Spatial and Temporal Patterns in Water Chemistry of Two High Elevation Lakes in Southeast Wyoming[1]

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Introduction

The Glacier Lakes Ecosystem Experiments Site (GLEES) was established to examine the effects of atmospheric deposition and climate change on alpine and subalpine ecosystems. The site contains East Glacier Lake (3282 m elevation) and West Glacier Lake (3276 m elevation), and their watersheds. These two small lakes are located 120 m from each other at the alpine/subalpine transition. The lakes are similar in surface area, depth, and volume, but differ in watershed size, flow patterns of input, and water chemistry (Musselman 1994). Water chemistry has been monitored on these lakes periodically since 1987. Preliminary data indicate that they are subject to acidification (Reuss et al 1993, Reuss 1994).

This report documents temporal and spatial trends during 1993 in water chemistry in East and West Glacier Lakes. Data are presented on seasonal and lake depth changes in water chemistry of the two lakes. The application of the results to appropriate sampling protocols for alpine lakes is discussed.

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Methods

Samples were collected at the deepest portion of each lake as determined from bathymetric maps. Water was collected from a small boat in summer, and through a 20-cm diameter augured hole in the ice in winter, using a peristaltic pump to draw water from the sampling depth to sample bottles. Samples were collected at 0.5 m from the surface and thereafter at 1.0-meter intervals from the top to the bottom of the water column. In addition, integrated samples were collected from each lake after column sampling, by collecting water in a 1.0 l container as the sample tube was pulled slowly through 1-2 complete cycles from the top to the bottom of the lake. The lakes were resampled at approximately monthly intervals. Both lakes were sampled during the same day, at midday. Samples were kept cool, returned to the lab the same day, and filtered for analysis. Samples were analyzed for cations and anions, pH, and conductivity at the Rocky Mountain Station Water Chemistry laboratory. Silica and aluminum were also measured for some sample dates. Appropriate blanks, duplicates, and blind samples were collected for analysis. Data were analyzed separately for each lake using the SPSS MANOVA program, with lake depth and date of sampling as the sources of variation. Depth by date interaction was also examined.

Results and Discussion

Results indicate that water chemistry in both lakes showed significant variation with both lake depth and season (table 1). Both depth in the lake, and date sampled were highly significant sources of variation for almost all water chemistry variables examined. Interaction (date by depth) was also significant for most variables. The data confirmed that the lakes stratify, then mix, at various times during the season. The lakes generally stratify under ice cover, mix at snowmelt, then stratify again during the late summer, early fall.

East Glacier Lake

Nitrate and phosphate levels were generally below detection limits, except for a brief period at

Table 1.—MANOVA Significance of F value.

	Variable													
Source	Cond	Ca	Mg	Na	K	NH_4	Cl	NO_3	SO_4	PO_4	pH	ANC	Al	SiO_2
East Glacier Lake														
Depth	0.00	0.00	0.00	0.00	0.002	0.347	0.124	0.008	0.00	0.08	0.167	0.00	0.380	0.001
Date	0.00	0.00	0.00	0.00	0.000	0.022	0.000	0.000	0.00	0.00	0.000	0.00	0.211	0.004
DepthxDate	0.00	0.00	0.00	0.00	0.000	0.235	0.041	0.000	0.00	0.00	0.307	0.00	0.873	0.009
Model	0.00	0.00	0.00	0.00	0.000	0.049	0.000	0.000	0.00	0.00	0.000	0.00	0.344	0.000
West Glacier Lake														
Depth	0.00	0.00	0.001	0.545	0.00	0.00	0.001	0.613	0.026	0.00	0.821	0.012	0.252	0.165
Date	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.000	0.00	0.002	0.000	0.954	0.000
DepthxDate	0.00	0.00	0.000	0.981	0.00	0.00	0.005	0.000	0.250	0.00	0.075	0.000	0.008	0.278
Model	0.00	0.00	0.000	0.000	0.00	0.00	0.000	0.000	0.000	0.00	0.014	0.000	0.171	0.000

the lake surface during snowmelt. The low nitrate and phosphate levels indicate that the deposition load is below the saturation level at this site. The lake was stratified in winter, and became mixed at snowmelt in the spring. The bottom meter of the lake became anaerobic in winter, with higher concentrations of the base cations Ca, Mg, and K, lower concentration of SO_4 anion, lower pH, higher alkalinity and conductivity at the bottom of the lake. Conductivity and alkalinity remained relatively constant throughout the summer. Seasonal change in pH was minimal, with a pH range of only about 0.5 pH units throughout the year. Lowest pH occurred at the bottom of the lake in winter, but never decreased below pH 6.3. Only a slight decrease in pH occurred at snowmelt. Secchi depth (data not shown) was deep during most of the year, with the lake bottom (7 m) visible during much of the year. The base cations Ca, Mg, Na, and K remained relatively low after snowmelt input. Sulfate, the major detectable acid anion, remained relatively low in concentration throughout the year. A slight decease in sulfate was evident at the lake bottom in winter, and a smaller decrease in sulfate occurred at snowmelt.

