	6.8	10.0	0	6			
7-16	.28	0	.09	15.9	0	12.1	.051	26.6	.07	17.0	8.0	2.5	0	6			
7-23	.26	0	.10	25.5	0	13.0	.037	20.3	.01	17.5	- -	5.0	1	0			
7-30	.21	0	.10	21.5	0	11.3	.027	13.9	.07	17.0	7.3	4.5	1	2			38.4
8-5	.17	0	.03	38.4	- -	11.8	.027	15.1	0	17.5	8.0	1.5	8	0			3.7
8-13	.21	0	.12	43.8	0	11.0	.027	22.0	.07	17.5	- -	0.5	14	0			11.3
8-20	.15	0	0	38.2	15	10.6	.034	18.5	.01	17.0	8.2	2.0	44	1			
8-26	0	0	.01	39.3	- -	14.3	.018	22.9	.05	- -	- -	- -	27	0			3.7.
9-2	.17	.05	0	38.4	0	10.3	- -	16.2	.01	- -	- -	5.5	12	0			33.5
9-11	.19	0	.09	35.2	9	11.0	.021	11.6	.04	12.0	- -	5.0	0	0			7.5
9-18	.20	0	0	30.0	12	11.4	.021	12.7	0	12.0	- -	3.0	2	0			3.7
9-22	.26	0	.08	29.4	0	10.6	.027	14.2	.04	11.0	8.3	2.0	0	11,23			- -
9-30	.28	0	.01	28.1	9	11.0	.021	13.7	.05	8.0		2.5	0	0			2.0
10-9	.19	0	.09	28.8	6	11.4	- -	7.4		9.0	7.9		0				0
10-14	.26	0	0	25.8	0	11.4	.024	10.9	.05	4.0		4.0	0	0			13
10-21	.22	0	0	27.3	0	11.4	.024	- -	0	6.0		3.0	0	0			0
10-28	.15	0	0	24.7	0	11.4	.021	6.5	0	5.5		2.0	0	7			

Appendix A. Continued

Raw Water

1986 Date	Ammonia	Nitrate	Phosphorus	Sulfate	Sulfide	Silica	Manganese	Chlorophyll	Copper	Temperature	pH	Actinomycetes	Anabaena	Asterionella	Iron	Dissolved oxygen	COD
4-30	- -	0	.13	- -	- -	- -	- -	- -	- -								
5-6	0	0	.09	14.9	0	13.0	.051	27.0	.02	6.0	7.2		3				
5-15	.18	0	.17	11.3	12	14.7	.054	31.3	.13	8.0	7.4	8.0	0				
5-20	.21	0	.05	9.2	0	15.2	.051	16.4	.02	12.0	7.2	22.5	4				
5-30	- -	.08	.10	- -	- -	- -	- -	- -	.11	9.0	- -	23.5	0				
6-4	.32	0	.10	3.4	0	12.1	.057	12.3	0	14.0	7.0	23.5	0	0			
6-12	.95	0	.09	12.0	0	14.3	.065	15.1	.01	11.0	7.0	45.0	1	0			
6-19	.47	0	.03	5.3	0	11.7	.047	19.3	0	14.0	7.1	15.0	0	3			
6-25	.45	0	.06	5.9	0	10.1	.044	31.3		14.0	7.0	21.0	1	2			
7-2	.26	0	.06	11.3	9	10.9	.047	33.6	.05	15.0	7.0	8.5	1	0			
7-9	.32	0	.07	7.9	0	11.3	.044	15.6	0	16.0	6.8	10.0	0	6			
7-16	.28	0	.09	15.9	0	12.1	.051	26.6	.07	17.0	8.0	2.5	0	6			
7-23	.26	0	.10	25.5	0	13.0	.037	20.3	.01	17.5	- -	5.0	1	0			
7-30	.21	0	.10	21.5	0	11.3	.027	13.9	.07	17.0	7.3	4.5	1	2			38.4
8-5	.17	0	.03	38.4	- -	11.8	.027	15.1	0	17.5	8.0	1.5	8	0			3.7
8-13	.21	0	.12	43.8	0	11.0	.027	22.0	.07	17.5	- -	0.5	14	0			11.3
8-20	.15	0	0	38.2	15	10.6	.034	18.5	.01	17.0	8.2	2.0	44	1			
8-26	0	0	.01	39.3	- -	14.3	.018	22.9	.05	- -	- -	- -	27	0			3.7.
9-2	.17	.05	0	38.4	0	10.3	- -	16.2	.01	- -	- -	5.5	12	0			33.5
9-11	.19	0	.09	35.2	9	11.0	.021	11.6	.04	12.0	- -	5.0	0	0			7.5
9-18	.20	0	0	30.0	12	11.4	.021	12.7	0	12.0	- -	3.0	2	0			3.7
9-22	.26	0	.08	29.4	0	10.6	.027	14.2	.04	11.0	8.3	2.0	0	11,23			- -
9-30	.28	0	.01	28.1	9	11.0	.021	13.7	.05	8.0		2.5	0	0			2.0
10-9	.19	0	.09	28.8	6	11.4	- -	7.4		9.0	7.9		0				0
10-14	.26	0	0	25.8	0	11.4	.024	10.9	.05	4.0		4.0	0	0			13
10-21	.22	0	0	27.3	0	11.4	.024	- -	0	6.0		3.0	0	0			0
10-28	.15	0	0	24.7	0	11.4	.021	6.5	0	5.5		2.0	0	7			

