INTERNAL REPORT 30

GEOCHEMICAL EQUILIBRIA AND PRIMARY PRODUCTIVITY IN NATURAL LAKES

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ABSTRACT

The objectives for year 1 have been the gathering of existing information, initiation of monitoring water quality, evaluation of analytical methods and procedures for measuring nutrient regeneration in the sediment-water interface, and the study of growth-environment correlations in Findlay Lake, Chester Morse Reservoir, and Lakes Sammamish and Washington. Progress was made in all phases. An annual budget of total chemical elements entering and leaving Lake Sammamish should be largely completed during 1971. Preliminary data indicate that 3 years after the major portion of phosphorus was diverted from Lake Sammamish, the chemical and biological characters are showing only slight and probably insignificant changes compared to what has been observed in Lake Washington. The chemical and biological characteristics of the lakes reveal a graded sequence in chemical composition and productivity. A 4- to 20-fold increase in concentration is observed with most chemical and biological parameters when Findley and Chester Morse Lakes are compared to Lake Washington. Phytoplankton productivity (carbon assimilation rate) and total biomass (chlorophyll) show a progressive increase from Findley Lake (extreme oligotrophy) to Lake Washington (moderate eutrophy). Based on particle size distribution and carbon: nitrogen rations in surface sediments, the sediments of Findley and Chester Morse Lakes appear to be different from those of Lakes Sammamish and Washington. Higher ratios of carbon to nitrogen and coarser sediments are observed in the upper Cedar River drainage lakes.

To accomplish the overall objective of the full course of the study--that is, to measure the cycle of chemical elements in fresh water lakes as a means of evaluating the contribution of a given element to the biologic productivity in lake water--a series of critical objectives have been chosen for focus of study in the initial phases. Thus, the main objectives of the study in year 1, the development of procedures for measuring exchange rates of minerals between lake sediments and water, were expanded to include the gathering of existing information, initiation of monitoring lake water quality, and the study of growth-environment correlations in Findley Lake, Chester Morse Reservoir, and Lakes Sammamish and Washington.

After a detailed mapping of the Lake Sammamish basin, monthly monitoring of the chemical and biological quality of the lake water was initiated by sampling station and inflow and outflow early in the fall of 1970. Later in the spring of 1971, Findley and Chester Morse Lakes, as well as Lake Washington, were included in the study. The Lake

Washington study was related to the characterization of sediments and the measurements of water quality parameters other than those monitored by Dr. Edmondson's group under other funding.

An annual budget of total chemical elements entering and leaving Lake Sammamish should be largely completed during 1971. Biological response to nutrient diversion has been studied during 1970 and 1971 and, although the results are incomplete, some have been compared with a 1965-1965 prediversion study by the Municipality of Metropolitan Seattle. Comparisons include surface water content of total P, No_3-N, chlorophyll a, and primary productivity, as well as water clarity measured with a Secchi disk. The results of sewage diversion from Lake Sammamish, when compared to those observed in Lake Washington after sewage diversion during 1963-1967, are difficult to interpret. Winter maximum concentration of P in Lake Washington declined by 71 percent from 1962 to 1969. Little change in surface P content is apparent in Lake Sammamish after diversion. Phosphorus content increases to 70-100 μg per liter following turnover in November, but instead of remaining high all winter as it does in Lake Washington, the content in Sammamish decreases to around 20 μg per liter within a month or two. Although more than 500 μg per liter of NO_3-N is removed during the spring outburst of diatoms in Lake Sammamish, P is reduced by only about 10-15 μg per liter. This removal rate of N/P seems weighted heavily to N and suggests the the P turnover rate is much greater than that for N. Thus, P in Lake Sammamish behaves differently than in Lake Washington, particularly during winter, which suggests that in view of the similar reduction in P income in both lakes, interactions with P may be present in Lake Sammamish that are less significant in Lake Washington. Such interactions may be the shallower mean depth of Sammamish (17.7 compared to 34m) or the greater percentage of surface area that is shallower than the thermocline in Sammamish. These factors could suggest a greater interaction of sediments with water in controlling P concentrations in Lake Sammamish. Biological changes in Sammamish are equally as unimpressive as are changes in nutrient content. This is in great contrast to observations in Lake Washington. Maximum Secchi disk depth, an index of the suspended matter, has increased in Sammamish from 5 to over 6 meters from 1965 to 1970. Maximum chlorophyll a content decreased progressively in Lake Washington following diversion, however, and was correlated with the decrease in maximum P content. Thus, three years after the major portion of P was diverted from Lake Sammamish, the chemical and biological characteristics are showing only slight and probably insignificant changes compared to what has been observed in neighboring Lake Washington.

