# TROPHIC STATUS AND TRENDS IN WATER QUALITY FOR VOLUNTEER MONITORING PROGRAM LAKES IN NORTHWESTERN MONTANA, 1993–2007

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## INTRODUCTION

The Volunteer Lake Monitoring Program was initiated in 1993 by the Flathead Basin Commission. It was established to enable local residents an opportunity to collect baseline data on the trophic status of lakes in the area surrounding Kalispell, MT and monitor these lakes for possible impacts from human activities. The Flathead Lake Biological Station (FLBS) was utilized to provide input into developing a cost effective monitoring strategy, training in proper sampling protocol, lab space and chemical analysis in the Freshwater Research Laboratory.

The Flathead Basin Commission selected lakes based upon citizen concern for specific lakes and their commitment to continue monitoring them over several years. The lakes selected range in size from very small (Hanson-Doyle Lake, surface area of 8 acres) to very large (Flathead Lake, surface area of 122,319 acres). Some of the lakes, like Rogers Lake and Lake Five, have been sampled nearly every year from 1993 to 2007 and some have only been sampled once during that time. Over the last fourteen years 43 lakes have been included in the monitoring effort.

## METHODS

Due to funding limitations initial monitoring was restricted to a single water sample for each lake per year analyzed for total phosphorus and chlorophyll *a* concentrations (Table 1). In 2005, a small increase in program funding allowed for the addition of total nitrogen analysis. Ideally the lakes were sampled at the end of July or in early August to coincide with maximum water temperatures. However, some years monitoring extended into late August or early September. On each sampling trip a citizen volunteer would be accompanied by a Flathead Basin Commission staff person in a boat supplied by the volunteer. On the day of sample collection, volunteers used a Secchi disk to measure water clarity and a Yellow Springs Instruments probe (Model 95) to measure temperature and dissolved oxygen profiles to a maximum depth of 95 feet. The dissolved oxygen meter was calibrated on site, prior to use.

Integrated water samples for total phosphorus and total nitrogen analysis were collected by lowering a precleaned (rinsed 3X with tap water then rinsed 1X with 10% hydrochloric acid and finally rinsed 3X with deionized water) Tygon© tube to a depth equivalent to the photic zone, transferring the water into precleaned high density polypropylene carboy, mixed by inverting 2X, and transferred to precleaned high density polypropylene sample bottles. If the photic zone extended to the bottom of the lake, then the integrated depth extended to within 1 m of the bottom. Otherwise, the photic depth was estimated as 3X the Secchi disk depth. The samples were then placed on ice and transported to the Freshwater Research Lab where they were frozen. Integrated water samples for chlorophyll *a* analysis were collected by lowering a precleaned (rinsed 3X with tap water) garden hose to a depth equivalent to the photic zone, transferring the water into a precleaned opaque high density polypropylene carboy, mixed by inverting 2X, and transferred to precleaned opaque high density polypropylene sample bottles.

The samples were then placed on ice and transported to the Freshwater Research Lab where they were prepared for analysis. All work for chlorophyll *a* analysis was done in the shade or a darkened room in the laboratory to avoid photo degradation.

At the FLBS Freshwater Research Laboratory, analytical precision is quantified by the analytical standard error. This is calculated for every analysis result using a calibration curve. It is calculated by multiplying the regression standard error by the sample dilution. In addition, the analytical detection limit of each analysis also is quantified. The analytical detection level is the lowest concentration of an analyte at which a signal can be discerned from analytical background noise with a 95% confidence level. It is determined every time an analysis is performed that uses a calibration curve. An analytical blank or laboratory known of low concentration is analyzed three or more times periodically during an analysis. For analyses using a calibration curve, the standard deviation of the result is multiplied by 3. For analyses that do not use a calibration curve, ten or more replicates of a known concentration near the suspected detection level are analyzed with the standard deviation of the results multiplied by 3. Analytical accuracy and bias are quantified by analyzing audit samples during each analysis. Audit samples are known analyte concentrations obtained from either the USGS or from a commercial chemical supplies company (e.g., Inorganic Ventures, 195 Lehigh Ave., Suite 4, Lakewood, NJ 08701). Results are expressed as percent recovery.

Newly hired laboratory personnel at the Freshwater Research Laboratory are required to complete an Initial Demonstration of Capability before analyzing samples. All laboratory analysts are required to complete an Ongoing Demonstration of Capability (ODC) annually for the analyses for which they are responsible. The results of these tests are kept on file electronically. Details are contained in the Freshwater Research Laboratory Quality Assurance Program (QAP). All sample data, laboratory standard curves and quality control information are electronically archived by the FLBS Data Manager in the Biological Station's data storage and retrieval system (FLATDAT).

Lake surface and basin areas were calculated using Arc Coverage of major lakes downloaded from NRIS (Montana's spatial database), and overlayed that on top of a digital topographic layer (NRIS) of 1:24,000 scale. Also overlayed was a subwatershed coverage (NRIS) of the major streams. The major lakes that already had surface areas associated with the coverage were used. Otherwise, the lake was hand digitized to obtain the surface areas. As for the drainage areas, the subwatershed coverage (with some clipping) was used. Those without predefined subwatersheds were digitized using the topography layer and the subwatershed layer.

A 1:500,000 scale geologic layer of Montana from NRIS was used as a base layer to be clipped from both the digitized lake basin coverage and from the NRIS major lakes coverage. The following clip layer was then queried to estimate the geologic areas within each basin. Since the geologic layer was at a much larger scale than the lake basin coverage (1:24,000), some small error in overlap occurred, which is estimated to be about 10%. For Flathead and Kintla Lakes, the geology of the Canadian portion of the

catchments was obtained from British Columbia Digital Geology Maps (Version 1.0, 2005) at a scale of 1:250,000.

Lake location (latitude and longitude) and elevation were obtained using the Graphical Locator web page (http://www.esg.montana.edu/gl/index.html). Lake depth for all lakes except Flathead, Whitefish and Swan should be considered an approximation as we were unable to verify their accuracy (e.g., most were obtained from local watershed groups); if depth data were unavailable, the maximum depth where physico-chemical profiles were made was recorded. Trophic determination for each lake was based on the classification outlined by Wetzel (2001).

## RESULTS AND DISCUSSION

Excessive nutrients (e.g., nitrogen and phosphorus) were reported to be the leading cause of impairment in lakes in the Environmental Protection Agency's (EPA) National Water Quality Inventory in 1996 and the second leading cause of impairments reported by the States in their 1998 lists of impaired water bodies. According to USEPA (2000), nutrients contribute about 25–50% of the impairment nationally, where documentation of use impairment has been made. In excess, nutrients can result in overgrowth by algae and/or aquatic plants, low dissolved oxygen, fish kills, increased sediment accumulation rates and shifts in species composition of both plants and animals. In the very worst case scenarios, high nutrient loading can also result in potential human health risks, such as the growth of harmful algal blooms. Several harmful algal blooms have been reported over the years from lakes and reservoirs in Montana (e.g., Hebgen Lake, Canyon Ferry Reservoir, Nelson Reservoir), some of which resulted in the death of cattle.

The criteria chosen for monitoring water quality by FLBS when the program began in 1993 are the same criteria that are now recommended by USEPA for the development of regional nutrient criteria that are protective of designated uses (USEPA 2000). For each Nutrient Ecoregion (the Flathead is in Ecoregion II, Subecoregion 41), EPA developed a set of recommendations for two causal variables (total phosphorus and total nitrogen) and two early indicator response variables (chlorophyll *a* and some measure of turbidity, such as Secchi depth). Other indicators such as dissolved oxygen and aquatic plant growth or species determinations are also deemed useful, but the first four are considered the best indicators.

Following are the results from each of the 43 lakes monitored by volunteers, divided for convenience into categories of small, medium-sized and large lakes based upon their surface area. Data and graphics referenced in the discussion can be found in Tables 1–7 and Figures 1–6.

***Small Lakes (Surface Area <100 Acres)***

Abbot Lake

Abbot Lake is at an elevation of 2,999 feet located in the Flathead Valley northwest of Flathead Lake on the southern flank of Hash Mountain. It has a surface area of 41 acres and has a relatively small basin area of only 121 acres. The lake is in close proximity to Echo Lake, which is to the northeast, and Peterson Lake to the northwest. A waterway joins Peterson and Abbot Lakes when they are full. The lake is in glacial till and alluvium on the valley floor with a maximum water depth of approximately 20 feet.

Monitoring of Abbot Lake ran intermittently from 1995 to 2006 for a total of seven samplings. Vertical profiling of temperature and dissolved oxygen indicates that the lake is not stratified in late summer. Total phosphorus (mean = 12 µg $L^{-1}$), total nitrogen (mean = 330 µg $L^{-1}$), chlorophyll *a* (mean = 3.4 µg $L^{-1}$), and Secchi depth measures (mean = 3.4 m) indicate Abbot Lake is oligomesotrophic. No trends were apparent from time series trend analysis of total phosphorus and chlorophyll *a* concentrations.

Bailey Lake

Bailey Lake is at an elevation of 3,399 feet located on the northern flank of Teakettle Mountain in the North Fork Flathead River drainage. Bailey Lake is one of the smallest lakes sampled with a surface area of only 16 acres, but has a relatively large basin area of 2,638 acres. The geologic formations in the watershed are dominated by glacial till (55%) with the remaining drainage area split evenly between Grinnel argillite and the Piegan group belt series. The maximum water depth measured was 30 feet.

Bailey Lake was monitored 12 times from 1994 to 2007. Vertical profiling of temperature and dissolved oxygen indicates that the lake is occasionally stratified in late summer. Total phosphorus (mean = 9 µg $L^{-1}$), total nitrogen (mean = 256 µg $L^{-1}$), chlorophyll *a* (mean = 1.7 µg $L^{-1}$), and Secchi depth measures (mean = 5.0 m) indicate Bailey Lake is oligotrophic. However, results from time series trend analysis of total phosphorus and chlorophyll *a* concentrations indicate both have been increasing since 1994 ($p = 0.01$ and 0.007, respectively). Total phosphorus concentrations are rising at a rate of 0.39 µg $L^{-1}$ $yr^{-1}$ and chlorophyll *a* concentrations are rising at a rate of 0.09 µg $L^{-1}$ $yr^{-1}$. This is the only small lake to have a significant time series trend in either variable. In addition, when the lake was stratified, dissolved oxygen measured at the bottom reached a low of 12.7% saturation (2.53 mg $L^{-1}$). When dissolved oxygen levels are reduced to around 2 mg $L^{-1}$, significant amounts of phosphorus can be released from the sediments, thereby increasing phosphorus in the water column; such conditions often result in a decline in water quality due to the enhanced internal loading of phosphorus to the lake.

Halfmoon Lake

Halfmoon Lake is at an elevation of 3,300 feet located at the northwest toe of the Flathead Mountain Range in the upper Flathead River drainage south of West Glacier, MT. Halfmoon Lake is on

the valley floor near Lake Five with a surface area of 55 acres, a watershed area of 1,387 acres and a maximum depth of approximately 20 feet. The drainage basin is dominated by glacial till (78%) with the remainder composed of the Grinnel argillite belt series.

Halfmoon Lake was monitored 12 times from 1994 to 2007. Vertical profiling of temperature and dissolved oxygen indicates that the lake is occasionally stratified in late summer. Total phosphorus (mean = 11 µg $L^{-1}$), total nitrogen (mean = 543 µg $L^{-1}$), chlorophyll *a* (mean = 1.4 µg $L^{-1}$), and Secchi depth measures (mean = 5.1 m) indicate Halfmoon Lake is oligotrophic. However when stratified, minimum oxygen concentrations measured at the bottom of the lake reached a low of 18.5% saturation (2.1 mg $L^{-1}$) indicating the potential for release of phosphorus stored in the sediments. Results from time series trend analysis of total phosphorus and chlorophyll *a* concentrations indicate no trends are occurring.

Hanson-Doyle Lake

Hanson-Doyle Lake is located in a small valley below Pilot Knob of the Salish Mountain Range in the Stillwater River drainage northwest of Kalispell, MT at an elevation of 3,199 feet. This is the smallest of the lakes monitored with a surface area of only 8 acres and a basin area of 175 acres. The maximum depth recorded was 33 feet and the water column was stratified every time vertical profiles of temperature and dissolved oxygen were measured. The drainage area is dominated by the Ravalli group belt series (82%) with the reminder being glacial till on the valley floor.

Hanson-Doyle Lake was monitored twelve of the thirteen years from 1995 to 2007. Total phosphorus (mean = 16 µg $L^{-1}$), total nitrogen (mean = 910 µg $L^{-1}$), chlorophyll *a* (mean = 2.9 µg $L^{-1}$), and Secchi depth measures (mean = 5.2 m) indicate Hanson-Doyle Lake is oligomesotrophic. Another indication of a more productive lake is the minimum oxygen concentration at the bottom of the lake reaching a low of 4% saturation (0.4 mg $L^{-1}$). As mentioned previously, internal loading of phosphorus can occur in lakes when oxygen drops below about 2 mg $L^{-1}$. Time series trend analysis does not indicate any trends in either total phosphorus or chlorophyll *a* concentrations.

Jette Lake

Jette Lake is located in the foothills of the Salish Mountain Range along the southwest border of Flathead Lake at an elevation of 3,791 feet. It has a surface area of 261 acres and a basin area of 1,198 acres with a maximum water depth of about 30 feet. The drainage area lies entirely in the Ravalli group belt series.

Jette Lake was monitored nine times from 1994 to 2007. Total phosphorus (mean = 73 µg $L^{-1}$), total nitrogen (mean = 1,010 µg $L^{-1}$), chlorophyll *a* (mean = 12.2 µg $L^{-1}$), and Secchi depth measures (mean = 5.2 m) indicate Jette Lake is eutrophic. This is the only eutrophic lake monitored. In 1998 total phosphorus concentrations reached 400 µg $L^{-1}$ and chlorophyll *a* concentrations reached 65 µg $L^{-1}$ which are borderline values for hypereutrophic lakes. Vertical profiling of temperature and dissolved oxygen

indicates that the lake is occasionally stratified in late summer. The lowest dissolved oxygen measured at the bottom of Jette Lake was 7% saturation (0.8 mg $L^{-1}$). Time series trend analysis does not indicate any trends in either total phosphorus or chlorophyll *a* concentrations.

Lavon Lake

Lavon Lake is located in the upper Fisher River drainage in a high valley between the Salish and Cabinet Mountain Ranges at an elevation of 3,599 feet. Lavon Lake is a small lobe of Crystal Lake and has a surface area of 17 acres with a drainage area of 984 acres. The drainage area lies entirely in alluvium.

Lavon Lake was only sampled in 1995. That water sample had a total phosphorus concentration of 21 µg $L^{-1}$ and a chlorophyll *a* concentration of 8.4 µg $L^{-1}$ indicating this may be a mesotrophic lake.