[a]Values given are in the following units: Ammonia mg/L; Nitrate mg/L; Phosphorus mg/L; Sulfate mg/L; Sulfide µg/L; Silica mg/L; Manganese mg/L; Chlorophyll µg/L; Copper µg/L; Temperature °C; pH Units; Actinomyectes cells/ml; Anabaena cells; Asterionella cells; Iron mg/L; Dissolved Oxygen mg/L; Chemical Oxygen Demand mg/L

Appendix B. Chemical Data Collected During 1987

Date	Site	Ammonia mg/L	Nitrate mg/L	Silica mg/L	Phosphorus mg/L	Sulfate mg/L	Sulfide µg/L
6-5-87	River	0.15	0	12.6	0.05	25.2	20
		0.17	0	11.8	0.07	23.6	29
		0.12	0	10.3	0.03	23.6	29
	Lake	0.15	0	9.2	0	18.6	26
		0.17	0	9.2	0	20.0	17
		0.18	0	8.8	0	19.3	20
	Raw	0.14	0	9.5	0.11	20.0	17
		0.15	0	10.6	0.09	20.5	20
		0.10	0	10.3	0.09	23.1	23
7-7-87	River	0.25	0.07	12.4	0.05	76.2	23
		0.32	0.04	11.6	0.03	76.2	14
		0.32	0.07	11.2	0.02	78.4	17
	Lake	0.36	0.14	12.8	0.09	78.4	32
		0.30	0.11	11.2	0.10	74.0	23
		0.53	0.07	12.4	0.03	78.4	38
	Raw	0.34	0.11	13.2	0.07	78.4	17
		0.36	0.11	11.6	0.02	78.4	17
		0.43	0.14	11.6	0.06	76.2	17
8-6-87	River	0.69	0.21	- -	0.07	78.4	29
	Lake	0.66	0.04	- -	0.04	64.6	29
	Raw	0.62	0.09	- -	0.02	64.6	26
8-11-87	River	0.69	0.11	- -	0	66.3	38
	Lake	0.60	0.07	- -	0.13	62.9	29
	Raw	0.62	0.24	- -	0.02	62.9	45
8-13-87	River	0.60	0.09	- -	0	70.0	29
	Lake	0.60	0.07	8.1	0	70.0	41
	Raw	0.53	0.09	- -	0.05	64.6	29

Appendix C. Data Collected at the Water Plant in 1987

Date	Raw Alka-linity	Flow mgd	Raw Temp	Raw pH	Nit-rate	Phos-phorus	Ana-baena	Aster-ionella	Total Algal Count	Ammonia	Chloro-phyll	Manganese
5-1		3.0	10.5	7.1								
5-2		3.0	10.5	6.9								
5-3		3.0	11.0	7.2								
5-4		3.0	10.0	8.0								
5-5		3.0	10.0	8.3								
5-6	93	3.0	9.5	8.2								
5-7	90	3.0	10.0	8.2								
5-8	81	3.0	9.5	8.0								
5-9	90	3.0	9.5	8.0								
5-10	92	3.0	9.8	8.0								
5-11	90	3.0	11.0	8.1								
5-12	58	3.0	11.0	7.5								
5-13	60	3.0	11.5	7.6								
5-14	61	3.0	12.0	7.8			0	0	71		44.4	.040
5-15	61	3.0	11.5	7.6	.04	.13	0	0	77		39.2	.057
5-16	59	3.0	13.1	7.7	.00	.05	0	0	34		44.0	.125
5-17	61	3.0	12.0	7.6	.02	.04	0	1	20		--	--
5-18	61	3.0	12.5	7.4	.04	.04	0	0	34		35.6	--
5-19	59	3.0	12.2	7.6	.00	.04	0	2	22		36.7	.083
5-20	61	3.0	11.5	7.5	.09	.39	0	1	23		36.7	.079
5-21	58	3.0	11.0	7.8	.00	.02	0	1	18		33.6	.040
5-22	56	1.6	10.8	7.3	.04	.11	0	1	25		28.0	.057
5-23	58	1.8	9.0	7.4	.09	.13	0	1	24		44.0	.031
5-24	56	1.8	10.0	7.6	.09	.11	0	2	28		36.7	.028
5-25	56	1.8	10.0	7.5	.02	.05	0	1	32		30.4	.060
5-26	52	1.8	10.0	7.3	.09	.09	0	3	19		28.0	.047
5-27	68	1.8	10.5	7.6	.04	.05	0	0	19		25.6	.034
5-28	68	1.8	10.0	7.7	.00	.02	0	1	19		17.2	.034
5-29	54	1.8	10.0	7.7	.00	.04	0	0	24		21.6	.034
5-30	63	1.8	10.5	7.7	.04	.02	0	0	15		17.2	.034
5-31	61	1.8	10.5	7.6	.02	.02	0	0	11		36.8	.065
6-1	68	1.8	12.0	7.3	.04	.04	0	0	4		32.0	.044
6-2	66	3.0	12.0	7.9	.00	.18	0	0	31		62.3	.138
6-3	68	3.0	12.0	8.0	.00	.09	0	0	35		32.0	.072
6-4	68	3.0	12.0	7.8	.00	.03	0	1	38		25.6	.024
6-5	68	3.0	12.0	7.8	.00	.08	0	0	30		38.4	.034
6-6	66	3.8	12.5	7.8	.00	.03	0	0	41		36.8	.021

