Medicine Lake
Endothall Treatment to Control
Curlyleaf Pondweed
2004-2006

Status Report
Prepared
By

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Three Rivers
PARK DISTRICT

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Background

Medicine Lake is an important resource within the City of Plymouth that receives a considerable amount of recreational use. The lake has a history of degraded water quality that potentially inhibits recreational use. The City of Plymouth developed a Water Resources Management Plan in 2000 that identified Medicine Lake as a high priority resource that requires water quality improvements. A Medicine Lake subcommittee was established to develop and facilitate a comprehensive management plan to pro-actively address the water quality issues. Water quality goals were developed for Medicine Lake to provide guidelines in making management decisions that would improve in-lake water quality conditions. Currently, Medicine Lake water quality does not meet the established water quality goals. Due to the poor water quality, the Minnesota Pollution Control Agency (MPCA) also placed Medicine Lake onto the list of Impaired Waters for excess nutrients in 2004.

The Medicine Lake subcommittee determined that curlyleaf pondweed is a significant factor inhibiting recreational use as well as potentially degrading the in-lake water quality. Curlyleaf pondweed is an exotic species that typically competes with other native plant species because of its unique life cycle. The plant germinates from turions (seed structures) in early fall when most native plants have died back, and the plant continues to grow slowly during the winter months. Curlyleaf pondweed growth increases substantially after ice-out due to an increase in light availability. According to preliminary aquatic plant surveys in the spring, Medicine Lake has approximately 30% to 40% surface area coverage of curlyleaf pondweed with nuisance growth conditions that inhibits recreational use. The plant begins to die-off (called senescence) after the completion of turion production by the end of June or early July. The senescence of curlyleaf pondweed provides an internal source of nutrients within Medicine Lake. Similar to other lakes dominated by curlyleaf pondweed, Medicine Lake has a characteristic total phosphorus spike that coincides with senescence. Nutrients released from the senescence process are in a soluble form readily available for algae uptake. Consequently, algae blooms frequently develop causing a decrease in water clarity. The senescence of curlyleaf pondweed exacerbates the eutrophication process by causing poor water quality conditions earlier in the season.

A primary initiative of the Medicine Lake subcommittee was the formation of a Medicine Lake Aquatic Vegetation Management Group (AVM). The group consisted of members from the City of Plymouth Engineering Department, Three Rivers Park District, Minnesota Department of Natural Resources (MNDNR), Bassett Creek Watershed District, Association of Medicine Lake Area Citizens (AMLAC), City of Medicine Lake, and several lakeshore residents. The AVM group developed an aquatic plant management plan to control exotic species and promote the growth of native species as an effort to improve water quality conditions in Medicine Lake. The plan proposed to chemically treat the entire littoral area of the lake with an aquatic herbicide (Endothall) to control curlyleaf pondweed. A herbicide treatment for the entire littoral area had not been previously considered as a viable management approach because MNDNR rules and regulations limit herbicide applications to 15% of the lake littoral area. Monitoring data (water quality data and aquatic plant vegetation surveys) was provided to demonstrate the potential impact curlyleaf pondweed has on Medicine Lake water quality. The data was used to request a variance from the MNDNR to allow for a herbicide application over the entire littoral area.

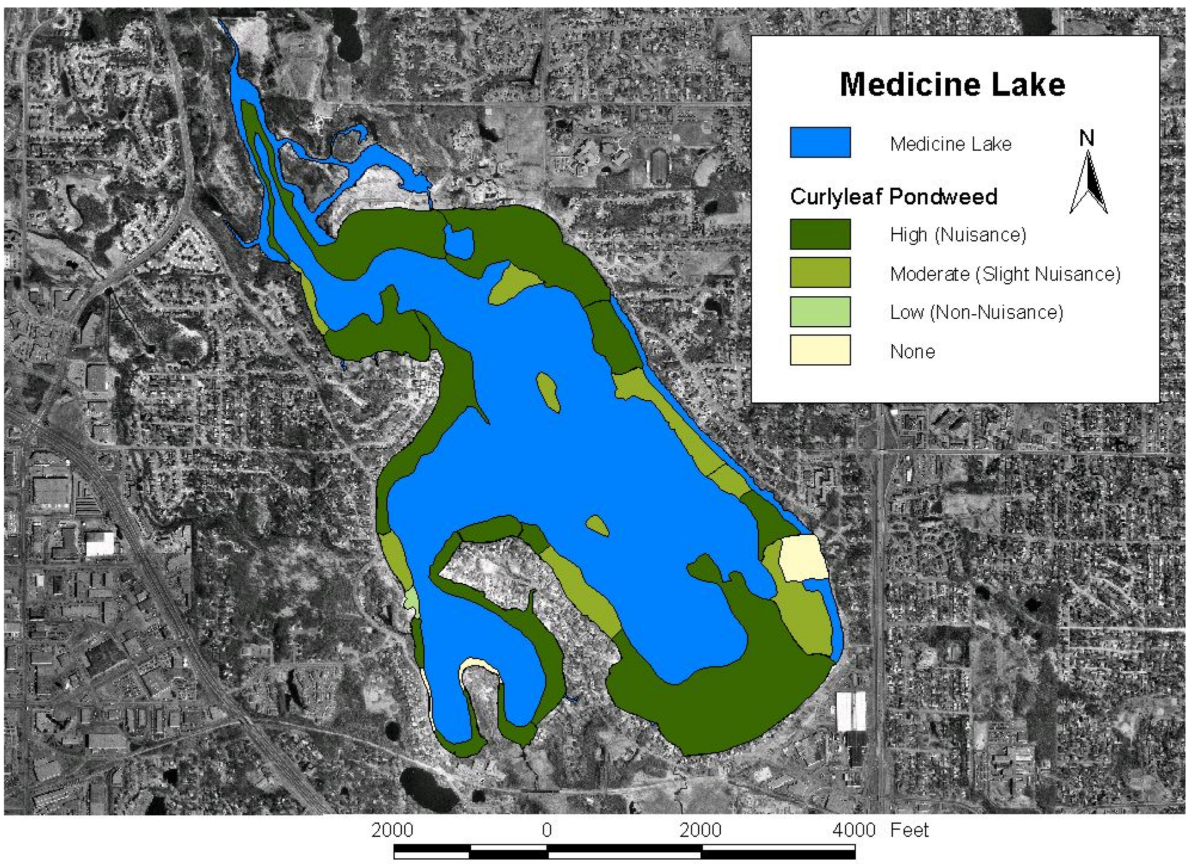
The proposed Medicine Lake herbicide treatment was considered a long-term management approach. Historically, curlyleaf pondweed management strategies have been primarily short-term approaches that temporarily control nuisance growth conditions to increase recreational use. Very few projects have considered a long-term management approach to control curlyleaf pondweed. The objective of the long-term management approach is to improve water quality conditions by reducing the amount of curlyleaf pondweed. Reducing the internal nutrient loading from curlyleaf pondweed senescence can potentially improve water clarity conditions and encourage native plant growth. Establishing a diverse native plant community can potentially inhibit the growth of curlyleaf pondweed and extend the longevity of the control programs. The MNDNR approved the project and granted a three-year variance (April 5, 2004) to the City of Plymouth for chemical control of curlyleaf pondweed in an area greater than 15% of the littoral area for Medicine Lake. Conditions of the permit required the implementation of an extensive monitoring program to determine whether project goals and objectives will be accomplished. The monitoring program was a collaborative effort among a group of agencies and consulting firms that included the following:

- **City of Plymouth** – Submission of application for the Medicine Lake herbicide treatment. Contact and obtain permission from City of Plymouth shoreline residents about herbicide application. Coordinate and schedule herbicide treatment with contractor.
- **City of Medicine Lake** – Contact and obtain permission from City of Medicine Lake shoreline residents about herbicide application.
- **Three Rivers Park District** – Perform an aquatic vegetation visual survey using GPS to identify curlyleaf pondweed nuisance growth areas and estimate acreage for treatment. Bi-weekly monitoring to determine seasonal changes in water quality for Medicine Lake. Analysis of curlyleaf pondweed samples for nutrient concentration and biomass estimates. Watershed monitoring to determine nutrient loading to Medicine Lake.
- **Lake Restoration** – Implement the Medicine Lake herbicide treatment with endothall (Aquathol-K). Monitor daily changes in water temperature to determine the time period for herbicide application.
- **Blue Water Science** – Collected curlyleaf pondweed stem density and biomass samples to determine herbicide treatment effectiveness.
- **US Army Corps of Engineers** – Point intercept aquatic macrophyte survey to monitor the diversity of the plant community for Medicine Lake.

This report provides a summary of the herbicide treatments from 2004-2006. The report includes monitoring data that was collected by the different agencies and consulting firms. The report will be submitted to the MNDNR as part of the permit application to control curlyleaf pondweed in Medicine Lake for 2007. The data will be further used to determine whether the herbicide applications to control curlyleaf pondweed was a viable long-term management approach at improving in-lake water quality.

Results

Medicine Lake historically has had annual nuisance growth of curlyleaf pondweed that inhibits recreational use. Aquatic vegetation surveys performed by Three Rivers Park District indicated that there was a minimum of 300 acres of annual curlyleaf pondweed growth. Typically, nuisance growth conditions are present on approximately 30% to 40% of the surface area of the lake. The lake had approximately 375 acres of curlyleaf pondweed in 2004 which was considered nuisance growth that inhibited recreational use. However, nuisance growth conditions in 2005 and 2006 did not develop due to the previous successful herbicide treatments. Despite a decrease in nuisance growth conditions, curlyleaf pondweed was observed in the same locations as 2004. Consequently, the locations that were chemically treated in 2004 were treated again in 2005 and 2006. The curlyleaf pondweed acreage estimated from the survey in 2004 was used to determine the amount of Aquathol-K necessary for the herbicide treatment. The map (below) represents the area that was chemically treated from 2004 through 2006.



Three Rivers PARK DISTRICT

Figure 1: Curlyleaf pondweed survey on Medicine Lake.

The riparian property rights of all shoreline owners were recognized. Permission from the shoreline residents was obtained by the City of Plymouth and the City of Medicine Lake in all areas of the proposed chemical application that were closer than 150 feet from the lake shoreline. The property owners were contacted at least two months prior to the herbicide application. The majority of the Medicine Lake shoreline residents (99%) were in favor of the herbicide treatment to control curlyleaf pondweed. Those property owners that were not in favor of the herbicide treatment were identified on a map. The herbicide treatment was only applied to those designated areas in which permission was granted.

The Medicine Lake herbicide (Aquathol-K) treatment in 2005 and 2006 occurred considerably earlier than the treatment in 2004 (Table 1). The time period of the herbicide treatment was water temperature dependent. Aquathol-K is a contact herbicide that is effective at killing curlyleaf pondweed at water temperatures as low as 55° F. The temperatures in 2005 and 2006 were considerably warmer earlier in the spring in comparison to temperatures observed in 2004. The herbicide treatment was completed early in spring to ensure that the curlyleaf pondweed was eradicated prior to the development of turions. Lake Restoration applied Aquathol-K to achieve a target concentration between 1 and 1.5 mg/L. The typical length of the curlyleaf pondweed plants during the time period of treatment was between 21 and 27 inches with 10 or 11 nodes. During the initial herbicide treatment in 2004, there was approximately 1,668 gallons of Aquathol-K applied to approximately 317 acres of the lake (Table1). The amount of herbicide used in 2005 and 2006 decreased due to the reduction in curlyleaf pondweed (Table 1). The curlyleaf pondweed plants in 2004 and 2005 did not develop turions prior to the herbicide treatment. Consequently, there was less curlyleaf pondweed in subsequent years following each successive treatment.

Table 1: Herbicide Treatment and Aquatic Vegetation Quadrant Survey Information.

Category	2004	2005	2006
Herbicide Application	May 8-11	April 19-21	April 18-20
Amount of Herbicide Used	1,668 Gallons	1,400 Gallons	1,357 Gallons
Area Treated	317 Acres	325 Acres	320 Acres
Pre-Treatment Quadrant Survey	May 06	April 22	April 24
Post-Treatment Quadrant Survey	June 14	June 02	May 25

To determine the effectiveness of the herbicide treatment at controlling curlyleaf pondweed, stem density aquatic macrophyte surveys were conducted prior to and after the herbicide treatments for each year (Table 2 & 3). Blue Water Science sampled stem densities at four sites on Medicine Lake. These same locations were sampled from 2004 through 2006. Each site was sampled at ten random 0.1-m^2 quadrants for 6 ft and 9 ft depth intervals. The pre-treatment surveys indicated that stem densities of curlyleaf pondweed decreased for each successive herbicide treatment from 2004 through 2006. At the 6 ft water depth, the average stem densities decreased from 643 stems/m^2 in 2004 to 127 stems/m^2 in 2006 (Table 2). These differences were more significant for sites surveyed at 9 ft water depth where the average stem densities decreased from 472 stems/m^2 in 2004 to 44 stems/m^2 in 2006 (Table 2). The data suggests that the herbicide treatments occurred prior to turion development. Consequently, there was less curlyleaf pondweed in subsequent years following each successive treatment. The post treatment surveys for each year further suggested that the herbicide application has been effective in killing the curlyleaf pondweed.