Lion Lake

Lion Lake is located just outside Hungry Horse, MT at the northern foot of Lion Hill in the Flathead Mountain Range at an elevation of 3,532 feet. The surface area of Lion Lake is 36 acres and the drainage basin is 818 acres. The maximum water depth measured in Lion Lake was 88 feet. This is the deepest small lake that was monitored. The Missoula group belt series makes up 62% of the catchment and the Piegan group belt series is 38%.

Lion Lake was sampled each year from 1994 to 1996. Total phosphorus (mean = 7 µg $L^{-1}$) and chlorophyll *a* (mean = 0.9 µg $L^{-1}$) concentrations indicate Lion Lake is an oligotrophic lake. Total nitrogen analysis did not begin until 2005 for the Volunteer Lake Monitoring Project and Secchi depth was not recorded for this lake. Trend analysis was not performed on this lake since it was only sampled for three years.

Loon Lake

Loon Lake is located on the eastern side of the Mission Mountain Range just west of the Swan Lake outlet on the valley floor at an elevation of 3,100 feet. It has a surface area of 44 acres and a drainage basin of only 112 acres. The geologic formation of the entire watershed is alluvium. The maximum depth recorded at Loon Lake was 33 feet.

Loon Lake was monitored each year from 1993 to 1999. Total phosphorus (mean = 18 µg $L^{-1}$), chlorophyll *a* (mean = 2.0 µg $L^{-1}$), and Secchi depth measures (mean = 6.8 m) indicate Loon Lake is mesotrophic. No total nitrogen data were available as monitoring for that variable did not begin until 2005. Although no trends were apparent in the data, there was a very large spike in both total phosphorus and chlorophyll *a* concentration in 1994; total phosphorus was 66 µg $L^{-1}$ and chlorophyll *a* was 8.7 µg $L^{-1}$. These concentrations are more indicative of a eutrophic lake.

McCaffery Lake

McCaffery Lake is located in the Flathead Valley northwest of Flathead Lake in the southern foothills of Hash Mountain at an elevation of 2,999 feet. McCaffery Lake has a surface area of 21 acres and the smallest basin area of all the lakes monitored at 85 acres. The area around Hash Mountain is commonly referred to as "Many Lakes". The catchment is dominated by glacial till (99%) with a small knob of Appekunny argillite belt series (1%). The maximum water depth in the lake is approximately 42 feet.

McCaffery Lake was sampled 9 times from 1995 to 2007. Total phosphorus (mean = 21 µg $L^{-1}$), total nitrogen (mean = 742 µg $L^{-1}$), chlorophyll *a* (mean = 5.2 µg $L^{-1}$), and Secchi depth measures (mean = 4.5 m) indicate McCaffery Lake is a mesotrophic lake. No trend was detected in either total phosphorus or chlorophyll *a* concentration.

McGilvray Lake

McGilvray Lake is located in the Flathead Valley northwest of Flathead Lake in the western foothills of Hash Mountain at an elevation of 2,983 feet. The surface area of McGilvray Lake is 37 acres and it has a catchment area of 237 acres. The catchment is entirely glacial till. The maximum depth recorded in the lake was 33 feet.

McGilvray Lake was sampled each year from 2005 to 2007. Total phosphorus (mean = 9 µg $L^{-1}$), total nitrogen (mean = 178 µg $L^{-1}$), chlorophyll *a* (mean = 1.0 µg $L^{-1}$), and Secchi depth measures (mean = 7.2 m) indicate McGilvray Lake is oligotrophic. Trend analysis was not performed on this lake since it was only sampled for three years.

Peterson Lake

Peterson Lake is located at an elevation of 2,999 feet located in the Flathead Valley northwest of Flathead Lake on the southern flank of Hash Mountain. It has a surface area of 94 acres and a watershed area of 304 acres. The catchment is entirely glacial till. The maximum water depth in the lake is approximately 30 feet. When Peterson and Abbot Lakes are full a waterway joins them on the southern ends.

Peterson Lake has been sampled twelve times from 1995 to 2007. Total phosphorus (mean = 13 µg $L^{-1}$), total nitrogen (mean = 356 µg $L^{-1}$), chlorophyll *a* (mean = 2.1 µg $L^{-1}$), and Secchi depth measures (mean = 5.2 m) indicate Peterson Lake is an oligotrophic lake. Time series trend analysis does not indicate any trends in either total phosphorus or chlorophyll *a* concentrations.

Skyles Lake

Skyles Lake is located west of Whitefish, MT in the Stillwater River drainage on the southwestern edge of Lion Mountain at an elevation of 3,199 feet. Skyles Lake has a surface area of 38 acres and a

drainage area of 1,260 acres. The maximum depth recorded was 13 feet. This is the shallowest lake monitored by the Volunteer Lake Monitoring Program. The drainage area is dominated by the Piegan group belt series (84%) with the remainder being composed of alluvium and glacial till.

Skyles Lake was sampled nine times from 1993 to 2002. Total phosphorus (mean = 15 µg $L^{-1}$), chlorophyll *a* (mean = 2.3 µg $L^{-1}$), and Secchi depth measures (mean = 2.4 m) indicate Skyles Lake is oligomesotrophic. No total nitrogen data were available as monitoring for that variable did not begin until 2005. No trends were apparent in either total phosphorus or chlorophyll *a* concentrations.

Spencer Lake

Spencer Lake is located on the western edge of the mountains west of Whitefish, MT in the Stillwater River drainage. It is at an elevation of 3,199 feet, has a surface area of 30 acres and a catchment area of 1,663 acres. The geology of the catchment is a combination of the Piegan group belt series (58%), alluvium (23%) and glacial till (12%).

Spencer Lake was sampled each year from 1993 to 1995. Total phosphorus (mean = 22 µg $L^{-1}$) and chlorophyll *a* (mean = 3.6 µg $L^{-1}$) concentrations indicate Spencer Lake is a mesooligotrophic lake. No total nitrogen data were available as monitoring for that variable did not begin until 2005. Trend analysis was not performed on this lake since it was only sampled for three years.

Sylvia Lake

Sylvia Lake is located in the Salish Mountains twenty three miles west of Whitefish, MT in the Salish Mountain Range at an elevation of 5,199 feet. It has a surface area of 22 acres and a watershed area of 172 acres. The Pricard formation belt series makes up 87% of the watershed while the remainder is composed of the Ravalli group belt series.

Sylvia Lake was sampled each year from 1995 to 1997. Total phosphorus (mean = 7 µg $L^{-1}$) and chlorophyll *a* (mean = 0.8 µg $L^{-1}$) concentrations indicate Sylvia Lake is oligotrophic. Total nitrogen analysis was not funded until 2005, thus data for that variable were not available. Trend analysis was not performed on this lake since it was only sampled for three years.

Tepee Lake

Tepee Lake is located in the North Fork Flathead River drainage, north of Polebridge, MT at the base of the Whitefish Mountain Range. It has a surface area of 43 acres and a catchment area of 7,070 acres at an elevation of 4,054 feet. The lake has a maximum depth of approximately 14 feet. This is one of the shallowest lakes sampled by the Volunteer Lake Monitoring Project and by far the largest catchment area of the small lakes sampled. The geology of the catchment area is a combination of the Piegan group belt series (75%) and glacial till (25%).

Tepee Lake was sampled three times from 1996 to 2001. Total phosphorus (mean = 13 µg $L^{-1}$), chlorophyll *a* (mean = 2.8 µg $L^{-1}$), and Secchi depth measures (mean = 4.0 m) indicate Tepee Lake is an

oligomesotrophic lake. Total nitrogen analysis did not begin until 2005, thus data was not available. Trend analysis was not performed on this lake since it was only sampled for three years.

Tetrault Lake

Tetrault Lake is located north of Eureka, MT in the Tobacco Plains along the eastern side of Lake Koocanusa at an elevation of 2,718 feet. It has a surface area of 96 acres and a catchment area of 924 acres. The catchment is composed of glacial till (65%) and glacial lake deposits (24%).

Tetrault Lake was only sampled in 1993. Total phosphorus (18 µg $L^{-1}$) and chlorophyll *a* (3.2 µg $L^{-1}$) concentrations measured in this single water sample indicate Tetrault Lake may be mesooligotrophic.

Lake of the Woods

Lake of the Woods is located in the Flathead Valley northwest of Flathead Lake in the western foothills of Hash Mountain at an elevation of 2,985 feet. It has a surface area of 63 acres, a catchment area of 365 acres and a maximum depth of approximately 20 feet. The catchment is entirely glacial till and alluvium.

Lake of the Woods was sampled nine times from 1995 to 2007. Total phosphorus (mean = 8 µg $L^{-1}$), total nitrogen (mean = 253 µg $L^{-1}$), chlorophyll *a* (mean = 1.3 µg $L^{-1}$), and Secchi depth measures (mean = 7.3 m) indicate Lake of the Woods is an oligotrophic lake. Time series trend analysis indicated no trend in either total phosphorus or chlorophyll *a* concentrations during the period of record.

***Medium Lakes (Surface Area 100–500 Acres)***

Beaver Lake

Beaver Lake is located northwest of Whitefish, MT on the northern edge of Lion Mountain at an elevation of 3,258 feet. Beaver Lake has a surface area of 144 acres and a catchment area of 2,043 acres. The maximum depth is over 95 feet. The catchment is composed of the Piegan group belt series (46%) and alluvium (38%).

There are 2 sites on Beaver Lake that were sampled. The West End site (we) was sampled ten times between 1994 and 2003, while the Woods Point site (wp) was only sampled three times between 1996 and 2000. Total phosphorus ($mean_{we}$ = 11 µg $L^{-1}$, $mean_{wp}$ = 10 µg $L^{-1}$), chlorophyll *a* ($mean_{we}$ = 1.8 µg $L^{-1}$, $mean_{wp}$ = 4.0 µg $L^{-1}$), and Secchi depth measures ($mean_{we}$ = 6.3 m, $mean_{wp}$ = 6.1 m) indicate Beaver Lake is an oligomesotrophic lake. Beaver Lake was stratified each time a dissolved oxygen profile was measured and the lowest oxygen level recorded was 1.8% saturation or 0.19 mg $L^{-1}$. As mentioned previously, increased loading of phosphorus to the lake from bottom sediments can occur at this low level of dissolved oxygen. Total nitrogen analysis was not performed prior to 2005, thus no data

were available. No trends in either variable were apparent from samples collected at the West End site. Trend analysis was not conducted on Woods Point data since it was only sampled three times.

Lake Blaine

Lake Blaine is located west of Kalispell, MT at the base of the Swan Mountain Range at an elevation of 2,999 feet. Lake Blaine has a surface area of 372 acres and a catchment area of 18,963 acres with a mean depth of 51 feet and the maximum depth recorded was 141 feet. The catchment is composed of glacial till (53%), Appekunny argillite belt series (36%) and glacial lake deposits (2%).

Lake Blaine was sampled each year from 1994 to 1997. Total phosphorus (mean = 17 µg $L^{-1}$) and chlorophyll *a* (mean = 6.5 µg $L^{-1}$) concentrations indicate Lake Blaine is mesooligotrophic. Time series trend analysis revealed a statistically significant ($p = 0.03$) positive trend in total phosphorus concentrations; total phosphorus was increasing at a rate of 5.4 µg $L^{-1}$ $yr^{-1}$. Although chlorophyll *a* concentrations appeared to be increasing as well, the trend was not statistically significant. The rate of increasing total phosphorus measured during the 4-year period was quite high, but a strong case for declining water quality cannot be made with 4 data points. However, this information should prompt initiation of the monitoring program at Lake Blaine once again so that a longer time series can provide insight into potentially changing conditions in this lake.

Blanchard Lake

Blanchard Lake is located southwest of Whitefish, MT in the Whitefish River drainage at an elevation of 3,179 feet. It has a surface area of 135 acres, a catchment area of 2,649 acres and a maximum depth of approximately 30 feet. The geologic formations in the watershed are dominated by glacial till (54%) with the remaining drainage area in the Piegan group belt series.

Blanchard Lake was sampled every year from 1994 to 2006 except for 2004. Vertical profiling of temperature and dissolved oxygen indicates that the lake is occasionally stratified in late summer. Total phosphorus (mean = 14 µg $L^{-1}$), total nitrogen (mean = 623 µg $L^{-1}$), chlorophyll *a* (mean = 2.0 µg $L^{-1}$), and Secchi depth measures (mean = 4.7 m) indicate Blanchard Lake is an oligomesotrophic lake. When the lake was stratified, dissolved oxygen measured at the bottom reached a low of 6.7% saturation (0.06 mg $L^{-1}$). At this low level of dissolved oxygen, phosphorus loading to the lake from the sediments would occur. Time series trend analysis does not indicate any trends in either total phosphorus or chlorophyll *a* concentrations.

Crystal Lake

Crystal Lake is located west of Kalispell, MT between the Salish and Cabinet Mountain Ranges in the Thompson Lakes chain at an elevation of 3,399 feet. It has a surface area of 191 acres and a catchment area of 1,559 acres. The catchment area is entirely alluvium.

Crystal Lake was sampled in 1995. Total phosphorus (11 µg $L^{-1}$) and chlorophyll *a* (1.9 µg $L^{-1}$) concentrations indicate Crystal Lake is probably an oligomesotrophic lake.

Lake Five

Lake Five is at an elevation of 3,261 feet located at the northwest toe of the Flathead Mountain Range in the upper Flathead River drainage south of West Glacier, MT. Lake Five is on the valley floor with a surface area of 145 acres and a catchment area of 4,360 acres. The maximum depth recorded was 63 feet. The drainage basin is dominated by glacial till (68%) with the remainder lying in the Grinnel argillite belt series.

Lake Five was sampled thirteen times from 1993 to 2007. Vertical profiling of temperature indicates that the lake is stratified in late summer. Total phosphorus (mean = 10 µg $L^{-1}$), total nitrogen (mean = 350 µg $L^{-1}$), chlorophyll *a* (mean = 3.0 µg $L^{-1}$), and Secchi depth measures (mean = 6.9 m) indicate Lake Five is oligotrophic. The lowest dissolved oxygen concentration measured at the bottom of the lake was 4.3% saturation (0.5 mg $L^{-1}$). Results from time series trend analysis of chlorophyll *a* concentrations indicate a significant increase occurred between 1993 and 2007 ($p = 0.02$). Chlorophyll *a* concentrations are increasing at a rate of 0.30 µg $L^{-1}$ $yr^{-1}$. At this rate Lake Five is rapidly approaching mesotrophy. Although total phosphorus appeared to be increasing over the period of record, variability was quite high and the trend was not statistically significant; however, the trend was relatively close to significance at $p=0.071$. Continued monitoring of the apparent decline in water quality is clearly needed in Lake Five.

Foy Lake

Foy Lake is located southwest of Kalispell, MT in the foothills of the Salish Mountains at an elevation of 3,301 feet. It has a surface area of 232 acres, a drainage basin of 6,023 acres and a maximum recorded depth of 138 feet. The basin area is dominated by the Piegan group belt series (86%) of the Salish Mountains with the remainder composed of glacial till.