Appendix C. Continued

Date	Raw Alka-linity	Flow mgd	Raw Temp	Raw pH	Nit-rate	Phos-phorus	Ana-baena	Aster-ionella	Total Algal Count	Ammonia	Chloro-phyll	Manganese
6-7	68	3.8	13.5	7.8	.00	.03	0	0	33		29.6	.015
6-8	--	3.8	14.2	7.6	.00	.09	0	0	30		40.0	.024
6-9	68	3.8	13.2	7.7	.00	.03	1	0	29		32.0	.031
6-10	68	3.8	14.0	7.8	.00	.04	1	0	31		40.8	.021
6-11	73	3.8	14.5	8.1	.04	.05	0	0	17		27.2	.015
6-12	78	3.8	16.0	7.9	.00	.02	0	0	13		24.8	.024
6-13	81	3.8	15.5	7.9	.00	.04	2	0	15		28.0	.009
6-14	78	3.8	16.0	7.9	.00	.02	1	0	11		24.0	.021
6-15	73	3.8	15.5	7.9	.00	.02	3	0	16		28.0	.027
6-16	78	3.8	15.2	7.8	.00	.03	0	1	11		32.8	.024
6-17	90	3.8	16.2	8.0	.04	.05	0	0	12		20.8	.015
6-18	95	3.8	16.2	8.1	.00	.02	0	0	12		44.8	.015
6-19	90	3.8	16.2	8.1	.00	.03	0	0	12		24.8	.015
6-20	90	3.8	15.5	8.0	.00	.02	0	0	10		32.0	.024
6-21	90	3.8	15.2	8.1	.04	.03	0	0	13		27.2	.021
6-22	105	3.8	15.2	7.8	.09	.03	0	7	24		20.0	.024
6-23	107	3.8	15.8	8.1	.00	.03	2	16	45		12.0	.040
6-24	110	3.8	16.0	7.9	.00	.05	0	6	18		14.4	.015
6-25	110	3.8	16.2	8.1	.08	.03	0	5	15		16.0	--
6-26	107	3.8	16.0	8.1	.02	.02	0	6	32		16.8	.091
6-27	110	3.8	16.0	8.0	.06	.00	1	3	35		16.0	.015
6-28	110	3.8	16.0	8.0	,04	,02	0	2	38		15.2	.015
6-29	107	3.8	16.0	8.1	.09	.03	1	4	47		16.0	.015
6-30	110	3.8	16.0	8.0	.09	.07	0	2	33		15.2	.034
8-1	116	3.8	19.0	8.4	.04	.02	16	0	25		28.0	.037
8-2	112	3.8	19.0	8.3	.04	.02	12	0	18		29.6	.051
8-3	114	3.8	19.5	8.4	.06	.03	15	0	25		28.8	.076
8-4	112	3.8	19.5	8.4	.03	.03	10	0	16		36.8	.040
8-5	124	3.8	19.0	8.4	.11	.00	19	0	25	.49	25.6	.027
8-6	124	3.8	18.5	8.4	.14	.02	15	0	24	.34	20.8	.003
8-7	122	3.8	18.5	8.4	.03	.00	4	0	15	.29	14.4	.006
8-8	120	3.8	18.0	8.4	.06	.03	3	0	11	.34	17.6	.040
8-9	122	3.8	18.0	8.3	.04	.02	4	0	12	.34	18.4	.040
8-10	120	3.8	18.5	8.4	.03	.00	5	0	10	.36	21.6	.018
8-11	120	3.8	19.0	8.3	.11	.04	1	0	15	.83	20.8	.040
8-12	120	3.8	18.0	8.3	.04	.05	0	0	11	.41	14.4	.021
8-13	120	3.8	17.5	8.4	.16	.02	0	0	6	.45	19.2	.012
8-14	118	3.8	17.0	8.2	.14	.03	0	0	3	.30	16.0	.044