Table 2: Pre-Treatment Quadrant Surveys in 2004, 2005, and 2006.

Site	Stem Density at 6-ft Depth			Stem Density at 9-ft Depth		
	2004 (Stems/m^2)	2005 (Stems/m^2)	2006 (Stems/m^2)	2004 (Stems/m^2)	2005 (Stems/m^2)	2006 (Stems/m^2)
1	761	415	24	572	192	38
2	928	600	205	432	215	22
3	555	11	159	666	43	100
4	327	650	121	219	120	15
Average	**643**	**419**	**127**	**472**	**143**	**44**

Data collected by Steve McComas and Jo Stuckert, Blue Water Science

The post-treatment surveys indicated that there was very little curlyleaf pondweed found in Medicine Lake (Table 3). The only year that had noticeable curlyleaf pondweed following the herbicide treatment was in 2006. The highest post-treatment stem densities in 2006 occurred in the southern portion of Medicine Lake. The post-treatment stem densities decreased for each sampling site in the northern portion of Medicine Lake. There was no curlyleaf pondweed found at the furthest northern sampling station (Site 1). The post-treatment stem density data suggests that prevailing winds from the south during herbicide application contributed to chemical drift toward the northern portion of the lake. The curlyleaf pondweed found in the southern portion of Medicine Lake was in very poor condition indicating that these plants were impacted by the herbicide application. Despite the differences in the effectiveness of the herbicide application, the treatment significantly reduced the amount of curlyleaf pondweed in Medicine Lake. Based on the preliminary data, the surveys suggest that consecutive whole-lake herbicide treatments have been effective in reducing the amount of curlyleaf pondweed in Medicine Lake. However, it is uncertain whether the amount of curlyleaf pondweed surviving after the herbicide treatment in 2006 will have an impact on future long term management efforts to control the invasive plant.

Table 3: Post-Treatment Quadrant Survey in 2004, 2005, and 2006.

Site	Stem Density at 6-ft Depth			Stem Density at 9-ft Depth		
	2004 (Stems/m^2)	2005 (Stems/m^2)	2006 (Stems/m^2)	2004 (Stems/m^2)	2005 (Stems/m^2)	2006 (Stems/m^2)
1	1	0	0	2	0	0
2	3	0	14	1	0	17
3	0	0	66	0	0	79
4	0	0	50	0	0	0
Average	**1**	**0**	**33**	**1**	**0**	**24**

Data collected by Steve McComas and Jo Stuckert, Blue Water Science

Aquatic macrophyte surveys were conducted in Medicine Lake to assess potential changes in the plant community following the herbicide treatments. The U.S. Army Corps of Engineers performed point-intercept surveys in April, June, and September from 2004 through 2006. Each survey was a compilation of 200 to 220 sampling points within the littoral area (depth $\leq$ 15 ft) of Medicine Lake (personal communication, John Skogerboe). The point-intercept method is a qualitative approach in which plant species are collected and identified from one rake throw at each sampling point. The pre-treatment and post-treatment surveys indicated that the herbicide was effective at killing curlyleaf pondweed in the year of treatment and reducing the amount of curlyleaf pondweed each consecutive year. The frequency of occurrence for curlyleaf pondweed decreased from 52% in April (pre-treatment) to 7% in June (post-treatment) of 2004, decreased from 37% in April (pre-treatment) to 5% in June (post-treatment) of 2005, and decreased from 22% in April (pre-treatment) to 1% in June (post-treatment) of 2006 (Table 4). During the early spring, there was not much diversity in the native plant community. The early spring herbicide treatment occurred prior to native plant germination. The fall (September) surveys from 2004 through 2006 indicated that the treatment did not appear to affect the native plant community.

Table 4: Medicine Lake Point-Intercept Aquatic Macrophyte Survey

Species	Percent Occurrence								
	2004			2005			2006		
	April	June	Sept	April	June	Sept	April	June	Sept
Ceratophyllum demersum	31	24	39	12	30	39	35	33	40
Elodea canadensis	2	5	4	6	11	14	21	24	18
Myriophyllum spicatum	13	0	8	3	13	18	24	45	70
Myriophyllum sibiricum	0	1	0	0	0	0	0	0	0
Potamogeton crispus	87	11	12	37	5	0	22	1	0
Najas flexilis	0	3	5	0	2	8	0	6	10
Nuphar advena	0	9	6	3	8	8	1	9	9
Nymphaea oderata	4	20	15	2	16	16	6	16	17
Potamogeton amplifolius	0	0	1	0	1	0	0	1	4
Potamogeton illinoensis	0	3	2	0	3	3	0	3	5
Potamogeton foliosus	1	0	1	0	0	1	0	0	0
Potamogeton praelongus	0	1	1	0	1	1	0	4	5
Potamogeton robinsii	0	0	2	0	0	0	0	0	0
Potamogeton zosteriformis	1	1	1	0	0	0	0	0	0
Scirpus validus	0	3	3	0	3	3	0	3	4
Stukenia pectinata	0	8	16	0	20	15	0	21	15
Vallisneria americana	0	24	27	0	30	33	0	31	32
Zosterella dubia	0	0	7	0	6	5	0	6	7
Zannichellia palustris	0	1	1	1	1	0	0	2	0
Chara spp.	7	42	13	8	26	17	6	30	19

Data collected and analyzed by John Skogerboe, US Army Corps of Engineers

Table 5: Medicine Lake Point-Intercept Aquatic Macrophyte Survey Summary Statistics.