Foy Lake was sampled three times from 1994 to 1997. Total phosphorus (mean = 8 µg $L^{-1}$) and chlorophyll *a* (mean = 1.8 µg $L^{-1}$) concentrations indicate Foy Lake is oligotrophic. Total nitrogen data were not available prior to 2005. Trend analysis was not performed on this lake since it was only sampled for three years.

Glen Lake

Glen Lake is located southeast of Eureka, MT at the foot of the western edge of the Whitefish Mountain Range at an elevation of 2,999 feet. It has a surface area of 297 acres, a basin area of 4,839 acres and a maximum depth of approximately 38 feet. The basin area is composed of alluvium (65%) and the Piegan group belt series (26%).

Glen Lake was sampled each year from 1994 to 1997. Total phosphorus (mean = 9 µg $L^{-1}$), chlorophyll *a* (mean = 0.9 µg $L^{-1}$), and Secchi depth measures (mean = 6.0 m) indicate Glen Lake is an oligotrophic lake. Trend analysis revealed a statistically significant increase in chlorophyll *a* concentration from 1994 to 1997 at a rate of 0.28 µg $L^{-1}$ $yr^{-1}$ ($p = 0.02$). Although not statistically significant, the data suggest that total phosphorus may also be increasing at the rate of about 0.95 µg $L^{-1}$ $yr^{-1}$. Although only 4 years of data have been collected, these results merit closer examination of Glen Lake, hence a continuous monitoring program should be reinstated.

Holland Lake

Holland Lake is located south of Condon, MT in the headwaters of the Swan River in the Swan Mountain Range at an elevation of 4,199 feet. It has a surface area of 423 acre, a basin area of 5,319 acres and the maximum depth recorded was 156 feet. The basin area is composed of both the Piegan group (39%) and Missoula group (32%) belt series and alluvium (20%).

Holland Lake was sampled four times from 1997 to 2005. Vertical profiling of temperature and dissolved oxygen indicate that the lake is stratified in late summer. Total phosphorus (mean = 11 µg $L^{-1}$), total nitrogen (single measure = 127 µg $L^{-1}$) and chlorophyll *a* (mean = 1.3 µg $L^{-1}$) concentrations indicate Holland Lake is oligotrophic. The lowest dissolved oxygen content measured in the hypolimnion (not at the lake bottom) was 38% saturation. Results from time series trend analysis of total phosphorus and chlorophyll *a* concentrations indicate no trends during the period of record.

Stillwater Lake, Lower

Lower Stillwater Lake is located south of Olny, MT in the Stillwater River Valley between the Whitefish and Salish Mountain Ranges at an elevation of 3,199 feet. It has a surface area of 281 acres, a drainage area of 103,490 acres and a maximum recorded depth of 53 feet. Lower Stillwater Lake has the largest drainage area by far of all the medium sized lakes. The geology of the drainage area is composed of alluvium (37%) and the Piegan group (19%), Ravalli group (19%) and Wallace formation (23%) of the belt series..

Lower Stillwater Lake was sampled four times from 1993 to 2003. Total phosphorus (mean = 25 µg $L^{-1}$), chlorophyll *a* (mean = 5.3 µg $L^{-1}$), and Secchi depth measures (mean = 5.5 m) indicate Lower Stillwater Lake is a mesotrophic lake. Total nitrogen analysis did not begin until 2005. No trend was apparent in either total phosphorus or chlorophyll *a* concentrations.

Murphy Lake

Murphy Lake is located south of Fortine, MT at the base of the Whitefish Mountain Range at an elevation of 3,150 feet. The surface area of Murphy Lake is 239 acres and the drainage area is 3,066 acres. The geology of the drainage basin is a composite of alluvium (52%), Ravalli group belt series (26%) and the Piegan group belt series (16%).

Murphy Lake was only sampled in 1995. Total phosphorus (9 µg $L^{-1}$) and chlorophyll *a* (1.3 µg $L^{-1}$) concentrations in the sample indicate Murphy Lake is probably oligotrophic.

Rogers Lake

Rogers Lake is located southeast of Marion, MT on the northern flanks of Haskill Mountain in the Salish Mountain Range at an elevation of 3,999 feet. It has a surface area of 239 acres, a drainage area of 3,066 acres and a maximum recorded depth of 16 feet. This is the shallowest of the medium sized lakes sampled as part of the Volunteer Lake Monitoring Project. The catchment is dominated by the Wallace formation belt series (75%) with the rest as glacial till.

Rogers Lake was sampled thirteen times from 1994 to 2007. Total phosphorus (mean = 16 µg $L^{-1}$), total nitrogen (mean = 742 µg $L^{-1}$), chlorophyll *a* (mean = 2.0 µg $L^{-1}$), and Secchi depth measures (mean = 4.6 m) indicate Rogers Lake is an oligo-mesotrophic lake. Vertical profiling of temperature indicates that the lake is not stratified in late summer. Time series trend analysis showed no trend in chlorophyll *a* concentrations. However, there is a highly significant increasing trend in total phosphorus concentration at a rate of 0.87 µg $L^{-1}$ $yr^{-1}$ ($p = 0.001$). Continued monitoring of Rogers Lake is clearly needed to assess a potential decline in water quality from the increasing total phosphorus.

***Large Lakes (Surface Area >500 Acres)***

Ashley Lake

Ashley Lake is located west of Kalispell, MT in the Salish Mountain Range at an elevation of 3,999 feet. It has a surface area of 2,840 acres, a basin area of 21,488 acres and a maximum depth of approximately 225 feet. The catchment is composed of the Wallace formation belt series (59%) glacial lake deposits (26%) and the Ravalli group belt series (3%).

There are two sites on Ashley Lake that were sampled. The northeast middle site (ne) was sampled nine times from 1993 to 2007, and the west end site (w) was sampled seven times from 1995 to 2007. Total phosphorus ($mean_{ne}$ = 16 µg $L^{-1}$, $mean_{w}$ = 14 µg $L^{-1}$), chlorophyll *a* ($mean_{ne}$ = 3.1 µg $L^{-1}$, $mean_{w}$ = 0.8 µg $L^{-1}$), and Secchi depth measures ($mean_{ne}$ = 8.6 m, $mean_{w}$ = 8.1 m) indicate Ashley Lake is oligomesotrophic. Time series trend analysis showed no trend in either total phosphorus or chlorophyll *a* concentrations at either site.

Bowman Lake

Bowman Lake is located northeast of Polebridge, MT along the western edge of the Lewis Mountain Range in Glacier National Park at an elevation of 3,999 feet. It has a surface area of 1,694 acres, a drainage area of 28,731 acres and a maximum recorded depth of 253 feet. The geology of the

drainage basin encompasses the Siyeh limestone belt series (29%), Grinnel argillite belt series (18%), Appekunny argillite belt series (15%), Missoula group belt series (8%) and glacial till (5%).

Bowman Lake was sampled six times from 1996 to 2005. This lake thermally stratifies in late summer. Total phosphorus (mean = 5 µg $L^{-1}$), chlorophyll *a* (mean = 0.6 µg $L^{-1}$), and Secchi depth measures (mean = 12.2 m) indicate Bowman Lake is an oligotrophic lake. No trends were apparent in either total phosphorus or chlorophyll *a* concentrations over the period of record.

Echo Lake

Echo Lake is at an elevation of 2,999 feet located in the Flathead Valley north west of Flathead Lake on the southern flank of Hash Mountain. It has a surface area of 672 acres, a basin area of 12,935 acres and a maximum depth of 66 feet. The drainage area is a composite of alluvium (52%), Grinnel argillite belt series (26%), Piegan group belt series (7%), glacial till (5%) and the Appekunny argillite belt series (3%).

Echo Lake was sampled eight times from 1993 to 2003. Vertical profiling of temperature and dissolved oxygen indicate that the lake is stratified in late summer and the minimum dissolved oxygen concentration recorded was 5.3% saturation (0.7 mg $L^{-1}$). Total phosphorus (mean = 15 µg $L^{-1}$), total nitrogen (single measure of 133 µg $L^{-1}$), chlorophyll *a* (mean = 2.9 µg $L^{-1}$), and Secchi depth measures (mean = 5.9 m) indicate Echo Lake is oligomesotrophic. Results from time series trend analysis of total phosphorus and chlorophyll *a* concentrations indicate no statistically significant trends are occurring.

Flathead Lake

Flathead Lake is located south of Kalispell, MT between the Mission and Salish Mountain Ranges at an elevation of 2,884 feet. It has a surface area of 122,425 acres, a basin area of 4,522,476 acres and a maximum depth of 368 feet. This is the largest lake in the study and only the results from the volunteer effort are summarized here. The geology of the Flathead Basin is a composite of numerous belt series formations (Appekunny argillite (4%), Grinnel argillite (6%), Missoula group (18%), Piegan group (10%), Ravalli group (4%), Siyeh limestone (3%) and Wallace formation (5%)), alluvium (14%), undifferentiated Cambrian (3%), glacial (8%), and undifferentiated tertiary sedimentary rocks (5%). The geology includes the Canadian portion of the watershed, hence the slight overlap in conventional designation of formations. All geological formations that comprised <3% of the total basin composition were not listed. See Stanford and Ellis (2002), Stanford et al. (1997) and Ellis (2006) for more in depth analysis of Flathead Lake limnology.

There were a total of sixteen sites sampled on Flathead Lake from 1994 to 2007 as a part of the Volunteer Lake Monitoring Project. Flathead Lake is stratified in late summer. Combining the data from all the sites, total phosphorus (mean = 6 µg $L^{-1}$), total nitrogen (mean = 113 µg $L^{-1}$), chlorophyll *a* (mean = 0.7 µg $L^{-1}$), and Secchi depth measures (mean = 7.8 m) indicate Flathead Lake is oligotrophic. Time series trend analysis was conducted on thirteen of the sites (those with more than three years of

sampling). Of the sites analyzed, three had a significant trend in either total phosphorus concentrations or both total phosphorus and chlorophyll *a* concentrations. At the Crescent Bay site (sampled four times from 1994 to 1998) there were significantly positive trends in both total phosphorus ($p = 0.03$) and chlorophyll *a* ($p = 0.01$) concentrations. The rate of increase in total phosphorus was 0.52 μg $L^{-1}$ $yr^{-1}$ and the rate of increase for chlorophyll *a* was 0.21 μg $L^{-1}$ $yr^{-1}$. At the Indian Bay site (sampled each year from 1994 to 1999) there was a significant increase in the total phosphorus concentration ($p = 0.03$) at a rate of 0.74 μg $L^{-1}$ $yr^{-1}$. At the Mack Alley site (sampled each year from 1994 to 1999) there were significantly positive trends in both total phosphorus ($p = 0.02$) and chlorophyll *a* ($p = 0.02$) concentrations. The rate of increase in the total phosphorus concentration was 0.62 μg $L^{-1}$ $yr^{-1}$ and the rate of increase for the chlorophyll *a* concentration was 0.10 μg $L^{-1}$ $yr^{-1}$.

None of the sites with significant increases have been sampled since 1999. The period of monitoring at these sites was quite short, at only 4–6 years. Other sites on Flathead Lake (Mission View Terrace, Marco Bay and Somers Bay) were monitored during the same time period (1994 to 1999) but were also sampled from 2000 to 2007. Interestingly, many of those sites also showed an increase during the early years but the trends did not continue and thus were not significant. Since the long-term monitoring of Flathead Lake occurs at only a single midlake deep site in the lake, it is important that all of the near shore sites be continuously monitored to detect any changes in water quality that might develop first in bays or close proximity to shore.

Kintla Lake

Kintla Lake is located northeast of Polebridge, MT along the western edge of the Lewis Mountain Range in Glacier National Park at an elevation of 4,190 feet. It has a surface area of 1,690 acres, a basin area of 34,665 acres and a maximum depth of approximately 390 feet. The catchment of Kintla Lake is dominated by the Siyeh limestone belt series (13%), followed by undifferentiated tertiary sedimentary rocks (5%), and Appekunny argillite (3%), Grinnel argillite (4%) and Missoula group (2%) belt series, Purcell Supergroup (Nicol Creek, Sheppard, Gateway, Phillips, Rooseville sedimentary formations: 49%), Purcell Supergroup (Kitchener Formation dolomitic carbonates: 19%). The geology includes the Canadian portion of the watershed, hence the slight overlap in conventional designation of formations. All geological formations that comprised <3% of the total basin composition were not listed.

Kintla Lake was sampled five times from 1996 to 2001. This lake thermally stratifies in late summer. Total phosphorus (mean = 4 μg $L^{-1}$), chlorophyll *a* (mean = 0.5 μg $L^{-1}$), and Secchi depth measures (mean = 13.2 m) indicate Kintla Lake is oligotrophic. Results from time series trend analysis of total phosphorus and chlorophyll *a* concentrations indicate no apparent trends.

Lindbergh Lake

Lindbergh Lake is located in the headwaters of the Swan River on the eastern side of the Mission Mountain Range south of Condon, MT at an elevation of 4,400 feet. It has a surface area of 832 acres, a

basin area of 26,065 acres and the maximum depth measured was 121 feet. The geology of the basin is composed of the Missoula group (77%) and Piegan group (19%) belt series.

Lindbergh Lake was sampled five times from 1997 to 2005. This lake thermally stratifies in late summer. Total phosphorus (mean = 9 µg $L^{-1}$), chlorophyll *a* (mean = 1.4 µg $L^{-1}$), and Secchi depth measures (mean = 9.3 m) indicate Lindbergh Lake is oligotrophic. Time series trend analysis showed no trends in total phosphorus or chlorophyll *a* concentrations.

Little Bitterroot Lake

Little Bitterroot Lake is located west of Kalispell, MT in the Salish Mountain Range at an elevation of 3,999 feet. It has a surface area of 2,941 acres, a basin area of 21,987 acres and a maximum recorded depth of 246 feet. The catchment of Little Bitterroot Lake is composed of the Wallace formation belt series (31%), alluvium (28%), Picard formation belt series (17%) and the Ravalli group belt series (11%).

Little Bitterroot Lake was sampled six times from 1995 to 2006. Total phosphorus (mean = 11 µg $L^{-1}$), total nitrogen (mean = 171 µg $L^{-1}$), chlorophyll *a* (mean = 1.0 µg $L^{-1}$), and Secchi depth measures (mean = 13.4 m) indicate Little Bitterroot Lake is an oligotrophic lake. Time series trend analysis showed no trends in either total phosphorus or chlorophyll *a* concentrations for the period of record.

Lake Mary Ronan

Lake Mary Ronan is located west of Proctor, MT in the Salish Mountain Range at an elevation of 3,711 feet. It has a surface area of 1,492 acres, a basin area of 18,977 acres and a maximum depth of approximately 47 feet. The geology of the drainage area is dominated by the Ravalli group belt series (87%) with the remainder split between the Wallace formation belt series (4%) and glacial till (1%).