Appendix C. Continued

Date	Raw Alkalinity	Flow mgd	Raw Temp	Raw pH	Nitrate	Phosphorus	Anabaena	Asterionella	Total Algal Count	Ammonia	Chlorophyll	Manganese
8-15	120	3.8	17.0	8.3	.16	--	3	0	6	.39	16.0	.065
8-16	120	3.8	16.5	8.3	.16	--	0	1	11	.41	22.4	.083
8-17	122	3.8	16.0	8.2	.02	--	2	0	15	.23	21.6	.065
8-18	120	3.8	15.5	8.2	.14	--	0	0	11	.15	20.0	0.37
8-19	114	3.8	15.5	8.2	.21	--	1	0	16	.98	17.6	.051
8-20	116	3.8	15.5	8.2	.26	--	1	2	17	.45	17.6	.044
8-21	112	3.8	16.0	8.2	.16	--	0	0	5	.22	18.4	.024
8-22	114	3.8	16.0	8.2	.14	--	0	1	12	.41	20.0	.065
8-23	114	3.8	16.0	8.2	.14	--	0	0	15	.45	44.0	.095
8-24	120	3.8	16.0	8.2	.16	--	1	1	4	.30	17.6	.051
8-25	110	3.8	15.8	8.3	.19	.04	0	0	13	1.15	20.8	.091
8-26	110	1.6	15.5	8.1	.21	.00	0	0	4	.51	12.0	.047
8-27	114	3.6	15.0	8.2	.21	.00	2	0	13	.47	14.4	.079
8-28	116	3.5	14.8	8.2	.19	.00	0	1	9	.45	41.6	.072
8-29	112	3.5	14.0	8.1	.21	.05	3	0	6	.41	44.0	.061
8-30	114	3.5	14.0	8.2	.19	.04	1	1	8	.45	43.2	.129
8-31	120	3.5	14.5	8.2	.21	.02	0	0	5	.51	21.6	
9-1	120	3.5	14.5	8.2	.21	.02	0	0	7	.45	32.0	
9-2	120	3.5	14.5	8.2	.16	.00	0	0	18	.51	38.4	
9-3	114	3.5	15.0	7.2	.16	.03	0	0	3	.49	18.4	
9-4	116	3.5	15.0	8.1	.21	.03	0	0	5	.45	--	
9-5	--	3.5	--	--	--	--	--	--	--	--	--	
9-6	--	3.5	--	--	--	--	--	--	--	--	--	
9-7	--	3.5	--	--	--	--	--	--	--	--	--	
9-8	116	3.5	14.0	8.3	.09	.04	0	0	8	.22	16.0	
9-9	116	3.5	14.0	8.3	.09	.02	0	0	12	.22	21.6	
9-10	120	3.5	14.0	8.3	.14	.03	0	0	7	.29	16.8	
9-11	120	3.5	14.0	8.3	.14	.03	0	0	9	.22	--	
9-12	120	3.5	14.0	8.3	.21	.02	0	0	10	.29	16.0	
9-13	120	3.5	14.0	8.3	.14	.02	0	0	3	.22	14.4	
9-14	120	3.5	14.0	8.3	.09	.00	0	0	8	.20	41.6	
9-15	120	3.5	13.0	8.3	.09	.03	0	0	7	.25	40.0	
9-16	120	3.5	13.1	8.3	.09	.02	0	0	10	.18	37.6	
9-17	120	3.5	13.0	8.3	.11	.00	0	0	2	.25	44.8	
9-18	120	3.5	12.0	8.3	.14	.02	0	0	4	.15	41.6	
9-19	120	3.5	12.0	8.3	.21	.02	0	0	1	.25	47.2	
9-20	120	3.5	12.0	8.3	.14	.00	0	0	2	.18	29.6	

Appendix C. Continued

Date	Raw Alka-linity	Flow mgd	Raw Temp	Raw pH	Nit-rate	Phos-phorus	Ana-baena	Aster-ionella	Total Algal Count	Ammonia	Chloro-phyll	Manganese
9-21	110	3.5	11.0	8.2	.07	.02	0	0	4	.55	27.2	
9-22	104	3.5	11.0	8.3	.19	.05	0	0	5	.69	24.8	
9-23	100	3.5	11.0	8.2	.21	.00	0	0	3	.69	21.6	
9-24	106	2.2	11.0	8.2	.30	.00	0	0	2	.29	20.0	
9-25	110	2.2	11.0	8.2	.16	.07	0	0	6	.24	40.8	
9-26	108	2.2	11.0	8.3	.11	.04	0	0	4	.19	33.6	
9-27	112	2.2	11.0	8.2	.04	.00	0	0	1	.37	20.8	
9-28	110	3.5	11.0	8.1	.07	.03	3	0	7	.18	17.6	
9-29	110	3.5	11.0	8.2	.11	.00	0	0	4	.19	24.2	

Alkalinity in mg/L
Temperature in ^{o}C
Nitrate mg/L
Phosphorus mg/L
Anabaena, Asterionella and Total Algal Count - 100 mls of water was filtered on a 0.45 micrometer pore size Millipore filter, a cross diameter count was done. Number of cells counted are reported.
Ammonia mg/L
Chlorophyll µg/L
manganese mg/L

Appendix D. Manganese Data for July 1987 in the Raw Water

Date	Manganese mg/L	Date	Manganese mg/L	Date	Manganese mg/L	Date	Manganese mg/L
7-1	.051	7-9	.021	7-17	.037	7-25	.024
7-2	.034	7-10	.057	7-18	.021	7-26	.009
7-3	.051	7-11	.057	7-19	.040	7-27	.061
7-4	.024	7-12	.034	7-20	.044	7-28	.044
7-5	.068	7-13	.054	7-21	.065	7-29	.047
7-6	.034	7-14	.095	7-22	.057	7-30	.015
7-7	- -	7-15	.044	7-23	- -	7-31	.031
7-8	.009	7-16	.116	7-24	.034		