Category	2004			2005			2006		
	April	June	Sept	April	June	Sept	April	June	Sept
% Potamogeton crispus	87%	11%	12%	37%	5%	0%	22%	1%	0%
% Myriophyllum spicatum	13%	0%	8%	3%	13%	18%	24%	45%	70%
% Native Species	43%	59%	63%	23%	64%	64%	48%	61%	67%
Native Species/Point	0.3	1.03	1.54	0.27	1.57	1.61	0.68	1.4	1.6
Number of Native Species	7	15	19	8	16	15	8	16	16

Data collected and analyzed by John Skogerboe, US Army Corps of Engineers

Medicine Lake has a diverse native plant community with 15 to 19 species present in the June and September surveys (Table 5). The dominant native species present were *Ceratophyllum demersum* (Coontail) and *Vallisneria americana* (Water Celery) (Table 4). It was anticipated that the decrease in curlyleaf pondweed would improve the abundance and enhance the distribution of the native plant community. Despite an existing diverse native plant community, there was no significant increase in the percent occurrence of most native plant species. The only substantial increase in percent occurrence for native species was *Elodea canadensis* (Table 4). Although there hasn't been an improvement, the percent occurrence for the native plant community has not significantly decreased. It is encouraging that the herbicide treatments did not appear to have a negative impact on the native plant community. Results from several previous projects indicated that the native plant community may not respond immediately to curlyleaf pondweed control (personal communication, John Skogerboe). The native plant community may require several years before there are noticeable improvements in percent occurrence. Consequently, this suggests that curlyleaf pondweed management efforts should be continued to allow for the further development of the native plant community.

The return of curlyleaf pondweed each spring may have inhibited the further development of the native plant community. Typically, there is early fall germination of curlyleaf pondweed from viable turions residing in the sediments from previous years production. The percent occurrence of curlyleaf pondweed germinating in the fall (September) of 2004 was 12.3% (Table 4 & 5). The following spring there was approximately 37% occurrence of curlyleaf pondweed in 2005. The percent occurrence of curlyleaf pondweed further decreased to 22% in the spring of 2006 (Table 4 & 5). The herbicide treatments from 2004-2006 occurred prior to the development of turions. The data suggests that the viable turion seed bank within the lake sediments was reduced each consecutive year following initial herbicide treatment in 2004. Although the turion seed bank was reduced, it appears that the remaining turions in the sediments remain viable for several years. Unfortunately, monitoring efforts were not incorporated to determine the turion seed bank reduction so it becomes difficult to predict the curlyleaf pondweed growth in 2007. Despite the potential for curlyleaf pondweed turion germination, the reduction in the amount of curlyleaf pondweed each consecutive year certainly improved conditions that are more conducive for expanding the distribution of the native aquatic plant community.

There was a concern that eradicating curlyleaf pondweed would cause Medicine Lake to shift toward a plant community dominated by Eurasian watermilfoil. Medicine Lake periodically has had nuisance growth conditions of Eurasian watermilfoil. Three Rivers Park District has previously harvested portions of the lake to remove Eurasian watermilfoil and improve recreational opportunities. These nuisance growth conditions do not necessarily occur every year. The point-intercept macrophyte surveys indicated that Eurasian watermilfoil percent occurrence was relatively low (8%) the first year of treatment in 2004 (Table 5). However, the percent occurrence of Eurasian watermilfoil increased significantly to 18% in 2005 and 70% in 2006 (Table 5). Based on the point-intercept survey, Eurasian watermilfoil has become the most common aquatic plant specie in Medicine Lake. It appears that Medicine Lake may be shifting toward a plant community dominated by Eurasian watermilfoil. The substantial increase in Eurasian watermilfoil may inhibit the potential increase in abundance of the diverse native plant community. Medicine Lake management efforts may have to consider controlling Eurasian watermilfoil to encourage native plant growth. Consequently, the monitoring efforts assessing the changes in the aquatic plant community should be continued to determine potential management objectives.

Another primary objective of the long-term management approach to controlling curlyleaf pondweed was to improve in-lake water quality conditions. Medicine Lake was monitored bi-weekly from 1990 to 2006 to determine seasonal changes in water quality. Prior to the herbicide treatments in 2004, Medicine Lake had a characteristic total phosphorus spike coinciding with curlyleaf pondweed senescence at the end of June and beginning of July. In 2004, the increase in phosphorus concentration coincided with the time period of the initial herbicide treatment (Figure 2). The amount of phosphorus released from the die-off of curlyleaf pondweed due to the herbicide treatment was estimated by performing phosphorus analysis on the biomass samples collected from the aquatic macrophyte quadrant survey (Table 6). Based on the phosphorus analysis from biomass samples, the die-off of curlyleaf pondweed released approximately 1,050 pounds of phosphorus as a consequence of the herbicide treatment (Table 5). The preliminary analysis provided an estimate of the internal loading from curlyleaf pondweed senescence. The data suggests that curlyleaf pondweed senescence provided a significant source of internal phosphorus loading. It was anticipated that management efforts to reduce curlyleaf pondweed abundance would further reduce internal phosphorus loading and improve water quality conditions.

Table 6: Medicine Lake estimated total phosphorus loading from curlyleaf pondweed in 2004.

Site	Acreage	Average Biomass (g dry wt/m^2)	Average TP Conc. (mg/g dry wt)	Average (lbs TP/Acre)	TP Loading (pounds)
1	147.3	83.4	4.80	3.19	469.8
2	42.2	92.1	2.29	1.86	78.4
3	136.3	92.8	3.73	3.08	419.7
4	50.0	38.6	4.91	1.65	82.6
Total					**1050**

There was no increase in total phosphorus coinciding with the herbicide treatments in 2005 or 2006 (Figures 3 & 4). The extended time period between sampling intervals prior to and after the herbicide treatment may have missed a potential phosphorus spike in 2005 (Figure 3). Consequently, the sampling frequency in 2006 was increased to detect potential changes in water quality relating to the herbicide treatment. Samples were collected every week for a month after the herbicide treatment in 2006. The water quality data in 2006 suggests that a phosphorus spike did not occur after the herbicide treatment (Figure 4). This was most likely due to the decrease in curlyleaf pondweed biomass from the previous treatments.