The survey of chemical characteristics of waters in the Lake Washington drainage reveals a graded sequence in chemical composition from the upper Cedar River basin to Lake Washington. Tables 1 and 2 show the mean summer average concentrations of several chemical constituents in surface waters of selected lakes and streams of Lake Washington drainage. Issaquah Creek, the main nutrient inflow to Lake Sammamish, carries about 85-90 percent of the chemical elements to the lake. Sammamish River is the only surface outflow of Lake Sammamish, which, together with Cedar River, is the major source of chemical elements for Lake Washington. A 4- to 10-fold increase in concentration is observed with most chemical parameters, when Findley and Chester Morse Lakes are compared to Lake Washington. These radical differences in chemical quality of the waters in the Lake Washington drainage result from the diversified human use of the lake basin and the lake water itself.

Preliminary measurements of P release in the sediment-water interface using Lake Sammamish sediments provided basic data for the construction of a laboratory simulation system for studying P regeneration from sediments of the four lakes. These experiments are still incomplete. To supplement the laboratory sediment P-release data, a monitoring of the P concentration in the lake water column as a function of season and other limnological parameters has been undertaken. The physical, mineralogical, and chemical characterization of surface lake sediments in relation to the depth of the water column and the type of lake also has been initiated. Preliminary results of particle size distribution and C:N ratios in sediments of Findley and Chester Morse Lakes, Lake Washington, and Lake Sammamish are presented in Tables 3 and 4. As was found with the chemical quality of the lake water, Findley and Chester Morse Lake sediments are distinctly different from those of Lake Washington and Lake Sammamish with respect to both the C:N ration and the particle size distribution. The sediments of the upper Cedar River basin lakes are generally coarser and have a markedly higher C:N ratio.

PLANKTON PRODUCTIVITY AND BIOMASS

The four lakes in the Cedar River watershed represent a trophic series from extreme oligotrophy to moderate eutrophy. Although precise comparison must await more complete data, available data are summarized in Table 2. Phytoplankton productivity (carbon assimilation rate) and biomass (chlorophyll) show a progressive increase from remote Findley Lake to Lake Washington in Seattle. Based on evaluations of North European lakes, a mean productivity of 1,000 mg Cm^{-2} day^{-1} during the growing season is said to indicate the lower limit of eutrophy. Thus, Lake Washington appears to be around the threshold of eutrophy and mesotrophy based on productivity. The lower levels of chlorophyll and productivity from Lake Sammamish indicate a mesotrophic condition. This difference is even more apparent if one considers the lesser quantity of blue-green algae in Lake Sammamish during midsummer than in Lake Washington.

Oligotrophic Findley and Chester Morse Lakes have very low plankton algae abundance as indicated by chlorophyll content. Productivity may appear greater than expected from comparative chlorophyll content among the four lakes, but the greater clarity of the two oligotrophic lakes probably accounts for this, as productivity is summed over greater photic zone depths.

Nutrient availability is usually the principal factor that determines lake productivity, and increases of available nutrients contribute to advancing eutrophy. Nutrient availability is dependent upon rates of supply from several sources; surface and ground water inflow, sediment-water interchange, and biochemical regeneration within the water column. Nutrient concentrations may be only an indicator of this availability because, depending on the season, they simply may represent a difference between availability and assimilation. Nutrient content in Findley and Chester Morse Lakes, however, does seem to be related to productivity and biomass. In Lakes Sammamish and Washington, contents of N and P are inverse to productivity and biomass. These two lakes are clearly the most enriched of the four, but, as mentioned previously, concentrations may not indicate availability. An objective of future work will be to estimate nutrient supply rates from the above-mentioned sources to provide more precise estimates of nutrient availability as input data for modeling.

Zooplankton abundance is much greater in the two richer lakes than in the two oligotrophic lakes. Analyses are not far enough along to provide data at this time. Cladocerans in Lake Sammamish are principally *Daphnia* and *Bosmina longirostris*; copepods are *Diaptomus ashlandi* and *Cyclops bicuspidatus*; and roterifers are *Keratella*, *Kellicottia* and *Polyarthra*. Samples are not yet analyzed from the two oligotrophic lakes, but the large copepod *Limnocalanus* has been conspicuous in both lakes.

This annual report is necessarily brief. More detail will be forthcoming upon the tabulation of the summer data and the completion of a number of M.S. and Ph.D. theses by the end of 1971 and in 1972. A list of the prospective titles of the theses from which the data presented in this report has been abstracted is included.