Appendix E. Raw Data for River Samples

Ammonia mg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	.10	0	0	0	0	0	0
5/30	.29	.32	.16	.25	.17	.23	.19
8/5	.21	.19	.22	.22	.32	.32	.24
8/13	.34	.19	.21	.21	.19	.21	.22
10/9	.15	.19	.19	.28	.28	.21	.21

Chlorophyll µg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	14.1	9.7	6.0	13.4	39.8	36.1	37.1
5/30	4.4	3.7	3.0	4.6	2.8	5.6	23.5
8/5	13.3	18.5	17.9	12.7	9.3	21.4	11.6
8/13	6.9	6.9	9.8	8.7	5.8	9.8	31.3
10/9	4.1	16.2	3.0	9.5	6.0	4.4	6.5

Phosphorus mg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	.13	.48	.08	.09	.15	.11	.11
5/30	.09	.05	.03	.03	.07	.11	.18
8/5	.04	.03	.03	.02	.04	.04	.03
8/13	.21	.29	.27	.18	.15	.24	.27
10/9	.20	.24	.13	.20	.20	.20	.13

Sulfate mg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	0	0	0	0	6.5	12.7	12.7
5/30	0	0	0	0	4.0	5.9	6.6
8/5	3.3	1.6	1.6	4.9	22.0	47.8	56.7
8/13	1.6	0	0	10.0	22.5	47.8	42.9
10/9	3.3	4.9	1.6	1.6	17.9	27.0	25.2

Appendix E. Continued

Silica mg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	9.4	8.3	9.0	8.7	12.5	12.5	13.8
5/30	10.9	12.4	9.8	10.0	11.1	12.1	13.0
8/5	10.3	10.6	6.5	11.0	12.6	11.8	12.6
8/13	9.9	10.6	5.5	12.6	13.5	12.2	11.4
10/9	11.0	.13.0	8.1	9.9	11.8	12.6	.12.6

Manganese mg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	.031	.031	.021	.034	.057	.054	.065
5/30	.034	.033	.023	.039	.033	.057	.068
8/5	.021	.021	.009	.034	.024	.027	.024
8/13	.024	.024	.012	.037	.024	.031	.024

Temp °C

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
8/5	7.0	9.0	9.5	13.0	15.5	18.0	17.0
8/13	9.0	9.5	10.5	14.5	13.5	18.0	17.0
10/9	3.5	4.5	4.0	6.0	8.0	10.0	10.0

pH

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	7.0	7.0	7.0	6.8	6.7	6.8	6.6
5/30	7.2	7.2	7.0	7.1	7.1	7.0	6.9
8/5	7.9	7.7	7.9	7.8	8.2	8.2	8.3
8/13	8.2	7.7	8.3	7.9	8.4	8.5	8.6
10/9	8.1	8.1	8.0	7.7	8.0	7.8	8.0

Appendix E. Continued

Nitrate mg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	0	.10	0	0	.29	0	0
5/30	0	0	0	.03	0	0	0
8/5	.03	0	.05	0	0	0	0
8/13	0	0	0	0	0	0	0
10/9	0	0	.05	0	0	0	0

Sulfide µg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
4/30	6	3	0	0	0	0	6
5/30	3	6	3	1.5	3	1.5	3
8/13	0	0	3	0	0	0	3
10/9	6	6	0	0	0	0	0

Chemical Oxygen Demand mg/L

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
8/5	3.7	0	0	0	0	3.7	0
8/13	11.3	0	11.3	11.3	11.3	11.3	11.3
10/9	3.7	7.5	0	7.5	16	3.7	1.0

Actinomycetes cells/ml

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
5/30	27.0	12.0	10.0	24.5	32.5	43.0	27.0
8/5	1.0	1.5	0.0	2.0	1.5	0.0	0.0
8/13	0.0	1.0	1.0	1.5	3.5	2.5	1.0

Anabaena per 100 mls., cross diameter count

Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
5/30	2						
8/5	0	0	0	1 small	0	2 small	0
8/13	0	0	0	0	0	0	0
10/9	0	0	0	0	0	0	0

Appendix E. Continued

	Asterionella per 100 mls, cross diameter count						
Date	Several miles from Chambers lake	Bridge 1	Tunnel	Picnic area	Hohnholtz Lake	2nd Fishing area	Woods Landing
8/5	0	0	150	0	0	0	0
8/13	0	0	3	0	0	0	0
10/9	0	0	0	0	0	0	0

Mileage up river of the sampling sites

Woods Landing	0
Second Fishing Area	2.3
Hohnholtz Lake	14.2
Picnic Area	26.2
Tunnel	35.1
Bridge	35.8
Several miles from Chambers Lake	37.9