It was anticipated that a reduction in curlyleaf pondweed would eliminate the characteristic phosphorus spike that occurs following senescence at the end of June and beginning of July, and would improve water quality conditions later in the season. In 2006, there was no increase in the total phosphorus concentration that typically occurs at the end of June and the beginning of July (Figure 4). The total phosphorus concentrations in 2006 remained relatively low through the end of July. However, a total phosphorus spike did occur in 2005 at the beginning of July (Figure 3). The increase in phosphorus concentrations was not due to curlyleaf pondweed senescence because the early herbicide application in April effectively eliminated the plant. The temperature and dissolved oxygen profiles indicated that the increase in phosphorus concentration was due to the mixing of the water column causing a significant amount of internal loading. Medicine Lake has the potential to mix several times each year due to the prevailing northerly and southerly winds. These mixing events typically occur at the end of August and the beginning of September as water temperatures begin to change. Consequently, it was unexpected for Medicine Lake to have a mixing event at the beginning of July in 2005. Medicine Lake may have been more vulnerable for a mixing event to occur earlier in the season because there was a lack of vegetation to stabilize the sediments. Although there were some seasonal differences between 2005 and 2006, there was an improvement in phosphorus concentration relative to those years that had curlyleaf pondweed senescence.

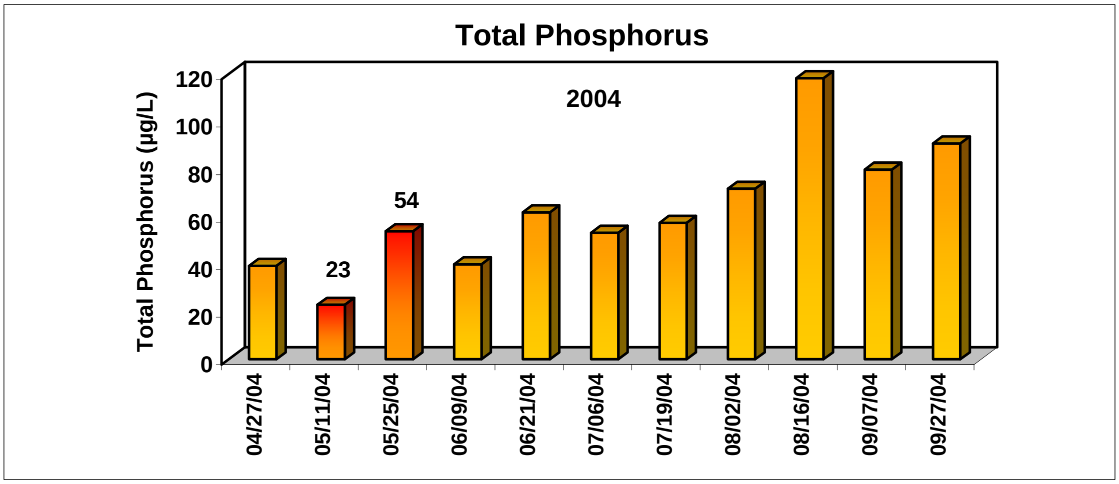


Figure 2: Seasonal Changes in total phosphorus concentration for Medicine Lake in 2004.

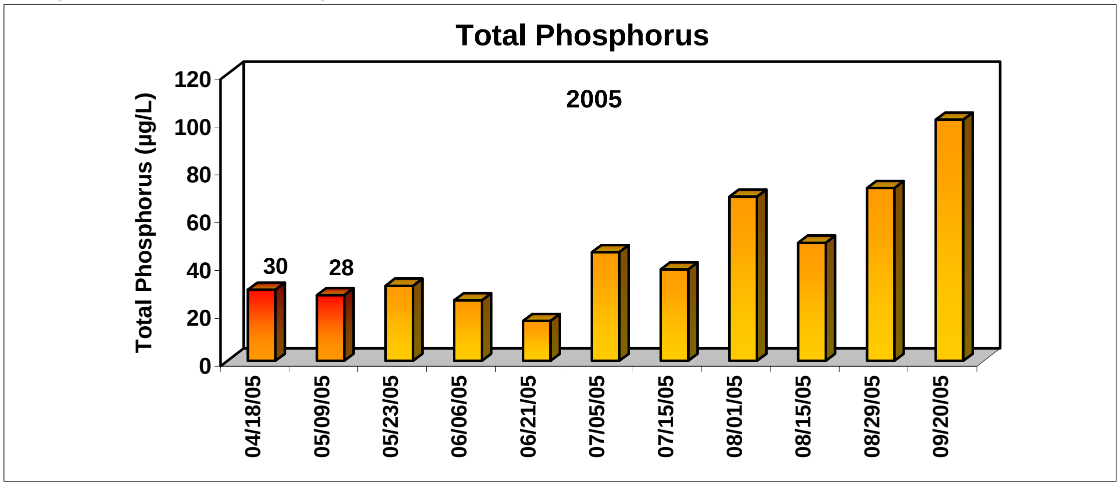


Figure 3: Seasonal changes in total phosphorus concentration for Medicine Lake in 2005.

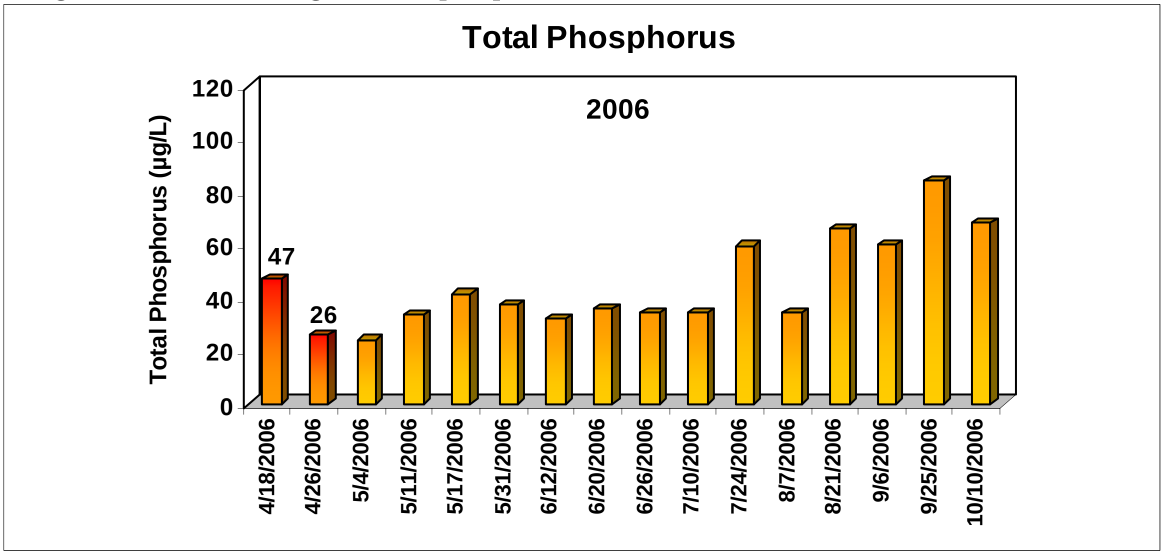


Figure 4: Seasonal changes in total phosphorus concentration for Medicine Lake in 2006.