There are two sites on Lake Mary Ronan that were sampled. The east middle site (em) was sampled eight times from 1995 to 2007, and the west middle site (wm) was sampled six times from 1993 to 2005. Total phosphorus ($mean_{em}$ = 75 µg $L^{-1}$, $mean_{wm}$ = 40 µg $L^{-1}$), chlorophyll *a* ($mean_{em}$ = 6.6 µg $L^{-1}$, $mean_{wm}$ = 6.4 µg $L^{-1}$), and Secchi depth measures ($mean_{em}$ = 5.7 m, $mean_{wm}$ = 5.6 m) indicate Lake Mary Ronan is a mesoeutrophic lake. No trends were apparent in either total phosphorus or chlorophyll *a* concentrations at either site.

McDonald Lake

McDonald Lake is located north of West Glacier, MT at the base of the Lewis Mountain Range in Glacier National Park at an elevation of 3,150 feet. It has a surface area of 6,898 acres, a basin area of 112,840 acres and a maximum depth of 430 feet. The geology of the drainage basin encompasses the Missoula group belt series (27%), Siyeh limestone belt series (24%), Grinnel argillite belt series (10%), Appekunny argillite belt series (8%), alluvium (4%) and glacial till (4%).

McDonald Lake was sampled ten times from 1996 to 2007. This lake thermally stratifies in late summer. Total phosphorus (mean = 5 µg $L^{-1}$), total nitrogen (mean = 274 µg $L^{-1}$), chlorophyll *a* (mean = 0.6 µg $L^{-1}$), and Secchi depth measures (mean = 12.9 m) indicate McDonald Lake is oligotrophic. Time series trend analysis showed no trends in either total phosphorus or chlorophyll *a* concentrations for the period of record.

McGregor Lake

McGregor Lake is located in the Salish Mountain Range west of Marion, MT at an elevation of 3,999 feet. It has a surface area of 1,500 acres and a drainage basin of 7,560 acres. The McGregor Lake catchment is dominated by the Ravalli group belt series (69%) with the rest consisting of glacial till and alluvium.

McGregor Lake was only sampled in 1995. Total phosphorus (6 µg $L^{-1}$) and chlorophyll *a* (0.7 µg $L^{-1}$) concentrations in the sample indicate McGregor Lake is probably oligotrophic.

Stillwater Lake, Upper

Upper Stillwater Lake is located north of Olny, MT in the Stillwater River Valley between the Whitefish and Salish Mountain Ranges at an elevation of 3,199 feet. It has a surface area of 694 acres, a drainage area of 79,986 acres and a maximum depth of 75 feet.The geology of the drainage basin encompasses alluvium (25%), and the Wallace formation (27%), Ravalli group (20%) and Piegan group (27%) of the belt series.

Upper Stillwater Lake was sampled three times from 1993 to 1999. Total phosphorus (mean = 10 µg $L^{-1}$), chlorophyll *a* (mean = 1.3 µg $L^{-1}$), and Secchi depth measures (mean = 7.0 m) indicate Upper Stillwater Lake is an oligotrophic lake. No total nitrogen data were available. Trend analysis was not performed on data from this lake since it was only sampled for three years.

Swan Lake

Swan Lake is located next to Swan Lake, MT between the Mission and Swan Mountain Ranges at an elevation of 3,199 feet. It has a surface area of 3,276 acres, a basin area of 421,612 acres and a maximum depth of 133 feet. The basin area is composed of alluvium (36%), and the Piegan group (30%), Missoula group (15%), Grinnel argillite (13%) and Appekunny argillite (4%) belt series.

There were a total of four sites sampled on Swan Lake from 1993 to 2007. Swan Lake is stratified in late summer. Combining the data from all the sites, total phosphorus (mean = 6 µg $L^{-1}$), total nitrogen (mean = 89 µg $L^{-1}$), chlorophyll *a* (mean = 4.2 µg $L^{-1}$), and Secchi depth measures (mean = 6.2 m) indicate Swan Lake is an oligotrophic lake. An analysis of the time series from each site indicates no trends in total phosphorus or chlorophyll *a* concentrations for the period of record.

Tally Lake

Tally Lake is located west of Whitefish, MT in the Salish Mountain Range at an elevation of 3,399 feet. It has a surface area of 1,206 acres, a basin area of 115,260 feet and is the deepest natural lake in Montana at 495 feet. The basin area is composed of the Wallace formation belt series (55%), Picard formation belt series (20%), alluvium (13%) and the Ravalli group belt series (11%).

Talley Lake was sampled each year from 1993 to 1998. Total phosphorus (mean = 11 µg $L^{-1}$), chlorophyll *a* (mean = 0.9 µg $L^{-1}$), and Secchi depth measures (mean = 4.5 m) indicate Tally Lake is an oligotrophic lake. Analysis of samples for total nitrogen analysis did not begin until 2005, thus no nitrogen data was available. No trends were apparent in either total phosphorus or chlorophyll *a* concentrations.

Middle Thompson Lake

Middle Thompson Lake is located west of Kalispell, MT between the Salish and Cabinet Mountain ranges in the Thompson Lakes chain at an elevation of 3,399 feet. It has a surface area of 557 acres and a basin area of 20,293 acres. The basin area is composed of the Ravalli group belt series (64%), alluvium (30%) and the Wallace formation belt series (1%).

Middle Thompson Lake was only sampled in 1995. Total phosphorus (15 µg $L^{-1}$) and chlorophyll *a* (1.9 µg $L^{-1}$) concentrations in the sample indicate Middle Thompson Lake is oligo-mesotrophic.

Whitefish Lake

Whitefish Lake is located next to Whitefish, MT at the southern end of the Whitefish Mountain Range at an elevation of 2,989 feet. It has a surface area of 3,299 acres, a basin area of 76,519 acres and a maximum depth of 223 feet. The geology of the basin is largely composed of the Piegan group belt series (42%) and alluvium (43%), with smaller formations of Grinnel argillite (8%) and Ravalli group (2%) belt series.

There were a total of three sites sampled on Whitefish Lake from 1994 to 2007. Whitefish Lake is stratified in late summer. Combining the data from all the sites, total phosphorus (mean = 6 µg $L^{-1}$), total nitrogen (mean = 83 µg $L^{-1}$), chlorophyll *a* (mean = 0.8 µg $L^{-1}$), and Secchi depth measures (mean = 7.8 m) indicate Whitefish Lake is an oligotrophic lake. Time series trend analyses indicated no trend in total phosphorus or chlorophyll *a* concentration for the period of study.

## SUMMARY – FUTURE MONITORING

The recent addition of nitrogen analysis will clearly add to our understanding of the natural range of nitrogen in this region and over the long-term, will provide a means for evaluating any potential trends in this important nutrient. In Flathead Lake, both nitrogen and phosphorus stimulate the production of algae (Spencer and Ellis 1990). The ratio of nitrogen to phosphorus is often used to determine which

nutrient is in the lowest supply and is thus limiting production. In general, if the molar ratio is less than 16:1 (Redfield ratio), then the lake is likely nitrogen limited but if it is more than 16:1, then it is likely phosphorus limited. The addition of that limiting nutrient will stimulate the production of algae in a lake which can result in a decline in water quality. The average molar ratio of nitrogen to phosphorus in all of the volunteer lakes where both were measured was 60 $\pm$ 33, with a range of 20–126. This indicates that the large majority of lakes should be phosphorus limited in our region; that is, that phosphorus is the nutrient most likely to stimulate the production of algae in the lake. However, keep in mind that ratios near the Redfield number can exhibit co-limitation by both nutrients (i.e., that both nitrogen and phosphorus can stimulate algal growth, particularly during summer).

A number of lakes exhibited statistically significant increasing trends in total phosphorus and/or chlorophyll *a*: Bailey Lake, Lake Blaine, Lake Five, Glen Lake, Rogers Lake and 3 bays or areas of Flathead Lake (Crescent Bay, Indian Bay and Mack Alley). Those lakes that were monitored for 10 years or more and showed significant increasing trends are of particular concern: Bailey Lake, Lake Five and Rogers Lake. Due to natural interannual variation in nutrient concentrations and biological response variables, like chlorophyll, a record of only 4 years is short and inconclusive (e.g., Lake Blaine, Glen Lake and Crescent Bay in Flathead Lake). The period of record was a bit longer at 6 years for Indian Bay and Mack Alley in Flathead Lake. Long-term records of nutrient and response variables for lakes, including Flathead Lake, have shown that selection of only a few years can result in a false interpretation due to the natural fluctuation inherent in these complex systems (Wetzel 2001, Ellis 2006). However, even though the record was short for some of these lakes, a positive trend in nutrients or chlorophyll warrants a more thorough examination. Monitoring was discontinued for some of these lakes and every effort should be made to reinstate the annual measures. It is difficult to monitor trends when data are collected sporadically and on top of that, there is natural variation that occurs in the ecosystem from climatic factors (e.g., temperature, hydrology). Hence it is very important that a continuous record of these water quality criteria is maintained, so that interannual variation in the criteria is monitored as well. In addition, every effort should be made to obtain water samples as near to the same time every year as possible – from late July to early August.

There were also a couple of lakes which exhibited very large spikes in nutrients and/or chlorophyll that should be closely monitored. The spike in total phosphorus in Lake Mary Ronan was 3.5X the next highest value (Figure 6), while in Jette Lake the spike was 6X the next highest measure (Figure 2) of a lake in their size class. Chlorophyll *a* was also orders of magnitude higher in Jette Lake on the same date in 1998 at 4X the next highest value (Figure 1) of a lake in its size class. In some cases, high total phosphorus was observed when high chlorophyll *a* was measured; such coherence suggests the measures were valid. We were unable to attribute any of the results from the aforementioned sites to contamination during collection, but it is always a possibility. In addition to continuing to monitor these lakes annually, sufficient funds should be sought to include the collection of duplicate samples and blank quality control field samples to enhance the quality control of sample collection. Other smaller peaks in

monitoring criteria were observed in Loon Lake, McCaffery Lake, Lower Stillwater Lake, Lake Blaine, Ashley Lake and Lake Five.

The volunteers and Flathead Basin Commission staff should be applauded for their efforts. At very minimal costs, baseline data have now been generated for 43 lakes in northwestern Montana. Some warning signs are evident and should not be ignored. With perhaps the combined effort of the volunteers and the Flathead Basin Commission, additional funding should be sought to add a seasonal component to the sampling in addition to the recommendations above. Seasonal monitoring would not only provide a more statistically sound basis for trend analysis but would also provide reference data for EPA's development of defensible water quality criteria that are protective of designated uses. Water may be the State's most valuable resource and protecting that resource should be everyone's concern.

## REFERENCES

American Public Health Association. 1985. Standard methods for the examination of water and wastewater (16th ed.). American Public Health Association, Washington, District of Columbia. 1,193 pp.

Ellis, B. K. 2006. Alternate states in a large oligotrophic lake: A retrospective analysis of nutrient loading and food web change. Ph.D. dissertation, The University of Montana.

Marker, A. F. H., E. A. Nusch, H. Rai and B. Riemann. 1980. The measurement of photosynthetic pigments in freshwater and standardization of methods: Conclusions and recommendations. Ergebnisse der Limnologie. 14:91–106.

Spencer, C. N. and B. K. Ellis. 1990. Co-limitation by phosphorus and nitrogen, and effects of zooplankton mortality on phytoplankton in Flathead Lake, Montana, U.S.A. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 24:206–209.

Stanford, J. A. and B. K. Ellis. 2002. Natural and cultural influences on ecosystem processes in the Flathead River Basin (Montana, British Columbia), p. 269–284. *In* J. S. Baron [ed.], Rocky Mountain Futures: An Ecological Perspective. Island Press.

Stanford, J. A., B. K. Ellis, J. A. Craft, and G. C. Poole. 1997. Water Quality Data and Analyses to Aid in the Development of Revised Water Quality Targets for Flathead Lake, Montana, p. 154 + Appendices 111. Prepared for The Flathead Basin Commission, Kalispell, Montana by Flathead Lake Biological Station, The University of Montana.

USEPA. 2000. Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria; Lakes and Reservoirs in Nutrient Ecoregion II, U. S. Environmental Protection Agency, Washington, D. C. EPA-822-B-00-007.

Wetzel, R. G. 2001. Limnology. (3$^{nd}$ edition). Academic Press, New York, NY. 1006 pp.

Wetzel, R. G. and G. E. Likens. 1991. Limnological Analyses. Springer-Verlag, New York, New York.

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Table 1. Biophysical variables and methods used in monitoring water quality for the Volunteer Lakes Monitoring Program.

| Variable (units) | Method (references) | Detection limit |
|---|---|---|
| Analyses of water samples | | |
| phosphorus (µg $L^{-1}$-P) | | |
| total | persulfate digestion; modified automated ascorbic acid (1) | 0.3 |
| nitrogen (µg/l-N) | | |
| total persulfate | persulfate digestion (2); auto. cadmium reduction (1) | 20.0 |
| Biological analyses | | |
| chlorophyll *a* (mg $m^{-3}$) | acetone extraction (1,2) | 0.1 |
| Physical profiles | | |
| temperature (°C) | thermistor (3) | 0.15 |
| dissolved oxygen (ppm) | electrode (3) | 0.2 |
| Secchi depth (m) | Secchi disk (4) | 0.25 |

[1]APHA, 2005

[2]Marker *et al.*, 1980

[3]measured *in situ* using YSI system

[4] Wetzel and Likens, 1991

Table 2. Location and physical attributes of lakes monitored in the Volunteer Lakes Monitoring Program from 1993–2007.