Appendix F. Raw Data for Perimeter of Lake

Date	Chlorophyll µg/L	Temperature °C	pH	Dissolved Oxygen mg/L	Chemical Oxygen Demand mg/L	Ammonia mg/L	Nitrate mg/L	Phosphorus mg/L	Sulfate mg/L	Sulfide µg/L	Silica mg/L	Manganese mg/L	Anabaena cells	Asterionella cells	Copper µg/L	Secchi disc feet
North - 3 meters from surface																
8-7	11.0												14	3		
8-14	26.6	16.0	8.3			.15	0.0	.19	43.8	9.0	11.4	.034	2	2	0.05	
8-18	7.5	17.0	8.2		18.7	.15	0.0	.00	43.8	6.0	11.8	.027	5	1	0.07	
8-26	22.2	16.5	8.1			.10	0.0	.24	39.2		10.6	.034	36	0	.10	7
Northeast - 2 meters from surface																
8-11	9.3	17.5	8.2	4.9									20	0		9
8-26	22.2	16.5	8.3			.12	0.0	.21	42.9		11.0	.031	42	0	.07	
9-2	15.6	15.5	8.2			.15	0.0	.00	41.0		10.6		19			8
Northeast - 3 meters from surface																
8-11	22	17.5	8.2	5.2									18	3		9
8-18	22	17.0	8.3		44.4	.10	0.0	.37	40.1	0.0	11.4	.047	38	0	0.00	8.5
8-26	20.8	16.5	8.3			.12	0.0	.29	37.8		10.3	.037	45	0	0.09	8
9.2	26.6	15.5	8.2			.12	0.0	0.0	41.0		11.0		24			8
Outlet - 3 meters from surface																
8-14	41.7	16.0	8.2			.13	0.0	.24	45.8	3.0	11.0	.037	11	2	0.01	
8-18	18.5	17.0	8.2		11.3	.15	0.0	.00	41.9	9.0	11.8	.031	37	0	0.03	7
8-26	27.8	16.5	8.2			.15	0.0	.27	37.6		10.6	.021	45	1	0.07	7
Inlet - 3 meters from surface																
8-11	20.8	17.0	8.1	4.9									5	6		9
8-14	23.2	15.0	8.2			.17	0.0	.34	41.9	9.0	11.8	.034	22	15	.01	7
8-18	26.6	17.0	8.1		18.7	.13	0.0	.00	41.9	3.0	11.0	.040	14	1	.03	9
8-26	15.3	16.0	8.1			.12	0.0	.21	40.1	10.3	- -	.034	38	0	.07	7
Southmiddle - 3 meters from surface																
8-14	22	16.0	8.2			.15	0.00	.22	42.9	6.0	11.8	.037	18	0	.01	6
8-26	27.8	16.0	8.2			.10	0.13	.18	40.1	10.3		.037	48	0	.01	7

Appendix F. Continued

Date	Chloro-phyll µg/L	Temper-ature °C	pH	Chemical Dissolved Oxygen mg/L	Oxygen Demand mg/L	Ammo-nia mg/L	Nitrate mg/L	Phos-phorus mg/L	Sul-fate mg/L	Sul-fide µg/L	Silica mg/L	Man-ganese mg/L	Ana-baena cells	Asteri-onella cells	Copper µg/L	Secchi-disc feet
Southwest corner - 2 meters from surface																
8-11	8.1	17.0	8.1	5.8									9	2		8
8-14	22.0	16.0	8.3			.17	0.00	.09	41.0	3.0	11.0	.031	10	4	.10	
8-26	36.1	16.0	8.2			.13	0.00	.15	39.3		10.6	.031	45	0	.05	
9-2	17.4	15.5	8.2			.20	0.03	.00	40.1		10.6		27			8
Southwest corner - 3 meters from surface																
8-11	17.9	16.5	8.0	6.0									5	7		8
8-14	75.3	16.0	8.2			.00	0.00	0.61	45.8	0	11.4	.083	11	0	.43	7
8-26	44.0	16.0	8.0			.32	0.00	1.21	42.9		10.3	.060	30	0	.09	6
9-2	12.7	15.5	8.1			.15	0.05	.00	41.9		10.6		33			8
Southeast - 3 meters from surface																
8-14	12.7	16.0	8.1			.13	0.00	.24	41.9	6.0	12.6	.040	20	9	.03	7.5
8-18	17.4	17.0	8.1		11.3	.15	0.00	.00	42.9	3.0	11.4	.027	27	0		9
8-18	31.8	17.0	8.1		11.3	.08	0.00	.00	42.9	12.0	10.8	.031	10	1		9
8-26	21.5	16.0	8.1			.12	0.05	.19	39.3	10.6		.031	38	0		7
Middle East - 3 meters from surface																
8-14	9.8	16.0	8.1			.15	0.00	.19	40.1	0	11.4	.040	20	4	.01	
8-18	20.3	17.0	8.1		11.3	.17	0.00	.00	41.0	3.0	10.6	.037	47	3		9
8-26	23.6	16.5	8.1			.10	0.05	.19	38.4	- -	10.3	.027	59	0	0.3	7