West Glacier Lake

West Glacier Lake became mixed after snowmelt began and ice cover was gone. There also appeared to be some mixing in May, likely due to water flow under the ice. Nitrates and phosphates were considerably higher in WGL than in EGL. Considerably more anions are delivered to WGL in snowmelt. Nevertheless, nitrate and sulfate levels were relatively low, and were below detection limits in summer, indicating that anions delivered to WGL were utilized and the lake was below saturation for acid anions. The winter peak is an indication of stratification while the snowmelt peak is an indication of input from deposition. Chloride levels peaked during snowmelt, and gradually decreased throughout the season. As with EGL, sulfate was the major acid anion in WGL. Stratification was evident for sulfate during winter and at peak snowmelt (June). Highest sulfate concentrations occurred at initial snowmelt (May), with a dilution occurring as snowmelt progressed.

Acidity increased slightly during snowmelt, and acidity increased below the secchi depth during winter. The pH by season and depth ranged from about pH 6.0 to 6.8. The highest acidity was at the lake bottom (8.5 m) in early winter. Alkalinity and conductivity remained rather constant throughout the year, but alkalinity peaked at nearly 200 μeq/l near the lake bottom in winter. Alkalinity remained at about 50-80 throughout the profile the rest of the year. There was an increase in conductivity at the lake bottom at snowmelt after ice-out, but conductivity remained relatively constant and low throughout the year and throughout the profile.

Concentrations of the base cations Ca, Mg, Na, and K were lowest in summer, and increased slightly under ice in winter, particularly at the lower lake depths. Highest concentrations of these cations occurred at peak snowmelt. Na concentration patterns were similar to the other base cations except concentrations were highest at initial snowmelt, indicating elution of this ion from the snowpack earlier in the melt season. A slight decrease in cation concentration was evident at initial snowmelt. The initial input of cold meltwater under the ice may have caused mixing of the profile which would result in a dilution of the initial input water.

Integrated Sample Analysis

Analysis of integrated water samples indicates that samples from specific individual depths may not be representative of the overall lake chemistry (table 2). Means for integrated samples were consistently out of the range of those for individual depth samples. One explanation for the difference might be with the different portions of the water column collected in the two samples. Water from only a small layer of the lake water column is sampled at the individual depths. Thus, a large portion of the lake profile is not sampled with this sampling protocol. Although the integrated sample might provide a sample more representative of the complete lake column, the specific depth chemistry data are essential to explain biological changes noted from plankton samples collected concurrently from the same depths in these alpine lakes.

WGL hydrology suggests that water flow from catchments into the lake is more confined to defined stream beds than is flow into EGL (Musselman 1994), allowing less soil/water interaction. Soils in WGL watershed are shallower and less developed, and a large percentage of the watershed is exposed quartzite bedrock. There is also a considerable amount of flow directly from the permanent snowfield. There is little opportunity for ion exchange with the watershed. Much of the flow into EGL is from overland flow rather than confined to stream channels at snowmelt, and flow ceases when snowmelt is complete. As a result, nitrate and phosphate levels are considerably higher in WGL than EGL.

Conclusions

EGL and WGL have differing flow patterns, water chemistry, watershed size, and turnover rates. However, both lakes show similar temporal and spatial patterns of change in water chemistry. Both lakes stratify in winter under ice, and show similar types of changes in water chemistry with lake depth and time of season.

The data indicate that caution must be exercised when sampling high elevation alpine lakes such as these. A sample taken when the lakes are stratified may not be representative of lake water chemistry. Stratification can not be verified when sampling from a single depth. In addition, any sample taken at the lake surface or any other specific depth may not be representative of an integrated water sample taken throughout the lake profile. Such samples should represent only that specific depth when describing lake chemistry. This difference can occur even for small lakes that might appear to be well mixed in late summer or early fall.

Literature Cited

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Reuss, J.O.; Vertucci, F.A.; Musselman, R.C.; Sommerfeld, R.A. 1993. Biogeochemical fluxes in the Glacier Lakes catchments. Research Paper RM-314. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment.

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Table 2.—Comparison of integrated lake samples and mean of all specific depth samples for East Glacier Lake and West Glacier Lake by date of sampling.

East Glacier Lake separate-depth sample and integrated sample water chemistry analysis 95% confidence intervals for integrated samples, with means of single/subsample data.