It appears that the reduction in curlyleaf pondweed may have had an impact on total phosphorus concentrations within Medicine Lake. Preliminary analysis of water quality data from 1995-2006 indicated that average phosphorus concentration calculated from May through mid-July (the time period of typical curlyleaf pondweed growth and senescence) was lower in 2005 and 2006 (Figure 5). This was attributed to the reduced amount of curlyleaf pondweed from consecutive herbicide treatments. The data suggests that the characteristic total phosphorus spike prior to the 2004 herbicide treatment was partially due to curlyleaf pondweed senescence. The total phosphorus concentrations in 2005 and 2006 did not significantly increase until the end of July or the beginning of August. Medicine Lake had total phosphorus concentrations at or near the water quality goal (38 µg/L) throughout a major portion of the summer in 2005 and 2006. These concentrations were an improvement in comparison to pretreatment years when excessive growth of curlyleaf pondweed contributed to phosphorus loading. Despite less curlyleaf pondweed biomass in 2005 and 2006, the decrease in phosphorus concentration from May through mid-July was not enough to result in a significant difference ($p < 0.05$) in the annual average total phosphorus concentrations for the entire growing season from 1995 through 2005 (Figure 6). Although these differences were not significant, it is encouraging that the annual average total phosphorus concentration has decreased considerably since the initial herbicide treatment in 2004.

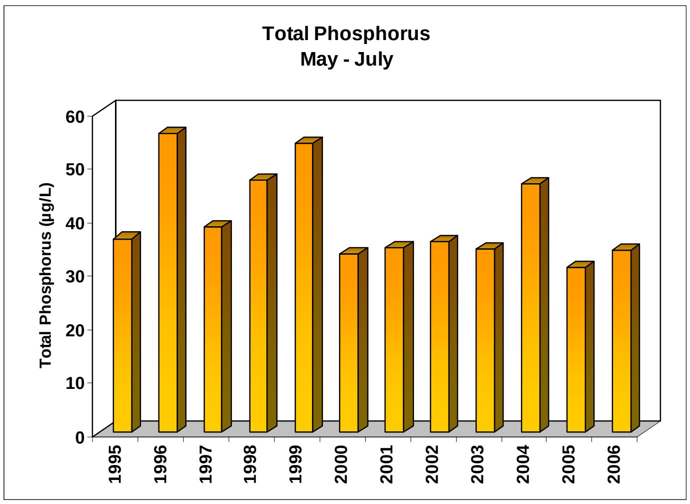


Figure 5: Medicine Lake average total phosphorus concentration from May through July.

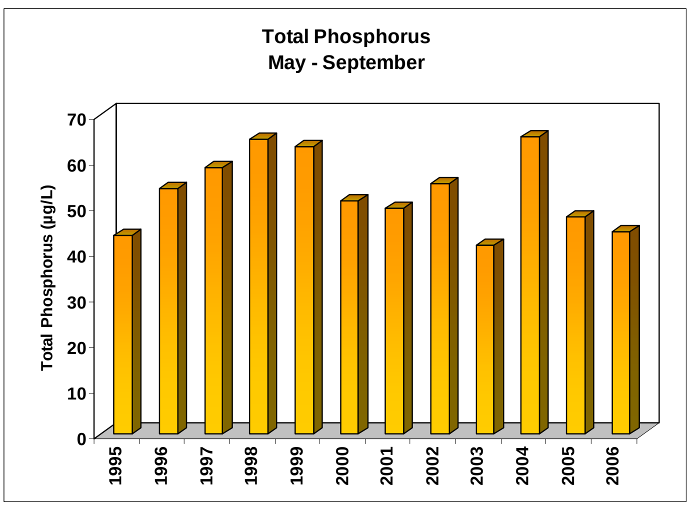


Figure 6: Medicine Lake average total phosphorus concentration from May through September.

The decrease in total phosphorus concentration from the reduction of curlyleaf pondweed may be offset by increases in watershed loading. Medicine Lake receives a considerable amount of nutrient loading from the watershed that potentially inhibits improvements in water quality. There were 1 monitoring stations installed with automated samplers/flow data loggers to determine the watershed nutrient loading to Medicine Lake (Figure 7). The watershed monitoring program was a collaborative effort with the City of Plymouth and Three Rivers Park District. Prior to the herbicide treatment, the in-lake total phosphorus concentrations appeared to correspond with the changes in total phosphorus watershed loading (Figure 8). However, the Medicine Lake watershed phosphorus loading has not significantly changed since the initial herbicide treatment in 2004, but the in-lake total phosphorus concentrations has declined (Figure 8). This further suggests that the reductions in Medicine Lake internal loading as a consequence of controlling curlyleaf pondweed may have contributed to the in-lake total phosphorus improvements. Although these improvements may be attributed to the reduction in curlyleaf pondweed, the dynamics between watershed nutrient loading and internal loading with respect to the water quality impacts are very complex and will require further investigation.

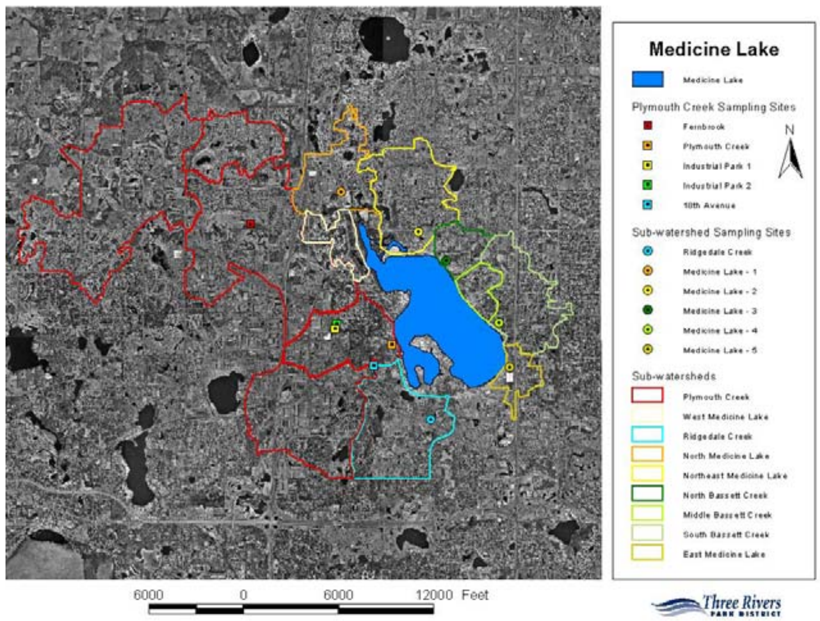


Figure 7: Medicine Lake watershed monitoring sites.