Appendix H. Formulations of Algal Media

Compound Micromoles per liter	Medium C Kratz and Myers	ASM-1 medium
$NaNO_3$	- -	2000
KNO_3	10,000	- -
NaCl	- -	- -
$MgCl_2$	- -	200
$MgSO_4.7H_2O$	1000	200
$CaCl_2$	- -	200
$Ca(NO_3)_2.4H_2O$	105	- -
K_2HPO_4	5750	100
Na_2HPO_4	- -	100
$FeCl_3$	- -	4
$Fe_2(SO_4)_3.6H_2O$	15.4	- -
Fe EDTA	- -	- -
Na_2 EDTA	—	20
Na citrate.$2H_2O$	1700	- -
H_3BO_3	46	40
$MnCl_2.4H_2O$	11	7
MnSO4.$4H_2O$	- -	- -
MoO_3	0.123	- -
$ZnCl_2$	- -	3.2
$ZnSO_4.7H_2O$	0.77	- -
$CuSO_4.5H_2O$	0.32	- -
$CuCl_2$	- -	0.0008
$CoCl_2$	- -	0.08

Ingredient	Amounts (g/L) in medium BG-11	MN	ASN-III
NaCl	- -	- -	25.0
$MgCl_2.6H_2O$	- -	- -	2.0
KCl	- -	- -	0.5
$NaNO_3$	1.5	0.75	0.75
$K_2HPO_4.3H_2O$	0.04	0.02	0.02
$MgSO_4.7H_2O$	0.075	0.038	3.5
$CaCl_2.2H_2O$	0.036	0.018	0.5
Citric acid	0.006	0.003	0.003
Ferric ammonium citrate	0.006	0.003	0.003
EDTA (disodium magnesium salt)	0.001	0.0005	0.0005
Na_2CO_3	0.02	0.02	0.02
Trace metal mix A5 + Co*	1 ml l^{-1}	1 ml l^{-1}	1 ml l^{-1}
Sea water	- -	750 ml	- -
Deonized Water	1000 ml	250 ml	1000 ml
pH after autoclaving and cooling	7.4	8.3	7.5

*Trace metal mix A5+Co contains (g/L): H_3BO_3, 2.86; $MnCl_2.4H_2O$, 1.81; $ZnSO_4.7H_2O$, 0.222; $Na_2MoO_4.2H_2O$, 0.390; $CuSO_4.5H_2O$, 0.079; $Co(NO_3)_2.6H_2O$, 0.0494.

Appendix G. Raw data for samples from the middle of the lake.

Date	M_0[a]	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						pH					
7/23		7.9	7.9	7.9	7.9	7.5	7.3	7.0	7.0	6.8	
7/30		8.0	8.1	7.9	8.0	8.0	7.9	7.9	7.6	7.5	
8/7	8.2	8.2	8.2	8.2	8.2	8.1	8.1	8.0	8.0	7.9	7.8
8/11	8.2	8.2	8.2	8.1	8.1	8.1	8.2	8.2			
8/18	8.2	8.1	8.1	8.1	8.1	8.1	8.1	7.9	7.9.	7.8	
8/26			8.1	8.1				8.0	8.0		
9/2			8.2	8.2					8.0	8.0	
9/15		8.1	8.2	8.0	8.2	8.2	8.2	8.2	8.2	8.1	
9/23		7.9	7.9	7.9	7.9	7.9	7.9	8.0	7.9	7.9	
10/21		7.8	7.8	7.8	7.8	7.9	7.9	8.0	8.2		

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Temp °C					
7/23											
7/30		17	17	17	16.5	16.5	16	16	16	15	
8/7	20	20	19	18.5	18.5	19	19	18	18	18	18.5
8/11	16.5	16.5	16.5	16.5	16	16	16	16			
8/18	17	17	17	17	17	16.5	16.5	16	16.5	16	
8/26			16	16				16.5	16		
9/2			15.5	15.5					15.5	14.5	
9/15		13	13	13	13	13	13	13	12.5	12.5	
9/23		12	12	12	12	12	12	12	12	11.5	
10/21		6	6	6	6	6	6	6	6		

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Sulfide µg/L					
7/23											
7/30	3	6	0	6	0	0	0	0	0	9	
8/7	0	6	6	3	0	6	0	9	3	3	0
8/11	0	9	0	3	0	0	3	0			
8/18	3	3	3	6	0	3	0	6	0	0	
8/26											
9/2			0	6					3	0	
9/15		0	0	0	0	0	0	0	3	0	
9/23		6	9	6	3	6	12	3	18	0	
10/21		6	0	3	0	6	0	0	0		

[a] M stands for meter and subscript refers to depth from the surface.

Appendix G. Continued

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Sulfate mg/L					
7/23											
7/30	29.3	31.8	29.3	29.3	30.1	27.0	27.8	28.6	31.0	34.4	
8/7	41.9	41.0	34.4	36.7	38.4	38.4	37.6	37.6	38.4	40.1	40.1
8/11	42.9	38.4	43.8	41.9	43.8	41.9	45.8	42.9			
8/18	39.3	42.9	42.9	40.1	41.0	43.8	42.9	45.8	39.3	42.9	
8/26			37.6	39.3				39.3	40.1		
9/2			41.0	40.1					39.3	42.9	
9/15		32.9		33.6	35.2	32.9	32.1	34.4	29.4	32.9	
9/23		31.4	32.9	31.4	28.8	32.9	31.4	30.0	27.5	35.2	
10/21		28.1	28.8	29.4	30.7	28.1	28.1	31.4	30.0		

