Medicine Lake
Endothall Treatment to Control
Curlyleaf Pondweed
2004-2007

Status Report
Prepared
By

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March 2008

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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) 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 typically has 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 future 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:

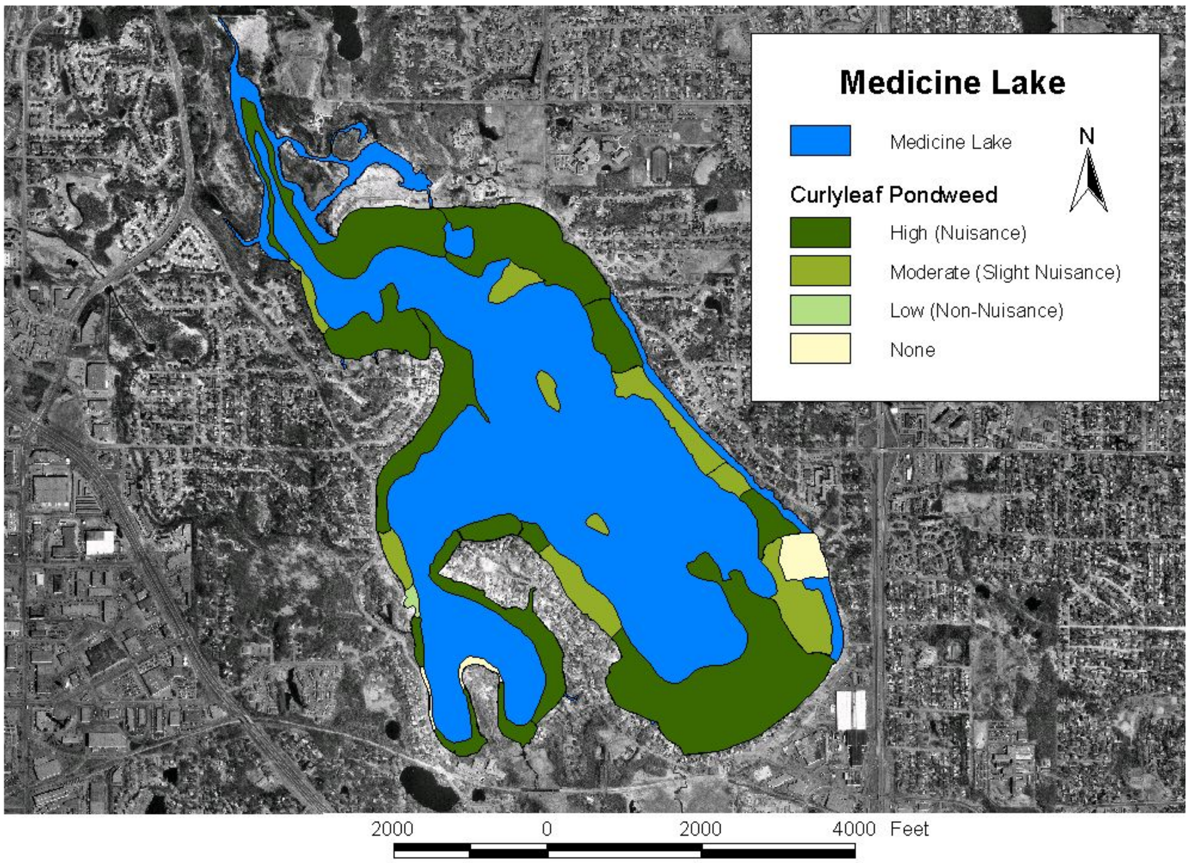
- **City of Plymouth** – Submission of application for the Medicine Lake herbicide treatment. Contact and obtain permission from City of Plymouth shoreline residents about herbicide application. Coordinate and schedule herbicide treatment with contractor.
- **City of Medicine Lake** – Contact and obtain 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 monitoring data collected by the different agencies and consulting firms from 2004 through 2007. The report will be submitted to the MNDNR as part of the permit application to control curlyleaf pondweed in Medicine Lake for 2008. The data will be further used to determine whether the herbicide applications to control curlyleaf pondweed were a viable long-term management approach to improve in-lake water quality.

Results

Aquatic Herbicide Treatments

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 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. Based on a visual survey, the Medicine Lake map (below) characterizes the growth conditions of curlyleaf pondweed in 2004. These areas were chemically treated from 2004 through 2006.