| Lake | County | Latitude °N | Longitude °W | Surface area (acre) | Basin area (acre) | Max depth[1] (ft) | Elevation (ft) |
|---|---|---|---|---|---|---|---|
| **Small Lakes (surface area <100 acres)** | | | | | | | |
| Abbot Lake | Flathead | 48.1181 | 114.0518 | 41 | 121 | 20 | 2,999 |
| Bailey Lake | Flathead | 48.4707 | 114.1323 | 16 | 2,638 | 30 | 3,399 |
| Halfmoon Lake | Flathead | 48.4717 | 114.0070 | 55 | 1,387 | 20 | 3,300 |
| Hanson-Doyle Lake | Flathead | 48.3585 | 114.4668 | 8 | 175 | 33 | 3,199 |
| Jette Lake | Lake | 47.7589 | 114.2493 | 26 | 1,198 | 30 | 3,791 |
| Lavon Lake | Lincoln | 48.0806 | 115.1463 | 17 | 984 | | 3,599 |
| Lion Lake | Flathead | 48.3712 | 114.0314 | 36 | 818 | 88 | 3,532 |
| Loon Lake | Lake | 48.0236 | 113.9901 | 44 | 112 | 33 | 3,100 |
| McCaffery Lake | Flathead | 48.1087 | 114.0620 | 21 | 85 | 42 | 2,999 |
| McGilvray Lake | Flathead | 48.1430 | 114.0810 | 37 | 237 | 33 | 2,983 |
| Peterson Lake | Flathead | 48.1222 | 114.0603 | 94 | 304 | 30 | 2,999 |
| Skyles Lake | Flathead | 48.4063 | 114.4021 | 38 | 1,260 | 13 | 3,199 |
| Spencer Lake | Flathead | 48.3937 | 114.4188 | 30 | 1,663 | | 3,199 |
| Sylvia Lake | Flathead | 48.3432 | 114.8196 | 22 | 172 | | 5,199 |
| Tepee Lake | Flathead | 48.9041 | 114.4205 | 43 | 7,070 | 14 | 4,054 |
| Tetrault Lake | Lincoln | 48.9454 | 115.1156 | 96 | 924 | | 2,718 |
| Woods, Lake of the | Flathead | 48.1451 | 114.0560 | 63 | 365 | 20 | 2,985 |
| **Medium Lakes (surface area 100–500 acres)** | | | | | | | |
| Beaver Lake | Flathead | 48.4343 | 114.4237 | 144 | 2,043 | 95+ | 3,258 |
| Blaine, Lake | Flathead | 48.2453 | 114.1185 | 372 | 18,963 | 141 | 2,999 |
| Blanchard Lake | Flathead | 48.3799 | 114.3647 | 135 | 2,649 | 30 | 3,179 |
| Crystal Lake | Lincoln | 48.0745 | 115.1413 | 191 | 1559 | | 3,399 |
| Five, Lake | Flathead | 48.4645 | 114.0206 | 145 | 4,360 | 63 | 3,261 |
| Foy Lake | Flathead | 48.1675 | 114.3618 | 232 | 6,023 | 138 | 3,301 |
| Glen Lake | Lincoln | 48.8642 | 114.9509 | 297 | 4,839 | 38 | 2,999 |

Table 2. (continued)

| Lake | County | Latitude °N | Longitude °W | Surface area (acre) | Basin area (acre) | Max depth[1] (ft) | Elevation (ft) |
|---|---|---|---|---|---|---|---|
| **Medium Lakes (continued)** | | | | | | | |
| Holland Lake | Missoula | 47.4493 | 113.5984 | 423 | 5,319 | 156 | 4,199 |
| Murphy Lake | Lincoln | 48.7349 | 114.8586 | 148 | 13,232 | | 3,150 |
| Rogers Lake | Flathead | 48.0659 | 114.6053 | 239 | 3,066 | 16 | 3,999 |
| Stillwater Lake, Lower | Flathead | 48.5241 | 114.5624 | 281 | 103,490 | 53 | 3,199 |
| **Large Lakes (surface area >500 acres)** | | | | | | | |
| Ashley Lake | Flathead | 48.2125 | 114.5919 | 2,840 | 21,488 | 225 | 3,999 |
| Bowman Lake | Flathead | 48.8410 | 114.1855 | 1,694 | 28,731 | 253 | 4,019 |
| Echo Lake | Flathead | 48.1234 | 114.0377 | 672 | 12,935 | 66 | 2,999 |
| Flathead Lake | Lake | 47.8777 | 114.1176 | 122,425 | 4,522,476 | 368 | 2,884 |
| Kintla Lake | Flathead | 48.9455 | 114.3342 | 1,690 | 34,665 | 390 | 4,190 |
| Lindbergh Lake | Missoula | 47.3892 | 113.7346 | 832 | 26,065 | 121 | 4,400 |
| Little Bitterroot Lake | Flathead | 48.1113 | 114.7179 | 2,941 | 21,987 | 246 | 3,999 |
| Mary Ronan, Lake | Lake | 47.9261 | 114.3958 | 1,492 | 18,977 | 47 | 3,711 |
| McDonald, Lake | Flathead | 48.5632 | 113.9495 | 6,898 | 112,840 | 430 | 3,150 |
| McGregor Lake | Flathead | 48.0382 | 114.8429 | 1,500 | 7,560 | | 3,999 |
| Swan Lake | Lake | 47.9309 | 113.8718 | 3,276 | 421,612 | 133 | 3,199 |
| Tally Lake | Flathead | 48.4187 | 114.5637 | 1,206 | 115,260 | 495 | 3,399 |
| Thompson Lake, Middle | Lincoln | 48.0324 | 115.0746 | 557 | 20,293 | | 3,399 |
| Stillwater Lake, Upper | Flathead | 48.5832 | 114.6324 | 694 | 79,986 | 75 | 3,199 |
| Whitefish Lake | Flathead | 48.4383 | 114.3698 | 3,299 | 76,519 | 223 | 2,989 |

[1]Maximum depth is an approximation; see methods.

Table 3. Chlorophyll *a* (chl *a*), total phosphorus (TP) and total persulfate nitrogen (TN) concentrations ($\mu g\ L^{-1}$) of depth integrated water samples collected for the Volunteer Lakes Monitoring Program from 1993 to 2007.

| Lake | Chl *a* n | Chl *a* mean | Chl *a* min | Chl *a* max | TP n | TP mean | TP min | TP max | TN n | TN mean | TN min | TN max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Small Lakes (surface area <100 acres)** | | | | | | | | | | | | |
| Abbot Lake | 7 | 3.4 | 1.4 | 9.9 | 7 | 12.0 | 8.3 | 14.3 | 2 | 330 | 320 | 340 |
| Bailey Lake | 12 | 1.7 | 0.9 | 2.7 | 12 | 9.3 | 5.8 | 14.5 | 3 | 256 | 226 | 295 |
| Halfmoon Lake | 12 | 1.4 | 0.6 | 2.3 | 12 | 10.9 | 6.9 | 18.6 | 2 | 543 | 451 | 650 |
| Hanson-Doyle Lake | 12 | 2.9 | 0.8 | 4.9 | 12 | 16.0 | 9.1 | 26.7 | 3 | 910 | 857 | 977 |
| Jette Lake | 9 | 12.2 | 1.9 | 65.5 | 9 | 72.7 | 15.8 | 400.4 | 3 | 1010 | 886 | 1211 |
| Lavon Lake | 1 | 8.3 | | | 1 | 20.6 | | | 0 | | | |
| Lion Lake | 3 | 0.9 | 0.7 | 1.1 | 3 | 7.3 | 6.9 | 8.9 | 0 | | | |
| Loon Lake | 7 | 2.0 | 0.4 | 8.7 | 7 | 17.7 | 7.3 | 65.9 | 0 | | | |
| McCaffery Lake | 9 | 5.2 | 1.5 | 16.7 | 9 | 20.6 | 10.9 | 56.2 | 2 | 742 | 724 | 760 |
| McGilvray Lake | 3 | 1.0 | 0.6 | 1.5 | 3 | 9.2 | 7.5 | 10.4 | 3 | 178 | 129 | 258 |
| Peterson Lake | 12 | 2.1 | 0.8 | 4.3 | 12 | 13.1 | 7.0 | 23.0 | 3 | 356 | 352 | 365 |
| Skyles Lake | 9 | 2.3 | 0.6 | 10.0 | 9 | 15.0 | 9.9 | 20.2 | 0 | | | |
| Spencer Lake | 3 | 3.6 | 1.4 | 5.8 | 3 | 22.3 | 14.5 | 35.1 | 0 | | | |
| Sylvia Lake | 3 | 0.8 | 0.5 | 1.3 | 3 | 6.9 | 5.5 | 8.5 | 0 | | | |
| Tepee Lake | 3 | 2.8 | 2.1 | 3.3 | 3 | 13.5 | 11.4 | 14.9 | 0 | | | |
| Tetrault Lake | 1 | 3.2 | | | 1 | 18.4 | | | 0 | | | |
| Woods, Lake of the | 9 | 1.3 | 0.6 | 2.4 | 9 | 8.0 | 5.7 | 10.6 | 2 | 253 | 209 | 297 |
| **Medium Lakes (surface area 100-500 acres)** | | | | | | | | | | | | |
| Beaver Lake (West end) | 10 | 1.8 | 0.4 | 5.7 | 10 | 10.8 | 5.8 | 32.1 | 0 | | | |
| Beaver Lake (Woods Point) | 3 | 4.0 | 0.8 | 9.6 | 3 | 10.2 | 6.6 | 16.6 | 0 | | | |
| Blaine, Lake | 4 | 6.5 | 0.6 | 12.5 | 4 | 16.7 | 6.8 | 23.1 | 0 | | | |
| Blanchard Lake | 12 | 2.1 | 0.9 | 4.4 | 11 | 13.7 | 9.1 | 18.8 | 2 | 623 | 593 | 654 |
| Crystal Lake | 1 | 1.9 | | | 1 | 11.0 | | | 0 | | | |
| Five, Lake | 13 | 3.0 | 1.0 | 8.1 | 13 | 9.6 | 5.0 | 12.5 | 2 | 350 | 272 | 429 |

Table 3. (continued)

| Lake | Chl *a* n | Chl *a* mean | Chl *a* min | Chl *a* max | TP n | TP mean | TP min | TP max | TN n | TN mean | TN min | TN max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Medium Lakes (continued)** | | | | | | | | | | | | |
| Foy Lake | 3 | 1.8 | 0.2 | 3.4 | 3 | 8.0 | 5.8 | 10.2 | 0 | | | |
| Glen Lake | 4 | 0.9 | 0.4 | 1.3 | 4 | 9.2 | 7.2 | 10.8 | 0 | | | |
| Holland Lake | 4 | 1.3 | 0.8 | 1.6 | 4 | 10.8 | 8.9 | 12.9 | 1 | 127 | | |
| Lower Stillwater Lake | 4 | 5.3 | 1.1 | 9.7 | 4 | 24.8 | 11.0 | 54.0 | 0 | | | |
| Murphy Lake | 1 | 1.3 | | | 1 | 9.0 | | | 0 | | | |
| Rogers Lake | 12 | 2.0 | 0.7 | 4.0 | 13 | 15.6 | 7.8 | 22.5 | 3 | 742 | 701 | 795 |
| **Large Lakes (surface area >500 acres)** | | | | | | | | | | | | |
| Ashley Lake (NE middle) | 9 | 3.2 | 0.4 | 15.3 | 10 | 15.6 | 9.7 | 24.8 | 1 | 211 | | |
| Ashley Lake (West) | 7 | 0.8 | 0.4 | 2.4 | 7 | 13.6 | 9.3 | 22.0 | 2 | 211 | 188 | 235 |
| Bowman Lake | 6 | 0.6 | 0.2 | 0.8 | 6 | 4.5 | 2.8 | 6.6 | 1 | 137 | | |
| Echo Lake | 8 | 2.9 | 1.4 | 5.8 | 8 | 14.7 | 5.3 | 26.2 | 1 | 133 | | |
| Flathead Lake (Bigfork) | 1 | 0.5 | | | 1 | 10.6 | | | 0 | | | |
| Flathead Lake (Conrad Point) | 7 | 0.7 | 0.3 | 1.2 | 8 | 6.7 | 4.1 | 11.7 | 2 | 124 | 83 | 166 |
| Flathead Lake (Crescent Bay) | 4 | 0.6 | 0.3 | 1.1 | 4 | 4.1 | 3.2 | 5.3 | 0 | | | |
| Flathead Lake (Dayton Bay) | 3 | 1.1 | 0.8 | 1.3 | 3 | 6.5 | 3.6 | 11.2 | 0 | | | |
| Flathead Lake (Indian Bay) | 6 | 0.7 | 0.5 | 0.7 | 6 | 5.5 | 3.1 | 7.5 | 0 | | | |
| Flathead Lake (Mack Alley) | 6 | 0.7 | 0.5 | 0.9 | 6 | 5.0 | 3.1 | 6.3 | 0 | | | |
| Flathead Lake (Marco Bay) | 9 | 0.9 | 0.3 | 1.6 | 9 | 5.9 | 3.7 | 10.5 | 3 | 116 | 75 | 162 |
| Flathead Lake (Mission View) | 9 | 0.6 | 0.2 | 1.1 | 10 | 4.9 | 2.9 | 7.9 | 3 | 105 | 79 | 125 |
| Flathead Lake (Narrows) | 6 | 0.8 | 0.3 | 1.7 | 6 | 4.2 | 2.8 | 5.2 | 0 | | | |
| Flathead Lake (NE shore) | 4 | 0.7 | 0.5 | 1.0 | 5 | 6.4 | 2.9 | 9.8 | 0 | | | |
| Flathead Lake (Polson) | 3 | 0.5 | 0.5 | 0.6 | 3 | 4.1 | 3.8 | 4.8 | 0 | | | |
| Flathead Lake (Sessions Point) | 5 | 0.7 | 0.5 | 1.0 | 6 | 5.8 | 3.0 | 11.8 | 0 | | | |
| Flathead Lake (Rollins Bay N) | 4 | 0.4 | 0.1 | 0.6 | 4 | 5.1 | 3.7 | 7.0 | 0 | | | |
| Flathead Lake (Rollins Bay S) | 4 | 0.9 | 0.2 | 2.5 | 4 | 4.2 | 3.0 | 5.3 | 0 | | | |
| Flathead Lake (Somers Bay) | 10 | 1.1 | 0.4 | 3.3 | 9 | 5.3 | 3.5 | 8.0 | 2 | 97 | 91 | 104 |

Table 3. (continued)

| Lake | Chl *a* n | Chl *a* mean | Chl *a* min | Chl *a* max | TP n | TP mean | TP min | TP max | TN n | TN mean | TN min | TN max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Large Lakes (continued)** | | | | | | | | | | | | |
| Flathead Lake (Woods Bay) | 5 | 0.8 | 0.3 | 1.0 | 5 | 5.1 | 3.0 | 6.9 | 1 | 123 | | |
| Kintla Lake | 5 | 0.5 | 0.2 | 0.8 | 5 | 4.0 | 3.1 | 5.0 | 0 | | | |
| Lindbergh Lake | 5 | 1.4 | 0.7 | 2.1 | 5 | 8.8 | 5.6 | 12.7 | 1 | 105 | | |
| Little Bitterroot Lake | 6 | 1.1 | 0.4 | 3.0 | 6 | 11.0 | 9.4 | 12.8 | 2 | 171 | 155 | 188 |
| Mary Ronan, Lake (E middle) | 8 | 6.6 | 0.2 | 11.3 | 8 | 75.3 | 16.4 | 330.5 | 2 | 881 | 674 | 1087 |
| Mary Ronan, Lake (W middle) | 6 | 6.4 | 0.7 | 13.5 | 6 | 40.4 | 16.5 | 83.5 | 1 | 633 | | |
| McDonald, Lake | 9 | 0.6 | 0.2 | 1.4 | 10 | 5.1 | 2.5 | 10.0 | 3 | 274 | 226 | 314 |
| McGregor, Lake | 1 | 0.7 | | | 1 | 6.4 | | | 0 | | | |
| Stillwater Lake, Upper | 3 | 1.3 | 0.9 | 1.7 | 3 | 9.6 | 8.6 | 11.2 | 0 | | | |
| Swan Lake (Loon Island Bay) | 9 | 0.9 | 0.4 | 1.7 | 8 | 6.4 | 4.8 | 9.0 | 2 | 90 | 73 | 107 |
| Swan Lake (Rock House) | 7 | 1.4 | 0.9 | 2.0 | 8 | 6.2 | 3.1 | 8.1 | 0 | | | |
| Swan Lake (Sixmile) | 10 | 1.1 | 0.2 | 2.5 | 10 | 6.3 | 3.5 | 9.3 | 2 | 74 | 71 | 76 |
| Swan Lake (State Island) | 11 | 1.4 | 0.3 | 2.8 | 12 | 6.4 | 3.7 | 8.2 | 3 | 103 | 80 | 135 |
| Tally Lake | 6 | 0.9 | 0.6 | 1.3 | 6 | 11.3 | 8.7 | 17.0 | 0 | | | |
| Thompson Lake, Middle | 1 | 1.9 | | | 1 | 15.4 | | | 0 | | | |
| Whitefish Lake (Monks Bay) | 9 | 0.5 | 0.1 | 1.4 | 10 | 6.4 | 4.2 | 12.2 | 2 | 82 | 63 | 100 |
| Whitefish Lake (N middle) | 10 | 0.9 | 0.2 | 2.2 | 10 | 6.4 | 4.5 | 8.4 | 2 | 85 | 81 | 90 |
| Whitefish Lake (S middle) | 5 | 1.0 | 0.7 | 2.0 | 5 | 6.6 | 5.6 | 7.9 | 0 | | | |