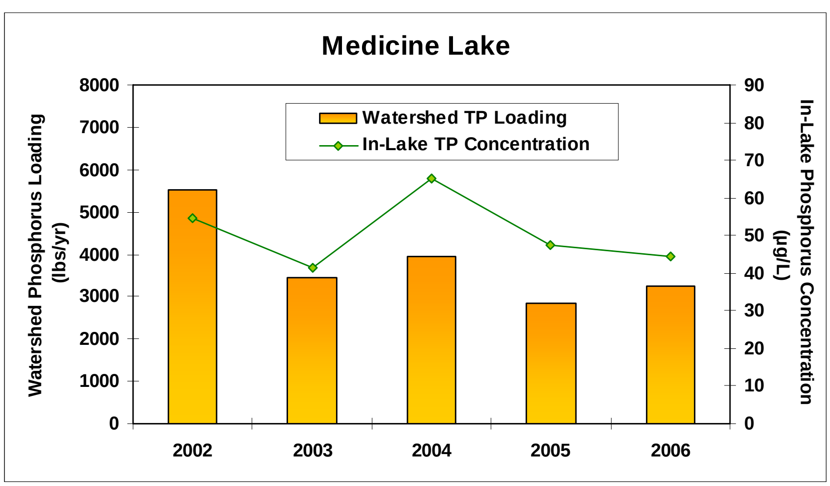


Figure 8: Changes in total watershed phosphorus loading and in-lake phosphorus concentrations.

The nutrients released from the die-off of curlyleaf pondweed are in a soluble form that is readily available for algae and potentially can have an impact on water clarity. Typically, Medicine Lake has an algae bloom following curlyleaf pondweed senescence at the end of June or beginning of July. It was anticipated that a decrease in phosphorus concentrations would reduce the severity of potential algae blooms and improve water clarity conditions. Despite a decrease in phosphorus concentrations for 2005 and 2006, there were no significant differences in chlorophyll-*a* concentrations or secchi depth transparency (Figure 9). Although curlyleaf pondweed biomass has been significantly reduced, algae blooms developed at the end of June or the beginning of July (Figures 10-12). Medicine Lake continues to have excessive amounts of phosphorus available for algae uptake even though concentrations have decreased. The curlyleaf pondweed die-off from the initial herbicide treatment in 2004 released a considerable amount of nutrients. The conditions following the early spring treatment in 2004 were not conducive for the development of an algae bloom. The water temperatures were relatively cool for several weeks following the treatments inhibiting the growth of algae. Consequently, algae blooms did not develop until early summer when water temperatures were warmer (Figure 9 & 10). The data suggests that the algae bloom may be dependent upon weather conditions when nutrients are not a limiting factor. Medicine Lake has excess external and internal sources of nutrient loading that inhibit improvements in water quality conditions. Due to these excessive amounts of nutrients, Medicine Lake typically develops poor water quality conditions in late summer. It is still too early to determine whether curlyleaf pondweed management efforts will reduce in-lake nutrients enough to significantly improve water quality conditions.

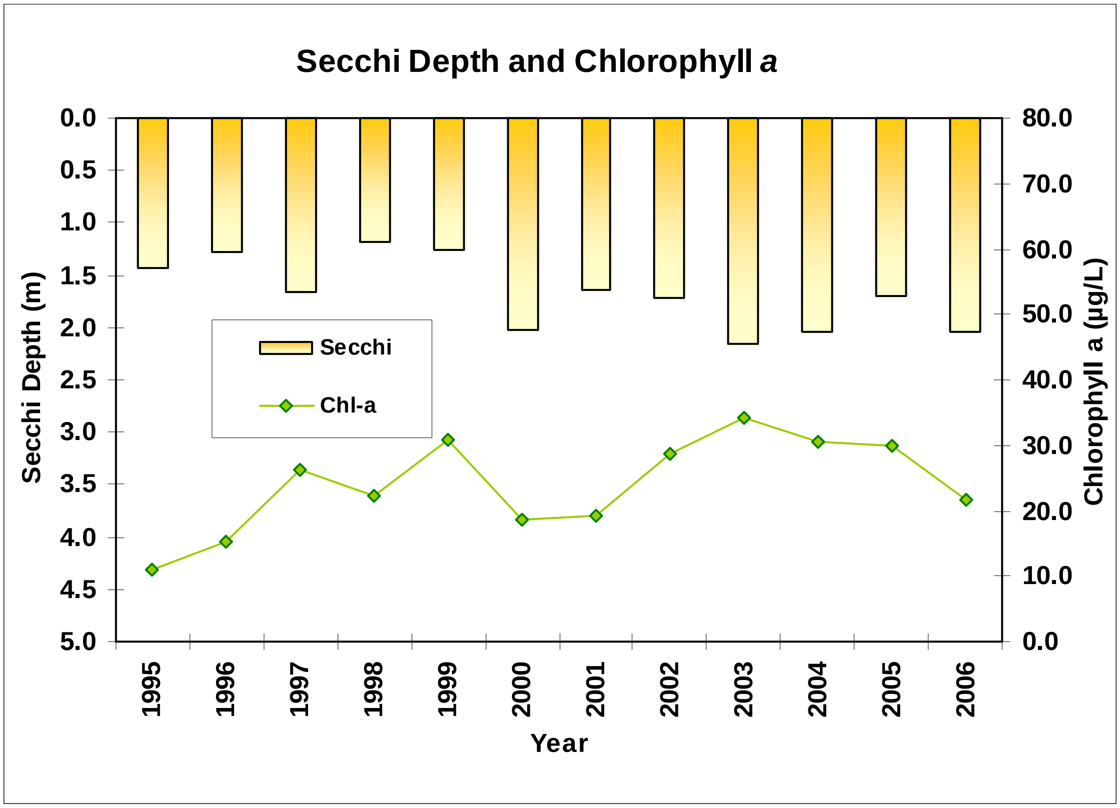


Figure 9: Annual changes in secchi depth and chlorophyll-a concentrations for Medicine Lake.