Three Rivers PARK DISTRICT

Figure 1: Curlyleaf pondweed survey on Medicine Lake.

The Medicine Lake herbicide (Aquathol-K) treatment from 2004 through 2006 occurred early in the spring (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. Consequently, the herbicide treatments in 2005 and 2006 were applied earlier in comparison to 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 1,668 gallons of Aquathol-K applied to 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

Stem Density Surveys

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). Differences in stem densities were more significant for sites surveyed at 9 ft water depth, where the average density 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 growth 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 in the year of treatment.

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 in Medicine Lake (Table 3). The only year that had noticeable curlyleaf pondweed following the herbicide treatment was in 2006 when relatively high stem densities occurred in the southern portion of Medicine Lake. The post-treatment stem densities decreased at each sampling site in the northern portion of Medicine Lake. There was no curlyleaf pondweed found at the northern most sampling station (Site 1). The post-treatment stem density data suggests that chemical drift due to prevailing winds from the south occurred during herbicide application. 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 was 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

There was no herbicide application completed in Medicine Lake to control curlyleaf pondweed in 2007. The stem density survey in April of 2007 indicated that the amount of curlyleaf pondweed was very low. The initial survey suggested that the previous treatment reduced the curlyleaf pondweed density in 2007. However, stem density surveys completed in May of 2007 indicated that there was significant curlyleaf pondweed growth. The average stem densities increased from 13 stems/m^2 in April to 43 stems/m^2 in May at a depth of 6 feet, and the average stem densities increased from 43 stems/m^2 in April to 111 stems/m^2 in May at a depth of 9 feet (Table 4). A few of the sampling sites had stem densities that reached nuisance conditions.

Table 4: Curlyleaf pondweed stem densities for Medicine Lake in 2007.

Stem Density ($Stems/m^2$) 2007				
Site	6-Ft Depth		9-Ft Depth	
	April	May	April	May
1	1	41	14	81
2	17	77	15	83
3	5	33	12	270
4	29	20	16	9
Average	13	43	14	111

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

Three Rivers Park District performed a visual survey to estimate the acreage of curlyleaf pondweed in June of 2007. The visual survey confirmed that Medicine Lake had approximately 224 acres of curlyleaf pondweed, in which approximately 60 acres had nuisance growth conditions (Figure 2). The amount of curlyleaf pondweed was not anticipated because a decrease in stem densities for each consecutive year of the herbicide treatments suggested a reduction in the turion seed bank. It is critical to reduce the turion seed bank to achieve long term control of curlyleaf pondweed and to establish a native plant community. Consequently, additional herbicide treatments in Medicine Lake are necessary to further reduce the viable turion seed bank. It is uncertain whether the amount of curlyleaf pondweed growth observed in 2007 will have a significant impact on the native plant community.