Table 4. Trophic status of the lakes sampled in the Volunteer Lakes Monitoring Project based on the general trophic classification of Wetzel (2001; upper section of table). The variables used were total phosphorus (TP, μg $L^{-1}$), total nitrogen (TN, μg $L^{-1}$), chlorophyll *a* (Chl*a, μg* $L^{-1}$) and Secchi depth (m).

| Trophic classification | TP mean (range) | TN mean (range) | Chl *a* mean (range) | Secchi mean (range) |
|---|---|---|---|---|
| oligotrophic | 8 (3.0-17.7) | 661 (307-1630) | 1.7 (0.3-4.5) | 9.9 (5.4-28.3) |
| mesotrophic | 26.7 (10.9-95.6) | 753 (361-1387) | 4.7 (3-11) | 4.2 (1.5-8.1) |
| eutrophic | 84.4 (16-386) | 1875 (393-6100) | 14.3 (3-78) | 2.45 (0.8-7.0) |
| hypereutrophic | (750-1200) | | (100-150) | (0.4-0.5) |

| Lake | TP mean | TN mean | Chl *a* mean | Secchi mean | Trophic status[1] |
|---|---|---|---|---|---|
| **Small Lakes (surface area <100 acres)** | | | | | |
| Abbot Lake | 12.0 | 330 | 3.4 | 3.4 | oligo-meso |
| Bailey Lake | 9.3 | 256 | 1.7 | 5.0 | oligo |
| Halfmoon Lake | 10.9 | 543 | 1.4 | 5.1 | oligo |
| Hanson-Doyle Lake | 16.0 | 910 | 2.9 | 5.2 | oligo-meso |
| Jette Lake | 72.7 | 1010 | 12.2 | 5.2 | eutro |
| Lavon Lake | 20.6 | | 8.3 | | meso |
| Lion Lake | 7.3 | | 0.9 | | oligo |
| Loon Lake | 17.7 | | 2.0 | 6.8 | oligo-meso |
| McCaffery Lake | 20.6 | 742 | 5.2 | 4.5 | meso |
| McGilvray Lake | 9.2 | 178 | 1.0 | 8.8 | oligo |
| Peterson Lake | 13.1 | 356 | 2.1 | 5.2 | oligo |
| Skyles Lake | 15.0 | | 2.3 | 3.9 | oligo-meso |
| Spencer Lake | 22.3 | | 3.6 | | meso-oligo |
| Sylvia Lake | 6.9 | | 0.8 | | oligo |
| Tepee Lake | 13.5 | | 2.8 | 4.0 | oligo-meso |
| Tetrault Lake | 18.4 | | 3.2 | | meso-oligo |
| Woods, Lake of the | 8.0 | 253 | 1.3 | 7.3 | oligo |

Table 4. (continued)

| Lake | TP mean | TN mean | Chl *a* mean | Secchi mean | Trophic status[1] |
|---|---|---|---|---|---|
| **Medium Lakes (surface area 100–500 acres)** | | | | | |
| Beaver Lake | 10.5 | | 2.9 | 6.2 | oligo-meso |
| Blaine, Lake | 16.7 | | 6.5 | | meso-oligo |
| Blanchard Lake | 13.7 | 623 | 2.1 | 4.7 | oligo-meso |
| Crystal Lake | 11.0 | | 1.9 | | oligo-meso |
| Five, Lake | 9.6 | 350 | 3.0 | 6.9 | oligo |
| Foy Lake | 8.0 | | 1.8 | | oligo |
| Glen Lake | 9.2 | | 0.9 | 6.0 | oligo |
| Holland Lake | 10.8 | 127 | 1.3 | | oligo |
| Murphy Lake | 24.8 | | 5.3 | | oligo |
| Rogers Lake | 9.0 | | 1.3 | 4.6 | oligo-meso |
| Stillwater Lake, Lower | 15.6 | 742 | 2.0 | 5.5 | meso |
| **Large Lakes (surface area >500 acres)** | | | | | |
| Ashley Lake | 14.6 | 210.9 | 2.0 | 8.7 | oligo-meso |
| Bowman Lake | 4.5 | 137 | 0.6 | 40 | oligo |
| Echo Lake | 14.7 | 133 | 2.9 | 74 | oligo-meso |
| Flathead Lake | 5.6 | 113.0 | 0.7 | 7.8 | oligo |
| Kintla Lake | 4.0 | | 0.5 | 13.2 | oligo |
| Lindbergh Lake | 8.8 | 105 | 1.4 | 9.3 | oligo |
| Little Bitterroot Lake | 11.0 | 171 | 1.1 | 13.4 | oligo |
| Mary Ronan, Lake | 57.9 | 756.8 | 6.5 | 5.6 | meso-eutro |
| McDonald, Lake | 5.1 | 274 | 0.6 | 12.9 | oligo |
| McGregor Lake | 6.4 | | 0.7 | | oligo |
| Stillwater Lake, Upper | 9.6 | | 1.3 | 7.1 | oligo |
| Swan Lake | 6.3 | 88.9 | 1.2 | 6.2 | oligo |
| Tally Lake | 11.3 | | 0.9 | 4.5 | oligo |
| Thompson Lake, Middle | 15.4 | | 1.9 | | oligo-meso |
| Whitefish Lake | 6.5 | 83.5 | 0.8 | 7.8 | oligo |

[1] oligo = oligotrophic, meso = mesotrophic, eutro = eutrophic, hyereutro = hypereutrophic

Table 5. Temperature and dissolved oxygen measures in lakes of the Volunteer Monitoring Lakes Program from 1993 to 2007.

| Lake | Minimum dissolved oxygen measured (%Sat) | Thermocline | Mean surface temperature ($^{o}$C) | Mean bottom temperature ($^{o}$C) | Maximum surface temperature ($^{o}$C) |
|---|---|---|---|---|---|
| **Small Lakes (surface area <100 acres)** | | | | | |
| Abbot Lake | 85.0 | no | 22.3 | 22.0 | 27 |
| Bailey Lake | 12.7 | occasional | 21.7 | 18.0 | 24 |
| Halfmoon Lake | 18.5 | occasional | 21.5 | 16.6 | 28 |
| Hanson-Doyle Lake | 4.0 | yes | 21.7 | 8.5 | 25 |
| Jette Lake | 6.6 | occasional | 20.2 | 14.4 | 25.5 |
| Lavon Lake | | | | | |
| Lion Lake | | | | | |
| Loon Lake | 2.0 | yes | 20.9 | 12.3 | 24 |
| McCaffery Lake | | | | | 26 |
| McGilvray Lake | | | | | 28.5 |
| Peterson Lake | | | | | 26 |
| Skyles Lake | | | | | 25 |
| Spencer Lake | | | | | |
| Sylvia Lake | | | | | |
| Tepee Lake | | | | | 23 |
| Tetrault Lake | | | | | |
| Woods, Lake of the | | | | | 26 |
| **Medium Lakes (surface area 100-500 acres)** | | | | | |
| Beaver Lake | 1.8 | yes | 21.6 | NA | 29 |
| Blaine, Lake | | | | | |
| Blanchard Lake | 6.7 | occasional | 21.2 | 17.0 | 23 |
| Crystal Lake | | | | | |
| Five, Lake | 4.3 | yes | 20.7 | 7.2 | 25 |
| Foy Lake | | | | | |
| Glen Lake | | | | | 25 |
| Holland Lake | 38.0 | yes | 22.7 | NA | |
| Murphy Lake | | | | | |
| Rogers Lake | | no | | | 25 |
| Stillwater Lake, Lower | | | | | 24.5 |

Table 5. (continued)

| Name | Minimum dissolved oxygen measured (%Sat) | Thermocline | Mean surface temperature (°C) | Mean bottom temperature (°C) | Maximum surface temperature (°C) |
|---|---|---|---|---|---|
| **Large Lakes (surface area >500 acres)** | | | | | |
| Ashley Lake | 65.7 | yes | 20.1 | 6.2 | 26 |
| Bowman Lake | 79.0 | yes | 17.0 | NA | 22 |
| Echo Lake | 5.3 | yes | 22.4 | 4.7 | 25 |
| Flathead Lake | 86.1 | yes | 21.1 | NA | 26 |
| Kintla Lake | 85.2 | yes | 17.7 | NA | 20 |
| Lindbergh Lake | | | | | 19 |
| Little Bitterroot Lake | 67.1 | yes | 19.9 | NA | 20.4 |
| Mary Ronan, Lake | | | | | 23 |
| McDonald, Lake | | | | | 21 |
| McGregor Lake | | | | | |
| Swan Lake | | | | | 27 |
| Tally Lake | | | | | 25 |
| Thompson Lake, Middle | | | | | |
| Stillwater Lake, Upper | | | | | 18 |
| Whitefish Lake | | | | | 26 |

Table 6. Summary of Secchi depth measured by volunteers from 1993 to 2007.

| Lake | Secchi depth n | Secchi depth (m) mean | Secchi depth (m) min | Secchi depth (m) max |
|---|---|---|---|---|
| **Small Lakes (surface area <100 acres)** | | | | |
| Abbot Lake | 20 | 3.4 | 1.5 | 4.7 |
| Bailey Lake | 107 | 5.0 | 2.6 | 7.4 |
| Halfmoon Lake | 122 | 5.1 | 3.3 | 6.7 |
| Hanson-Doyle Lake | 39 | 5.2 | 3.9 | 6.8 |
| Jette Lake | 63 | 5.2 | 3.5 | 6.7 |
| Lavon Lake | | | | |
| Lion Lake | | | | |
| Loon Lake | 19 | 6.8 | 4.8 | 9.7 |
| McCaffery Lake | 43 | 4.5 | 2.3 | 7.1 |
| McGilvray Lake | 11 | 8.8 | 7.2 | 9.6 |
| Peterson Lake | 51 | 5.2 | 2.1 | 11.3 |
| Skyles Lake | 28 | 3.9 | 2.4 | 5.0 |
| Spencer Lake | | | | |
| Sylvia Lake | | | | |
| Tepee Lake | 38 | 4.0 | 2.1 | 5.3 |
| Tetrault Lake | | | | |
| Woods, Lake of the | 72 | 7.3 | 4.3 | 13.1 |
| **Medium Lakes (surface area 100–500 acres)** | | | | |
| Beaver Lake (West End) | 84 | 6.3 | 3.5 | 8.9 |
| Beaver Lake (Woods Point) | 89 | 6.1 | 3.4 | 8.9 |
| Blaine, Lake | | | | |
| Blanchard Lake | 19 | 4.7 | 3.7 | 6.1 |
| Crystal Lake | | | | |
| Five, Lake | 45 | 6.9 | 4.3 | 9.8 |
| Foy Lake | | | | |
| Glen Lake | 89 | 6.0 | 1.5 | 8.5 |
| Holland Lake | | | | |
| Murphy Lake | | | | |
| Rogers Lake | 99 | 4.6 | 2.4 | 7.2 |
| Stillwater Lake, Lower | 26 | 5.5 | 4.1 | 7.7 |
| **Large Lakes (surface area >500 acres)** | | | | |
| Ashley Lake (NE middle) | 69 | 8.6 | 2.6 | 14.0 |
| Ashley Lake (West) | 79 | 8.9 | 3.1 | 13.4 |
| Bowman Lake | 40 | 12.2 | 3.0 | 24.0 |
| Echo Lake | 74 | 5.9 | 2.6 | 9.5 |

Table 6. (continued)

| Lake | Secchi depth n | Secchi depth (m) mean | Secchi depth (m) min | Secchi depth (m) max |
|---|---|---|---|---|
| **Large Lakes (continued)** | | | | |
| Flathead Lake (Bigfork) | | | | |
| Flathead Lake (Conrad Point) | 97 | 6.4 | 0.4 | 11.3 |
| Flathead Lake (Crescent Bay) | 33 | 9.1 | 2.9 | 11.9 |
| Flathead Lake (Dayton Bay) | 14 | 7.8 | 4.0 | 11.6 |
| Flathead Lake (Indian Bay) | 39 | 9.1 | 0.9 | 12.6 |
| Flathead Lake (Mack Alley) | 42 | 9.0 | 1.2 | 12.6 |
| Flathead Lake (Marco Bay) | 222 | 4.9 | 0.5 | 10.0 |
| Flathead Lake (Mission View) | 181 | 6.1 | 0.4 | 12.5 |
| Flathead Lake (Narrows) | 33 | 9.2 | 3.4 | 11.7 |
| Flathead Lake (NE shore) | 30 | 8.2 | 2.3 | 11.6 |
| Flathead Lake (Polson) | 16 | 5.7 | 4.9 | 6.1 |
| Flathead Lake (Sessions Point) | 20 | 8.7 | 5.6 | 11.9 |
| Flathead Lake (Rollins Bay N) | 18 | 8.6 | 4.9 | 12.5 |
| Flathead Lake (Rollins Bay S) | 16 | 9.2 | 5.1 | 11.8 |
| Flathead Lake (Somers Bay) | 188 | 5.0 | 0.5 | 11.5 |
| Flathead Lake (Woods Bay) | 55 | 9.4 | 2.8 | 14.9 |
| Kintla Lake | 63 | 13.2 | 5.0 | 22.0 |
| Lindbergh Lake | 8 | 9.3 | 7.8 | 11.6 |
| Little Bitterroot Lake | 9 | 13.4 | 10.5 | 17.1 |
| Mary Ronan, Lake (E middle) | 59 | 5.7 | 2.5 | 8.7 |
| Mary Ronan, Lake (W middle) | 65 | 5.6 | 1.8 | 8.8 |
| McDonald, Lake | 65 | 12.9 | 3.2 | 19.8 |
| McGregor Lake | | | | |
| Stillwater Lake, Upper | 4 | 7.1 | 6.1 | 8.4 |
| Swan Lake (Loon Island Bay) | 32 | 6.1 | 2.7 | 8.8 |
| Swan Lake (Rock House) | 58 | 6.0 | 1.5 | 9.9 |
| Swan Lake (Sixmile) | 83 | 6.6 | 1.5 | 11.6 |
| Swan Lake (State Island) | 113 | 6.0 | 1.8 | 9.5 |
| Tally Lake | 24 | 4.5 | 2.0 | 6.9 |
| Thompson Lake, Middle | | | | |
| Whitefish Lake (Monks Bay) | 58 | 7.3 | 2.3 | 15.5 |
| Whitefish Lake (N middle) | 103 | 8.4 | 1.3 | 12.8 |
| Whitefish Lake (S middle) | 60 | 7.8 | 3.2 | 11.2 |