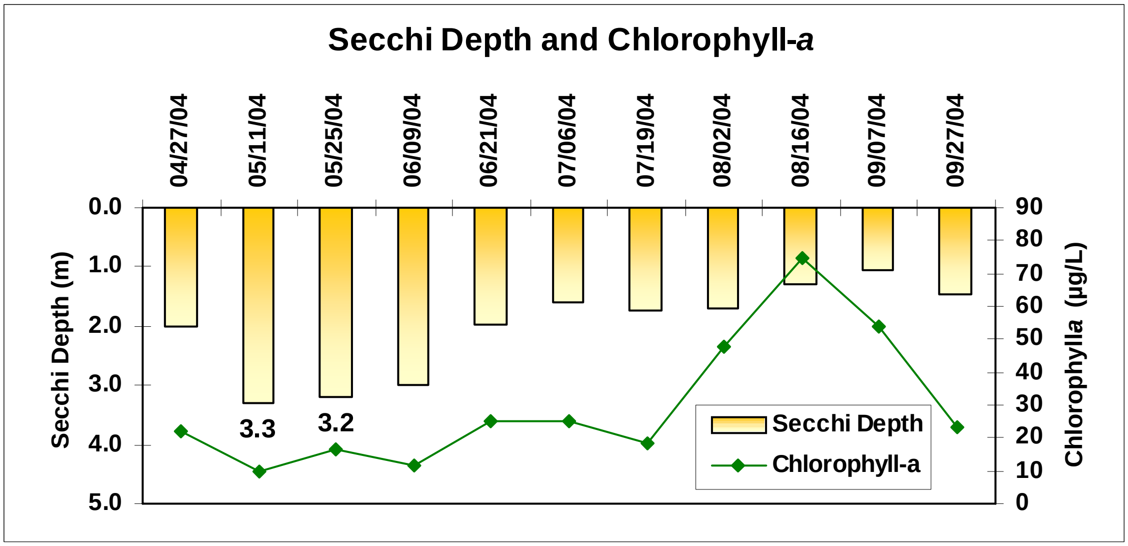


Figure 10: Seasonal changes in secchi depth and chlorophyll-a concentrations for Medicine Lake in 2004.

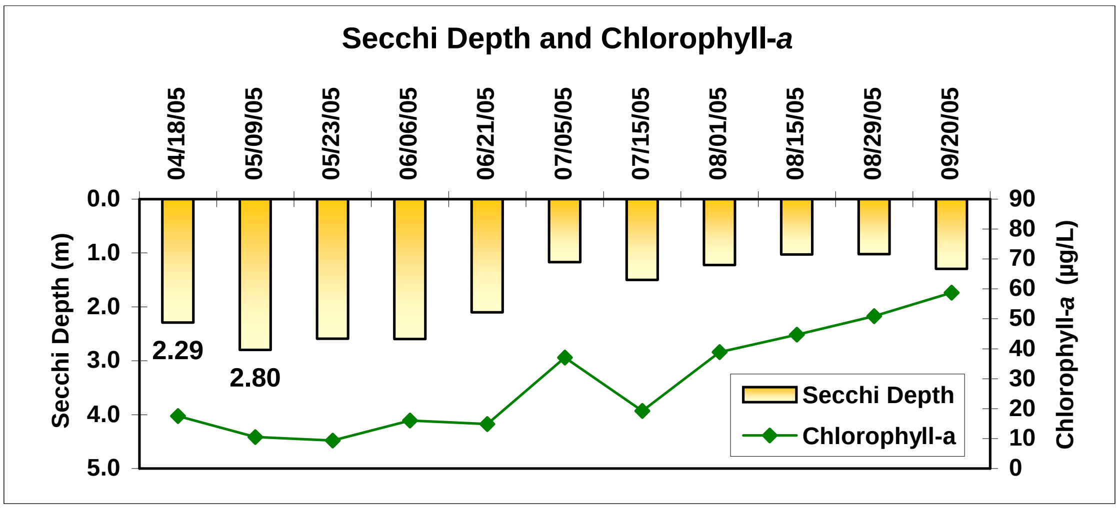


Figure 11: Seasonal changes in secchi depth and chlorophyll-a concentrations for Medicine Lake in 2005.

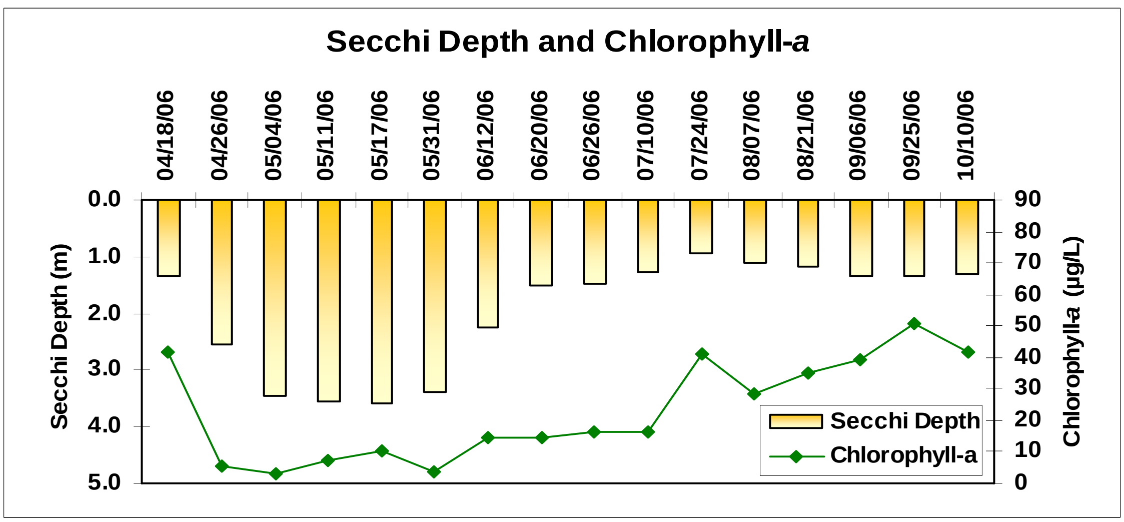


Figure 12: Seasonal changes in secchi depth and chlorophyll-a concentrations for Medicine Lake in 2005.