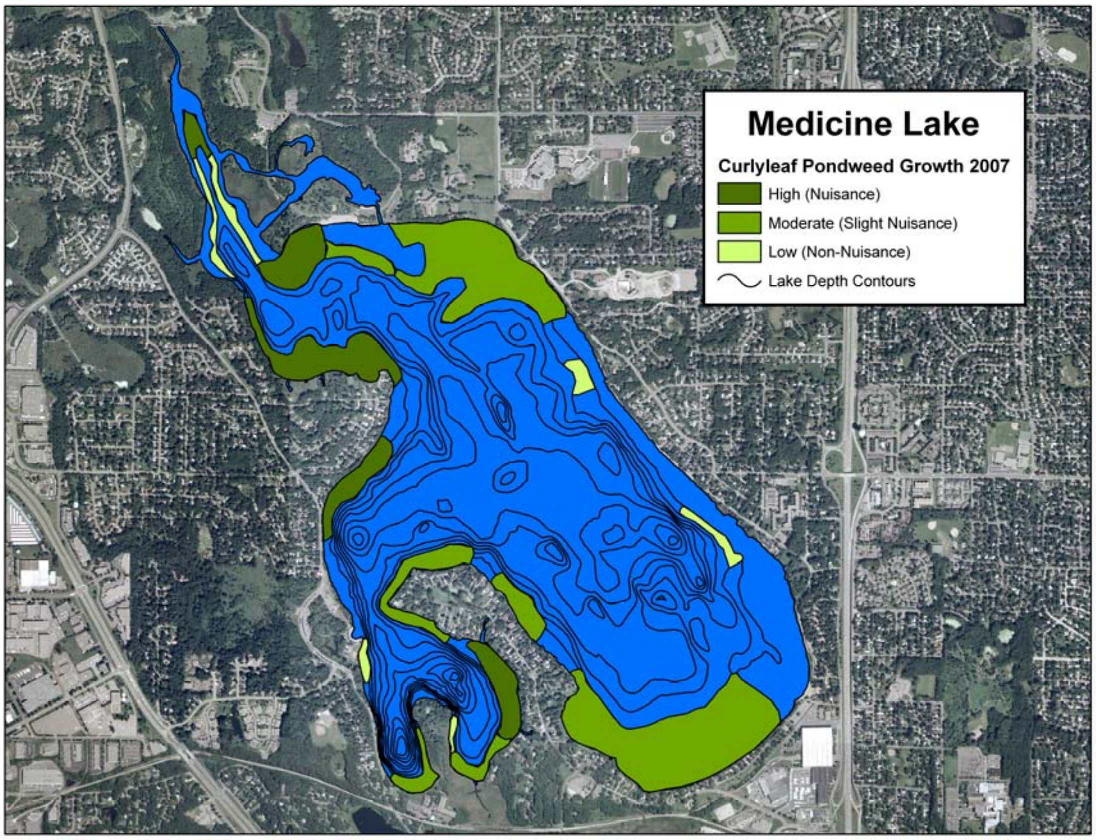


Figure 2: Curlyleaf pondweed growth in 2007.

Point-Intercept Surveys

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 2008. Each survey was a compilation of 200 to 220 sampling points within the littoral area (depth ≤ 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 percent occurrence was calculated for each plant species observed during the point-intercept survey for Medicine Lake (Table 5).

The point-intercept survey was similar to the stem density data with regards to the herbicide treatment effectiveness. The herbicide treatment was effective at killing curlyleaf pondweed prior to turion development in the year of treatment. The amount of curlyleaf pondweed was also reduced for 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 5). The early spring herbicide treatment occurred prior to native plant germination. Consequently, there was not much diversity in the native plant community.

It was anticipated that there would be a further reduction in the percent occurrence of curlyleaf pondweed in 2007. The percent occurrence of curlyleaf pondweed decreased from 22% in April of 2006 to 15% in April of 2007. It appears that the amount of decrease in the percent occurrence for curlyleaf pondweed has become reduced from 2006 through 2007 (Figure 3). 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 viable turions persist in the lake sediments for several years. It appears that several more years of herbicide treatments are required to eliminate the turion seed bank. Since there was no early season herbicide treatment for curlyleaf pondweed in 2007, the percent occurrence of curlyleaf pondweed increased to 22% in June of 2007. These plants developed turions and senesced at the end of June and the beginning of July. It is anticipated that the percent occurrence will increase due to the turion production in 2007. The anticipated increase in curlyleaf pondweed may impact the native plant community.