Table 7. Results from linear regression trends analysis for chlorophyll *a* (Chl *a*) and total phosphorus (TP) concentrations. Sites with less than four years of data were not analyzed and are recorded as NA. All significant trends ($p<0.05$) were positive trends (i.e., concentration increasing over time) and are shown in bold type.

| Lake | Chl *a* p values | TP p values |
|---|---|---|
| **Small Lakes (surface area <100 acres)** | | |
| Abbot Lake | 0.846 | 0.902 |
| Bailey Lake | **0.007** | **0.010** |
| Halfmoon Lake | 0.703 | 0.467 |
| Hanson-Doyle Lake | 0.667 | 0.394 |
| Jette Lake | 0.960 | 0.845 |
| Lavon Lake | NA | NA |
| Lion Lake | NA | NA |
| Loon Lake | 0.173 | 0.508 |
| McCaffery Lake | 0.176 | 0.782 |
| McGilvray Lake | NA | NA |
| Peterson Lake | 0.861 | 0.450 |
| Skyles Lake | 0.194 | 0.780 |
| Spencer Lake | NA | NA |
| Sylvia Lake | NA | NA |
| Tepee Lake | NA | NA |
| Tetrault Lake | NA | NA |
| Woods, Lake of the | 0.283 | 0.755 |
| **Medium Lakes (surface area 100–500 acres)** | | |
| Beaver Lake (West End) | 0.396 | 0.089 |
| Beaver Lake (Woods Point) | NA | NA |
| Blaine, Lake | 0.130 | **0.034** |
| Blanchard Lake | 0.545 | 0.310 |
| Crystal Lake | NA | NA |
| Five, Lake | **0.017** | 0.071 |
| Foy Lake | NA | NA |
| Glen Lake | **0.022** | 0.227 |
| Holland Lake | 0.190 | 0.411 |
| Murphy Lake | NA | NA |
| Rogers Lake | 0.554 | **0.001** |
| Stillwater Lake, Lower | 0.118 | 0.559 |

Table 7. (continued)

| Lake | Chl *a* p values | TP p values |
|---|---|---|
| **Large Lakes (surface area >500 acres)** | | |
| Ashley Lake (NE middle) | 0.468 | 0.942 |
| Ashley Lake (West) | 0.891 | 0.735 |
| Bowman Lake | 0.453 | 0.379 |
| Echo Lake | 0.559 | 0.750 |
| Flathead Lake (Bigfork) | NA | NA |
| Flathead Lake (Conrad Point) | 0.667 | 0.279 |
| Flathead Lake (Crescent Bay) | **0.030** | **0.015** |
| Flathead Lake (Dayton Bay) | NA | NA |
| Flathead Lake (Indian Bay) | 0.119 | **0.032** |
| Flathead Lake (Mack Alley) | **0.018** | **0.023** |
| Flathead Lake (Marco Bay) | 0.993 | 0.678 |
| Flathead Lake (Mission View) | 0.510 | 0.259 |
| Flathead Lake (Narrows) | 0.271 | 0.120 |
| Flathead Lake (NE shore) | 0.094 | 0.321 |
| Flathead Lake (Polson) | NA | NA |
| Flathead Lake (Sessions Point) | 0.213 | 0.485 |
| Flathead Lake (Rollins Bay N) | 0.255 | 0.617 |
| Flathead Lake (Rollins Bay S) | 0.191 | 0.069 |
| Flathead Lake (Somers Bay) | 0.368 | 0.535 |
| Flathead Lake (Woods Bay) | 0.492 | 0.357 |
| Kintla Lake | 0.076 | 0.487 |
| Lindbergh Lake | 0.290 | 0.795 |
| Little Bitterroot Lake | 0.915 | 0.286 |
| Mary Ronan, Lake (E middle) | 0.300 | 0.146 |
| Mary Ronan, Lake (W middle) | 0.942 | 0.259 |
| McDonald, Lake | 0.678 | 0.779 |
| McGregor Lake | NA | NA |
| Stillwater Lake, Upper | NA | NA |
| Swan Lake (Loon Island Bay) | 0.369 | 0.844 |
| Swan Lake (Rock House) | 0.842 | 0.759 |
| Swan Lake (Sixmile) | 0.742 | 0.999 |
| Swan Lake (State Island) | 0.760 | 0.135 |
| Tally Lake | 0.340 | 0.429 |
| Thompson Lake, Middle | NA | NA |
| Whitefish Lake (Monks Bay) | 0.344 | 0.861 |
| Whitefish Lake (N middle) | 0.864 | 0.666 |
| Whitefish Lake (S middle) | 0.835 | 0.801 |

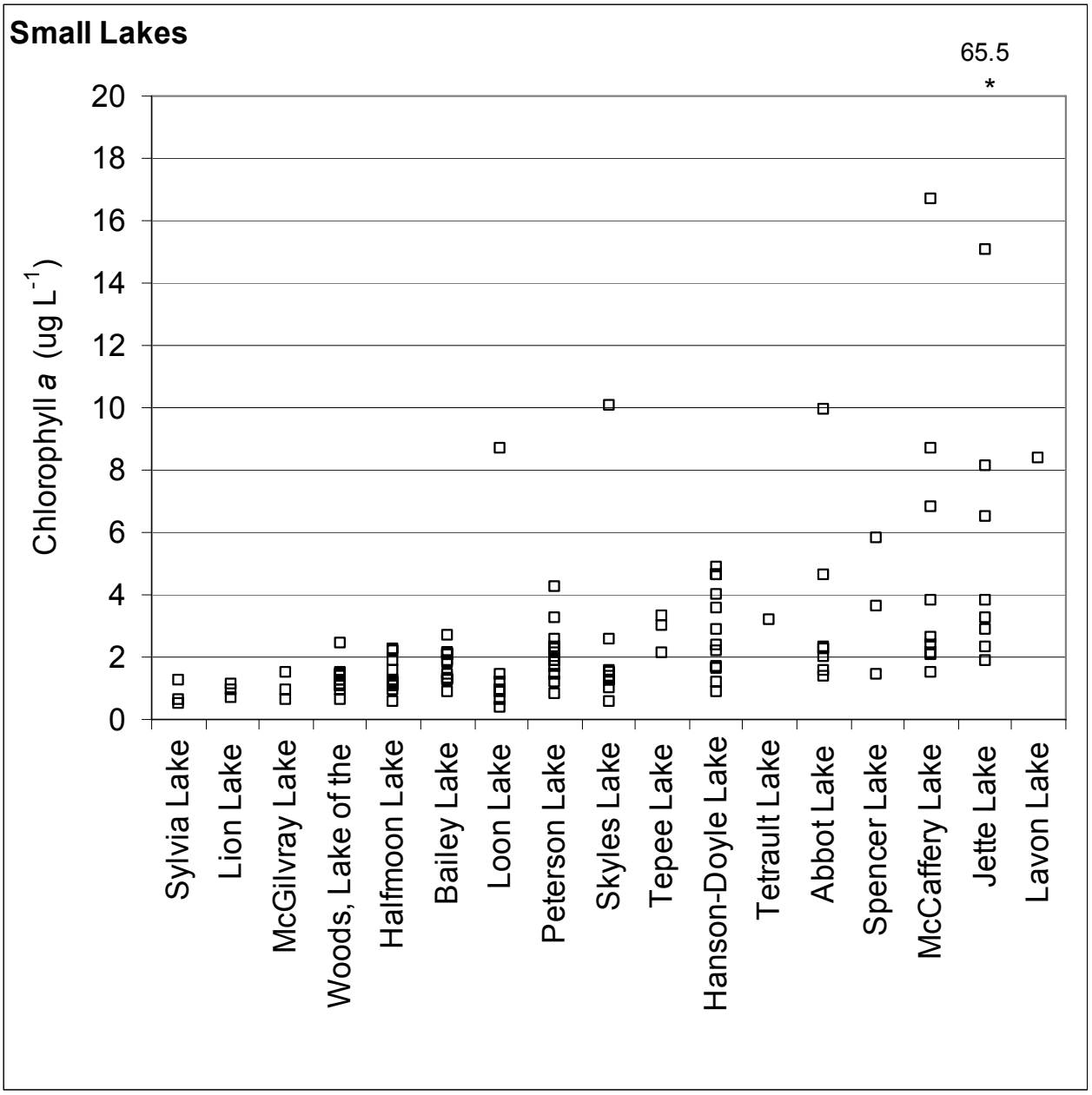


Figure 1. Chlorophyll *a* concentrations measured in the small lakes (<100 acres in surface area) of the Volunteer Monitoring Lakes Program from 1993 to 2007. Only one site (site with the greatest sampling frequency) is shown for lakes with multiple sites.

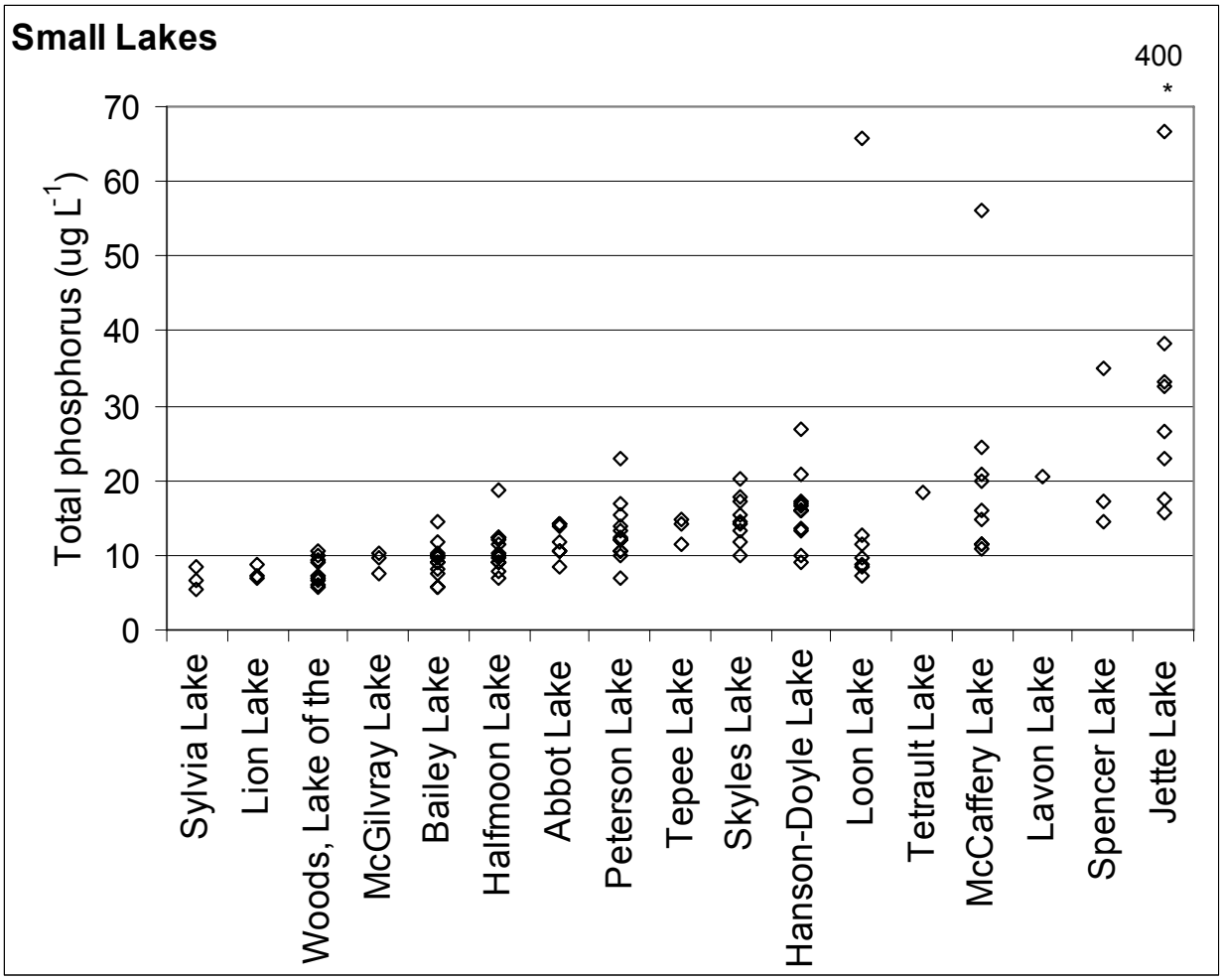


Figure 2. Total phosphorus concentrations measured in the small lakes (<100 acres in surface area) of the Volunteer Monitoring Lakes Program from 1993 to 2007. Only one site (site with the greatest sampling frequency) is shown for lakes with multiple sites.