Masters and Ph.D. Theses, Completed or Nearing Completion, on Lakes of Lake Washington Drainage

BARNES, R. S. 1971. Trace Metal Survey of Lake Washington Drainage from Alpine Regions to Lowland Lakes. M.S. thesis, Univ. Wash., Seattle, Wash.

BAUER, D. H. 1971. Nitrogen and Carbon Contents of Surface Sediments from Selected Lake Washington Drainage Lakes. M.S. thesis, Univ. Wash., Seattle, Wash. December.

EMERY, R. M. 1972. The Response of Lake Sammamish Limnoplankton to Nutrient Diversion. Ph.D. thesis, Univ. Wash., Seattle, Wash.

HENDREY, G. R. 1972. Productivity and Nutrient Assimilation in Findley and Chester Morse Lakes. Ph.D. thesis, Univ. Wash., Seattle, Wash.

HORTON, M. A. 1971. The Chemistry of Phosphorus in Lake Sammamish. M.S. thesis, Univ. Wash., Seattle, Wash. December.

KOSMERCHOCK, M. R. 1971. Zooplankton Grazing Rates Estimated in situ in Lakes of Lake Washington Drainage. M.S. thesis, Univ. Wash., Seattle, Wash. December.

LANICH, J. S. 1971. Mineralogy and Cation-Exchange Capacity of Surface Sediments from Selected Lakes of Lake Washington Drainage. M.S. thesis, Univ. Wash., Seattle, Wash. December.

MOON, C. E., 1971. The Effect of Waste Water Diversion on the Nutrient Budget of Lake Sammamish. M.S. thesis, Univ. Wash., Seattle, Wash. December.

RODGERS, A. V. 1972. Seasonal Changes in Abundance and Dominant Species of Zooplankton in Lakes of Lake Washington Drainage. Ph.D. thesis. Univ. Wash., Seattle, Wash. Fall.

Zadorojny, C. 1971. Chemical Water Quality of Lake Sammamish. M.S. thesis. Univ. Wash., Seattle, Wash. June.

Table 1. Chemical Composition of Surface Waters of Lake Washington Drainage (Summer (1971).

Lake or stream	HCO_3	SO_4	Cl	Ca	Mg	Na	Specific conductance
			Mg 1⁻¹				*Micromhos cm⁻¹ at 25 C*
Issaquah Creek at L. Sammamish	53.2	6.8	2.8	6.9	4.8	5.1	116
L. Sammamish	41.5	6.9	2.4	5.0	5.0	4.3	102
Sammamish River at L. Sammamish outlet	42.0	6.9	2.6	6.0	5.2	4.2	103
Findley Lake	9.8	0.4	0.6	0.8	0.5	0.8	21
Chester Morse Lake	10.4	0.5	0.8	1.0	0.6	1.4	28
Cedar River at L. Washington	38.1	4.0	1.4	3.2	3.8	3.3	93
L. Washington	36.2	7.2	2.8	4.6	5.4	4.7	104

Table 2. Mean Summer Averages of Plankton Productivity (Daily Rate of Carbon Assimilation) and Biomass (Chlorophyll) and Inorganic Nutrient Concentrations in Lake Surface Waters of Lake Washington Drainage.

Lake	Total P	Ortho PO_4-P	NO_3-N	Si	Chlorophyll	Carbon	Transparency (Secchi disks)
	$\mu g l^{-1}$					$mg\ C\ m^{-2}$	M
Findley (1971)	4.94	0.96	2.98	75.88	0.31	370.26	15.0
Chester Morse (1971)	5.07	1.03	16.32	373.32	1.61	520.43	7.3
Sammamish (1970)	48.0	7.0	86.0	1100.0	7.1	770.0	3.5
Washington* (1970)	18.7	1.1	56.5	-----	9.5	1070.0	2.3

*Data furnished by W. T. Edmondson, Dept. Zoology, Univ. of Washington.