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Phosphorus mg/L					
7/23											
7/30	.27	.31	.26	.16	.14	.09	.32	.29	.32	.64	
8/7	.12	.11	.09	.08	.04	.04	.16	.15	.21	.23	.26
8/11	.05	.21	.13	.19	.16	.22	.22	.06			
8/18	.19	.13	.08	.12	.11	.21	.27	.13	.12	.47	
8/26			.16	.19				.32	.24		
9/2			.00	.00					.00	.00	
9/15		.00	.00	.00	.00	.00	.00	.00	.00	.32	
9/23		.18	.21	.24	.29	.16	.19	.21	.19	.26	
10/21		.00	.00	.01	.16	.00	.00	.00	.04		

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Copper mg/L					
7/23											
7/30	.10										
8/7	.03	.01	.01	.03	.03	.00	.01	.00	.00	.00	.00
8/11	.05	.03	.03	.05	.07	.05	.09	.36			
8/18	.14		.05	.07	.07	.07	.03	.07	.09	.03	
8/26			.07	.03				.07	.07		
9/2											
9/15											
9/23		.02	..04	.00	.04	.07	.00	.02	.05	.30	
10/21		.01	.04	.02	.04	.02	.02	.04	.13		

Appendix G. Continued

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Manganese mg/L					
7/23											
7/30	.034	.037	.034	.034	.040	.040	.037	.044	.095	.296	
8/7	.037	.034	.037	.031	.037	.031	.037	.044	.076	.116	.219
8/11	.027	.027	.031	.031	.031	.034	.037	.120			
8/18	.027	.027	.034	.031	.031	.031	.044	.040	.051	.134	
8/26			.213	.031				.047	.076		
9/2				.006						.021	
9/15		.018		.021	.021	.021	.024	.018	.021	.087	
9/23		.027	.027	.024	.027	.027	.027	.024	.031		
10/21		.024	.021	.021	.021	.024	.029	.032	.083		

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Silica mg/L					
7/23											
7/30	11.7	13.0	12.5	12.5	12.5	12.5	12.5	12.1	13.0	14.7	
8/7	12.2	12.2	12.2	12.6	12.2	12.2	12.2	12.2	12.2	12.6	13.9
8/11	12.2	11.8	13.0	13.0	13.0	12.2	11.8	11.8			
8/18	11.4	11.0	11.4	11.0	12.2	12.2	11.8	11.4	12.2	12.6	
8/26			11.0	11.0				11.8	12.2		
9/2			11.0	10.6					11.0	11.4	
9/15		10.3	10.3	11.4	11.4	10.3	10.6	9.9	10.6	11.0	
9/23		9.9	10.3	9.9	9.9	11.0	10.3	10.3	11.4	12.2	
10/21		12.6	11.8	11.8	11.6	12.2	12.4	12.6	12.6		

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Anabaena cells					
7/23		2	4	3	5	0	1	0	- -	- -	
7/30	8	9	3	3	2	4	4	0	0	- -	
8/7	8	6	4	7	5	2	2	0	3	0	1
8/11	18	20	30	12	4	6	5	0			
8/18	21	26	35	30	27	28	19	12	6	0	
8/26			50	44				24	26		
9/2			26	23					18	27	
9/15		0	1	0	0	0	0	0	1	0	
9/23		0	1	0	0	1	0	3	0	0	
10/21		0	0	0	0	0	0	0	0		

Appendix G. Continued

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Ammonia mg/L					
7/23											
7/30	.24	.21	.21	.19	.19	.19	.22	.22	.22	.19	
8/7	.17	.19	.19	.21	.21	.17	.21	.19	.19	.24	.19
8/11	.22	.22	.21	.21	.19	.28	.21	.21			
8/18	.17	.22	.15	.17	.17	.15	.15	.13	.17		
8/26			.12	.17				.30	.26		
9/2			.13	.13					.17	.21	
9/15		.17	.34	.15	.19	.15	.17	.13	.19	.13	
9/23		.13	.15	.12	.15	.13	.12	.15	.17	.08	
10/21		.12	.12.	.15	.13	.12	.13	.10	.10		

Date	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
						Chlorophyll µg/L					
7/23		24.3	28.4	20.8	24.3	28.9	26.6	28.9	54.4	34.7	
7/30	23.7	24.9	24.9	24.9	24.9	23.2	25.5	27.8	24.9	67.7	
8/7	5.8	3.5	5.8	8.1	5.2	2.9	10.4	2.3	4.6	10.4	19.1
8/11	12.7	19.7	22.0	6.9	22.0	3.5	19.7	60.2			
8/18	13.9	8.1	9.3	6.9	9.3	9.8	8.1	17.9	8.1	64.8	
8/26			27.8	26.4				18.8	18.1		
9/2			16.2	20.8					9.3	15.6	
9/15		13.9	13.2	11.3	11.3	9.3	10.8	10.9	13.8	17.3	
9/23		22.6	12.0	9.0	9.6	13.2	12.5	11.2	16.4	15.2	
10/21		8.8	8.5	17.4	8.3	8.2	7.6	7.8	15.1		