Date	Mean Sep pH	Mean Int pH	SD Int pH	Mean Sep Cond	Mean Int Cond	SD Int Cond	Mean Sep Ca	Mean Int Ca	SD Int Ca	Mean Sep Mg	Mean Int Mg	SD Int Mg
01/13/93	6.68	–.–	–.–	10.93	–.–	–.–	1.46	–.–	–.–	0.40	–.–	–.–
02/18/93	6.67	6.56	0.03	11.99	12.37	0.14	1.45	1.33	0.02	0.40	0.36	0.00
04/08/93	–.–	–.–	–.–	11.95	11.75	0.05	1.62	1.46	0.01	0.40	0.35	0.00
05/06/93	6.57	6.42	0.03	12.60	19.30	0.13	1.61	2.33	0.05	0.39	0.58	0.02
06/30/93	6.45	6.36	0.10	7.09	7.12	0.06	0.88	0.97	0.04	0.22	0.24	0.00
07/21/93	6.48	6.43	0.02	6.99	7.33	0.02	0.89	0.88	0.10	0.21	0.20	0.01
08/25/93	6.59	6.62	0.01	6.36	6.42	0.11	0.92	0.95	0.16	0.22	0.23	0.02
09/22/93	6.71	6.72	0.02	6.51	6.27	0.04	0.80	1.80	1.73	0.21	0.23	0.06
12/08/93	6.63	6.73	0.02	8.50	8.32	0.11	1.00	0.99	0.02	0.25	0.25	0.01

Date	Mean Sep Na	Mean Int Na	SD Int Na	Mean Sep K	Mean Int K	SD Int K	Mean Sep NH4	Mean Int NH4	SD Int NH4	Mean Sep Cl	Mean Int Cl	SD Int Cl
01/13/93	0.38	–.–	–.–	0.20	–.–	–.–	0.02	–.–	–.–	0.18	–.–	–.–
02/18/93	0.39	0.29	0.01	0.19	0.20	0.00	0.02	0.00	0.01	0.19	0.18	0.01
04/08/93	0.39	0.34	0.00	0.22	0.20	0.01	0.01	0.00	0.00	0.18	0.16	0.00
05/06/93	0.39	0.44	0.01	0.16	0.25	0.01	0.03	0.49	0.04	0.20	0.24	0.01
06/30/93	0.22	0.21	0.00	0.10	0.11	0.01	0.05	0.03	0.05	0.08	0.08	0.00
07/21/93	0.35	0.36	0.02	0.09	0.11	0.00	0.00	0.00	0.00	0.09	0.10	0.01
08/25/93	0.23	0.22	0.00	0.05	0.05	0.01	0.00	0.00	0.00	0.04	0.04	0.00
09/22/93	0.22	0.23	0.01	0.03	0.02	0.01	0.00	0.00	0.01	0.02	0.02	0.00
12/08/93	0.29	0.29	0.00	0.04	0.04	0.00	0.01	0.02	0.02	0.02	0.02	0.00

Date	Mean Sep SO_4	Mean Int SO_4	SD Int SO_4	Mean Sep ANC	Mean Int ANC	SD Int ANC	Mean Sep SiO_2	Mean Int SiO_2	SD Int SiO_2	Mean Sep Al	Mean Int Al	SD Int Al
01/13/93	1.15	–.–	–.–	78.49	–.–	–.–	1.36	–.–	–.–	6.67	–.–	–.–
02/18/93	1.23	1.07	0.01	83.19	102.20	0.75	1.58	1.16	0.01	3.60	0.64	0.58
04/08/93	1.14	1.15	0.01	–.–	–.–	–.–	1.14	1.19	0.09	3.65	1.92	0.14
05/06/93	1.07	1.00	0.03	103.60	182.27	0.45	1.53	1.32	–.–	7.31	11.04	–.–
06/30/93	0.78	0.74	0.00	46.67	47.13	0.25	–.–	1.51	0.03	–.–	14.31	1.76
07/21/93	0.87	0.93	0.00	46.11	48.63	0.45	–.–	1.46	0.06	–.–	12.38	0.42
08/25/93	0.74	0.75	0.00	48.14	48.67	0.42	1.13	1.09	0.03	9.84	14.82	7.04
09/22/93	0.81	0.81	0.00	48.93	48.80	0.17	–.–	–.–	–.–	–.–	–.–	–.–
12/08/93	0.94	0.94	0.01	62.67	62.53	0.70	–.–	–.–	–.–	–.–	–.–	–.–

(Continued)

Table 2.—(Continued).

West Glacier Lake separate-depth sample and integrated sample water chemistry analysis 95% confidence intervals for integrated samples, with means of single/subsample data.