Table 3. Particle Size Distribution of Surface Sediments from Selected Lake Washington Drainage Lakes

Lake	Depth	Moisture	Sand	Silt	Clay
	M	%	%	%	%
Sammamish	19.0	52.9	5.3	80.9	13.7
	11.5	56.0	8.4	80.5	11.1
	6.5	74.0	13.4	71.9	14.7
	25.0	68.5	1.6	72.1	26.3
	11.0	38.9	62.9	28.7	8.3
	26.0	74.0	3.9	62.3	33.8
	22.0	80.0	7.6	66.0	26.4
	19.0	82.9	7.5	65.0	27.4
	21.0	78.5	9.6	70.9	19.5
	20.0	81.0	4.4	56.6	38.9
	18.5	79.2	19.6	60.3	20.2
	10.0	83.9	27.6	53.9	18.5
	18.0	83.7	9.5	56.6	33.9
	28.0	74.6	3.4	57.5	39.0
	20.5	73.8	12.2	62.0	25.7
	24.0	81.4	6.5	58.0	35.5
	19.0	76.12	14.9	58.8	26.3
	16.5	73.0	40.7	43.2	16.0
	22.0	82.4	3.4	54.9	41.6
	20.0	79.3	16.5	55.1	28.4
	19.5	81.0	8.5	60.7	30.8
	8.0	87.5	23.1	46.8	30.1
	9.0	86.0	13.8	51.6	34.6
	25.0	81.0	4.3	55.1	40.6
	22.0	80.0	4.1	63.3	32.6
	20.0	73.0	4.5	70.0	25.4
Findley	25.0	87.2	25.0	43.4	31.6
	5.0	66.8	77.0	13.9	9.1
	14.0	86.0	47.8	29.6	22.6
	7.0	85.9	31.6	40.8	27.6
	9.0	73.5	44.7	34.9	20.4
Chester Morse	25.0	74.7	9.6	64.9	25.5
	35.0	75.5	6.0	67.3	26.6
	35.0	77.4	6.9	70.7	22.4
	30.0	74.5	31.3	52.1	16.5
	4.0	22.7	97.3	1.8	0.9
Washington	10.0	71.6	1.7	77.7	20.6
	58.0	79.6	2.2	62.7	35.2
	62.0	81.2	4.6	61.7	33.7
	62.0	82.9	1.5	58.5	40.0
	30.0	68.7	1.7	66.8	31.5

Table 4. Nitrogen and Carbon Contents of Surface Sediments from Selected Lake Washington Drainage Lakes

Lake	Depth	Total N	Total C	C:N Ratio	Exchangeable NH_4-N in sediment
	M	*Mg* g^{-1} *sediment*	%		$\mu g\ g^{-1}$
Sammamish	19.0	2.26	2.90	12.8	115.0
	11.5	1.79	3.01	16.8	39.5
	6.5	3.86	4.70	12.2	55.0
	25.0	3.05	3.40	11.2	111.0
	11.0	1.18	1.62	11.2	35.0
	26.0	3.49	3.49	10.0	110.0
	22.0	4.41	4.51	10.2	93.0
	19.0	4.87	4.94	10.1	93.0
	21.0	4.21	4.21	10.0	71.0
	20.0	4.35	4.22	9.7	70.0
	18.5	4.46	4.56	10.0	87.0
	10.0	5.81	5.35	9.2	97.0
	18.0	5.73	6.89	12.0	33.0
	28.0	3.66	3.63	9.9	123.0
	20.5	4.36	4.91	11.3	108.0
	24.0	4.87	4.97	10.2	110.0
	19.0	4.40	5.11	10.4	102.0
	16.5	3.25	3.13	9.6	40.0
	22.0	4.53	4.45	9.8	119.0
	20.0	5.57	5.75	10.3	102.0
	20.0	5.61	5.44	10.4	99.0
	19.5	5.70	5.23	9.2	115.0
	8.0	10.61	12.93	12.2	53.0
	9.0	9.03	10.15	11.2	60.0
	9.0	9.33	10.15	10.9	71.0
	9.0	8.39	9.06	10.8	71.0
	25.0	4.33	3.73	8.6	129.0
	22.0	4.54	3.98	8.8	95.0
	22.0	5.11	4.31	8.4	75.0
	20.0	3.15	3.48	11.0	116.0
Findley	25.0	6.51	10.43	16.0	65.5
	5.0	5.60	10.61	19.0	9.5
	14.0	5.87	8.28	14.1	49.5
	7.0	5.20	6.51	12.5	10.0
	9.0	2.43	3.22	13.3	3.0
	9.0	2.42	3.29	13.6	4.0
Chester Morse	25.0	3.68	6.39	17.3	93.5
	35.0	3.67	6.78	18.5	111.0
	25.0	3.83	6.44	16.8	107.0
	35.0	3.74	5.78	15.4	83.0
	30.0	2.57	3.59	14.0	25.5
Washington	10.0	2.96	3.92	13.2	.8
	58.0	4.05	3.97	9.8	145.5
	62.0	4.35	5.21	12.0	146.0
	61.0	3.72	4.70	12.6	138.0
	62.0	3.57	3.86	10.8	172.0
	30.0	2.20	2.53	11.5	148.0