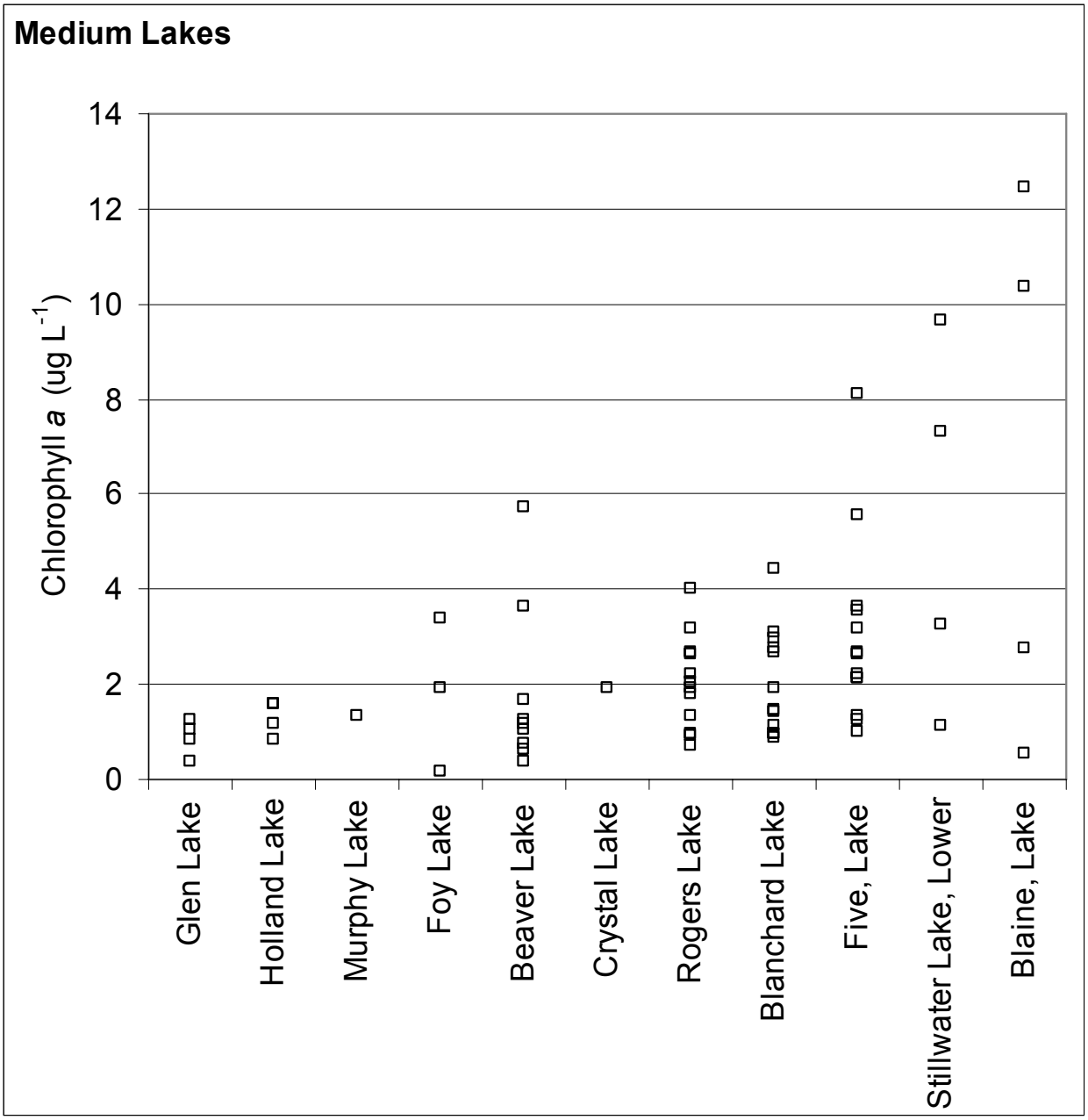


Figure 3. Chlorophyll *a* concentrations measured in the medium-sized lakes (100–500 acres in surface area) of the Volunteer Monitoring Lakes Program from 1993 to 2007. Only one site (site with the greatest sampling frequency) is shown for lakes with multiple sites.

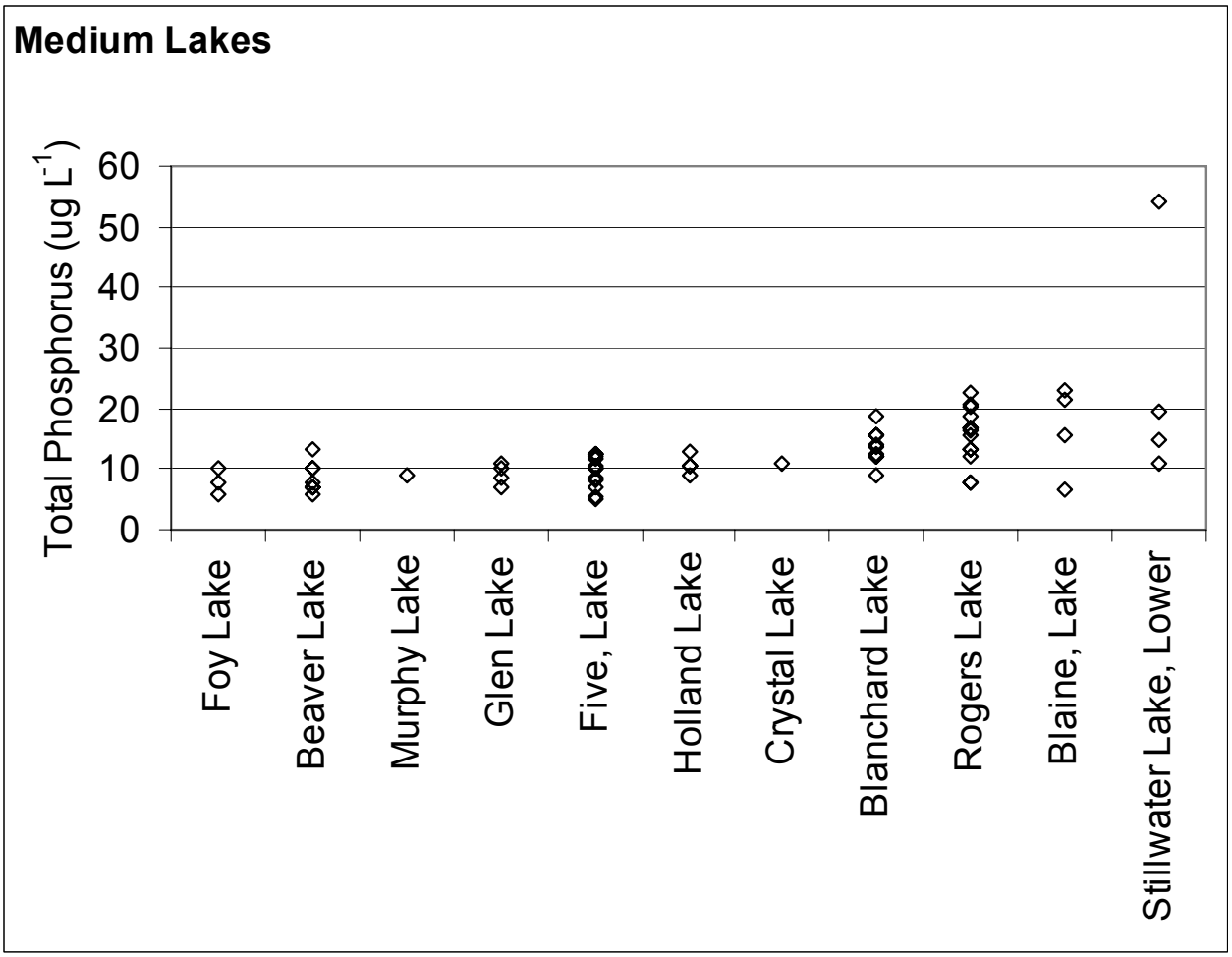


Figure 4. Total phosphorus concentrations measured in the medium-sized lakes (100–500 acres in surface area) of the Volunteer Monitoring Lakes Program from 1993 to 2007. Only one site (site with the greatest sampling frequency) is shown for lakes with multiple sites.

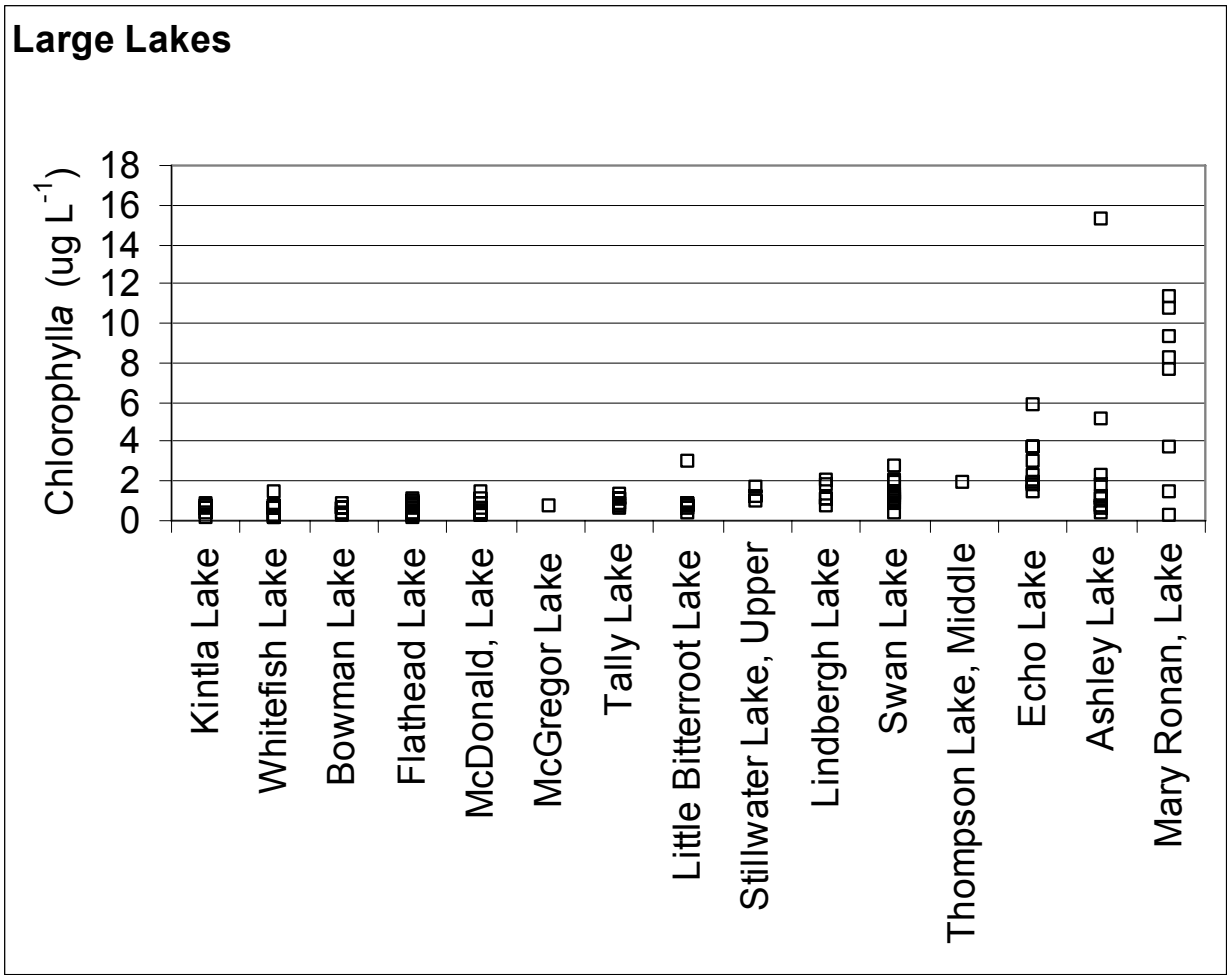


Figure 5. Chlorophyll *a* concentrations measured in the large lakes (>500 acres in surface area) of the Volunteer Monitoring Lakes Program from 1993 to 2007. Only one site (site with the greatest sampling frequency) is shown for lakes with multiple sites.

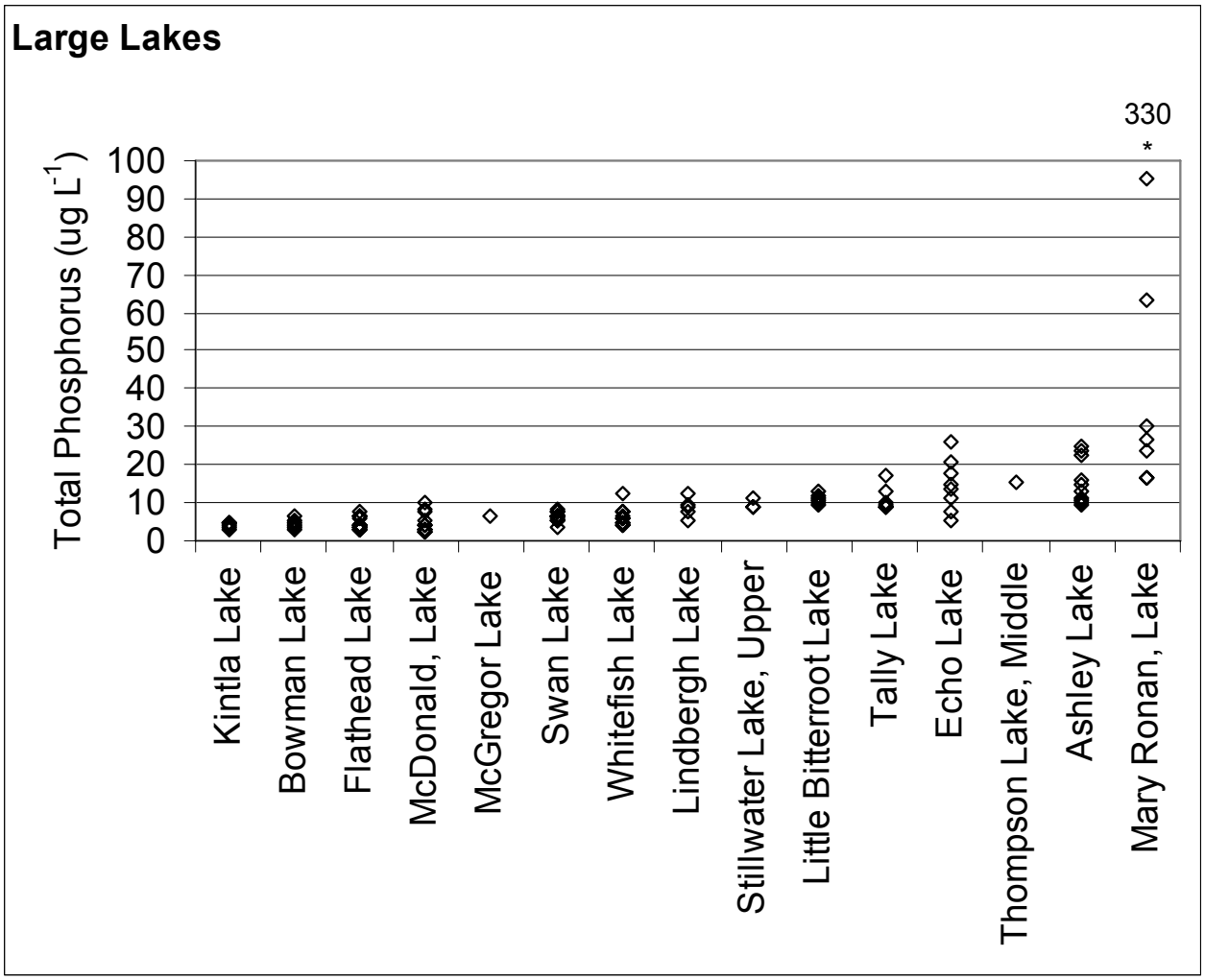


Figure 6. Total phosphorus concentrations measured in the large lakes (>500 acres in surface area) of the Volunteer Monitoring Lakes Program from 1993 to 2007. Only one site (site with the greatest sampling frequency) is shown for lakes with multiple sites.