Date	Mean Sep pH	Mean Int pH	SD Int pH	Mean Sep Cond	Mean Int Cond	SD Int Cond	Mean Sep Ca	Mean Int Ca	SD Int Ca	Mean Sep Mg	Mean Int Mg	SD Int Mg
01/13/93	6.72	–.–	–.–	8.49	–.–	–.–	1.04	–.–	–.–	0.32	–.–	–.–
02/18/93	6.48	6.61	0.02	9.92	9.60	0.03	1.31	1.27	0.05	0.39	0.39	0.01
04/08/93	–.–	–.–	–.–	11.66	10.91	0.02	1.45	1.36	0.04	0.43	0.40	0.01
05/06/93	6.52	6.61	0.04	10.90	10.96	0.03	1.44	1.56	0.02	0.40	0.41	0.00
06/30/93	6.41	6.36	0.02	12.19	12.28	0.15	1.44	–.–	–.–	0.40	–.–	–.–
07/21/93	6.61	6.73	0.04	6.39	6.49	0.35	0.82	0.77	0.08	0.20	0.20	0.02
08/25/93	6.53	6.57	0.03	5.37	5.41	0.04	0.73	0.80	0.04	0.17	0.18	0.00
09/22/93	6.67	6.67	0.04	5.44	5.46	0.04	0.72	0.79	0.10	0.19	0.20	0.01
12/08/93	6.41	6.35	0.04	8.23	7.87	0.16	0.92	0.90	0.03	0.25	0.24	0.00

Date	Mean Sep Na	Mean Int Na	SD Int Na	Mean Sep K	Mean Int K	SD Int K	Mean Sep NH4	Mean Int NH4	SD Int NH4	Mean Sep Cl	Mean Int Cl	SD Int Cl
01/13/93	0.25	–.–	–.–	0.11	–.–	–.–	0.04	–.–	–.–	0.08	–.–	–.–
02/18/93	0.27	0.28	0.00	0.15	0.14	0.01	0.10	0.05	0.00	0.09	0.09	0.00
04/08/93	0.25	0.27	0.01	0.18	0.17	0.00	0.16	0.09	0.01	0.11	0.10	0.01
05/06/93	0.36	0.38	0.02	0.17	0.16	0.02	0.11	0.46	0.27	0.12	0.13	0.01
06/30/93	0.25	–.–	–.–	0.22	–.–	–.–	0.30	–.–	–.–	0.11	0.13	0.01
07/21/93	0.27	0.28	0.01	0.12	0.13	0.04	0.00	0.00	0.01	0.08	0.08	0.00
08/25/93	0.15	0.16	0.00	0.06	0.06	0.00	0.00	0.00	0.00	0.05	0.05	0.00
09/22/93	0.19	0.18	0.00	0.06	0.07	0.01	0.01	0.00	0.00	0.06	0.05	0.00
12/08/93	0.27	0.27	0.00	0.12	0.12	0.00	0.07	0.03	0.01	0.07	0.07	0.00

Date	Mean Sep SO_4	Mean Int SO_4	SD Int SO_4	Mean Sep ANC	Mean Int ANC	SD Int ANC	Mean Sep SiO_2	Mean Int SiO_2	SD Int SiO_2	Mean Sep Al	Mean Int Al	SD Int Al
01/13/93	0.91	–.–	–.–	61.80	–.–	–.–	0.62	–.–	–.–	5.46	–.–	–.–
02/18/93	0.83	0.95	0.01	81.79	71.03	0.25	1.11	0.84	0.03	6.51	9.48	0.66
04/08/93	0.76	0.88	0.00	–.–	–.–	–.–	1.28	1.12	0.08	8.24	6.35	–.–
05/06/93	1.30	1.33	0.01	77.94	79.00	0.44	1.74	1.05	0.00	7.50	6.40	–.–
06/30/93	0.66	0.47	0.18	102.15	168.73	53.34	0.00	2.59	0.56	–.–	37.60	32.81
07/21/93	0.84	0.85	0.06	44.69	47.37	1.63	0.00	1.41	0.01	–.–	11.41	1.97
08/25/93	0.63	0.63	0.00	25.94	26.37	0.78	0.29	0.31	0.02	7.90	7.94	0.99
09/22/93	0.73	0.72	0.00	39.84	40.30	0.56	–.–	–.–	–.–	–.–	–.–	–.–
12/08/93	0.89	0.87	0.00	64.06	59.87	1.31	–.–	–.–	–.–	–.–	–.–	–.–

"Mean Sep" = Mean of the separate depths sample data.
"Mean Int" = Mean of the integrated sample data.
"SD Int" = Standard deviation of the integrated sample data.
"–.–" = No data.