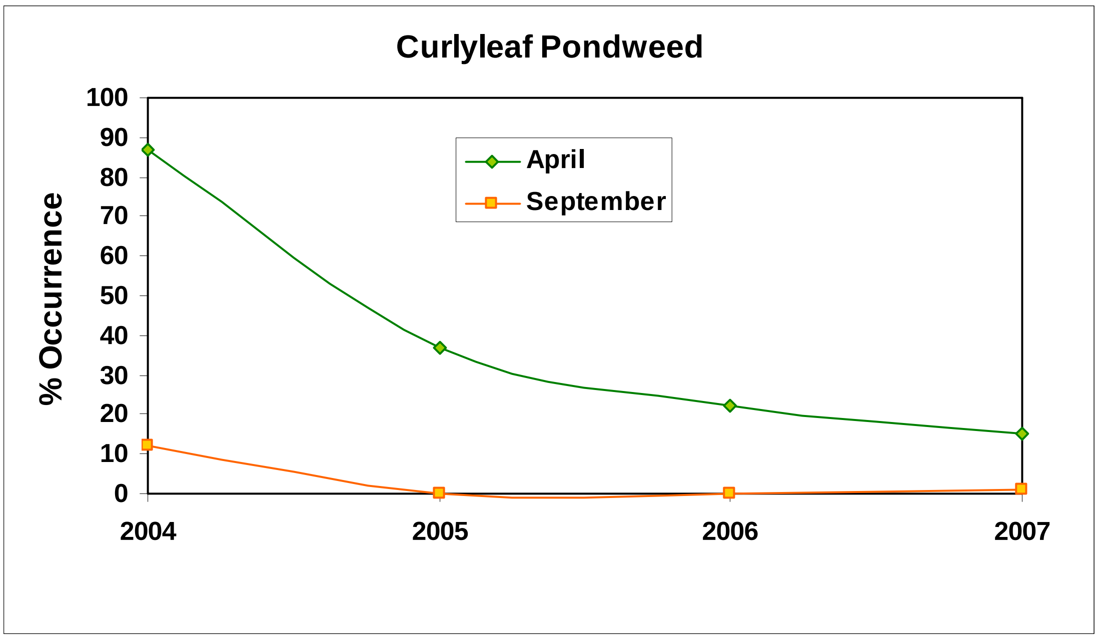


Figure 3: The annual change in curlyleaf pondweed percent occurrence for Medicine Lake in April and September.

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

Species	Percent Occurrence											
	2004			2005			2006			2007		
	April	June	Sept	April	June	Sept	April	June	Sept	April	June	Sept
Ceratophyllum demersum	31	24	39	12	30	39	35	33	40	24	40	53
Elodea cnadansis	2	5	4	6	11	14	21	24	18	11	12	3
Myriophyllum spicatum	13	0	8	3	13	18	24	45	70	40	60	70
Myriophyllum sibiricum	0	1	0	0	0	0	0	0	0	0	0	0
Potamogeton crispus	87	11	12	37	5	0	22	1	0	15	22	1
Najas flexilis	0	3	5	0	2	8	0	6	10	0	5	3
Nuphar advena	0	9	5	3	8	8	1	9	9	0	8	3
Nymphaea odorata	4	20	15	2	16	16	6	16	17	0	15	15
Potamogeton amplifolius	0	0	1	0	1	0	0	1	40	0	0	0
Potamogeton illinoensis	0	3	2	0	3	3	0	3	5	0	3	5
Potamogeton foliosus	1	0	0	0	0	0	0	0	0	0	0	0
Potamogeton praelongus	0	1	0	0	1	1	0	4	5	0	4	1
Potamogeton robinsii	0	0	2	0	0	0	0	0	0	0	0	0
Potamogeton zosteriformis	1	1	0	0	0	0	0	0	0	0	0	1
Scirpus validus	0	3	3	0	3	3	0	3	4	0	4	4
Stukenia pectinata	0	8	16	0	20	15	0	21	15	0	12	7
Vallisneria americana	0	24	27	0	30	33	0	31	32	0	18	19
Zosterella dubia	0	0	7	0	6	5	0	6	7	0	4	1
Zannichellia palustris	0	1	0	0	1	0	0	2	0	0	0	0
Chara spp.	7	42	13	8	26	17	6	30	19	1	15	8

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

Table 6: Medicine Lake Point-Intercept Aquatic Macrophyte Survey Summary Statistics.

Category	2004			2005			2006			2007		
	April	June	Sept	April	June	Sept	April	June	Sept	April	June	Sept
% Potamogeton Crispus	87%	13%	12%	37%	5%	0%	22%	1%	0%	15%	22%	1%
% Myriophyllum spicatum	11%	0%	8%	3%	13%	18%	24%	45%	70%	40%	60%	70%
% Native Species	43%	59%	63%	23%	64%	64%	48%	61%	67%	29%	59%	68%
Native Species/Point	0.3	1.03	1.54	0.27	1.57	1.61	0.68	1.4	1.6	0.36	1.2	1.22
Number of Native Species	7	15	19	8	16	15	8	16	16	3	12	12

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 (Tables 5 & 6). The dominant native species present were *Ceratophyllum demersum* (Coontail) and *Vallisneria americana* (Water Celery) (Table 5). 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 (Figure 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, curlyleaf pondweed management efforts may need to continue to allow for the further development of the native plant community.

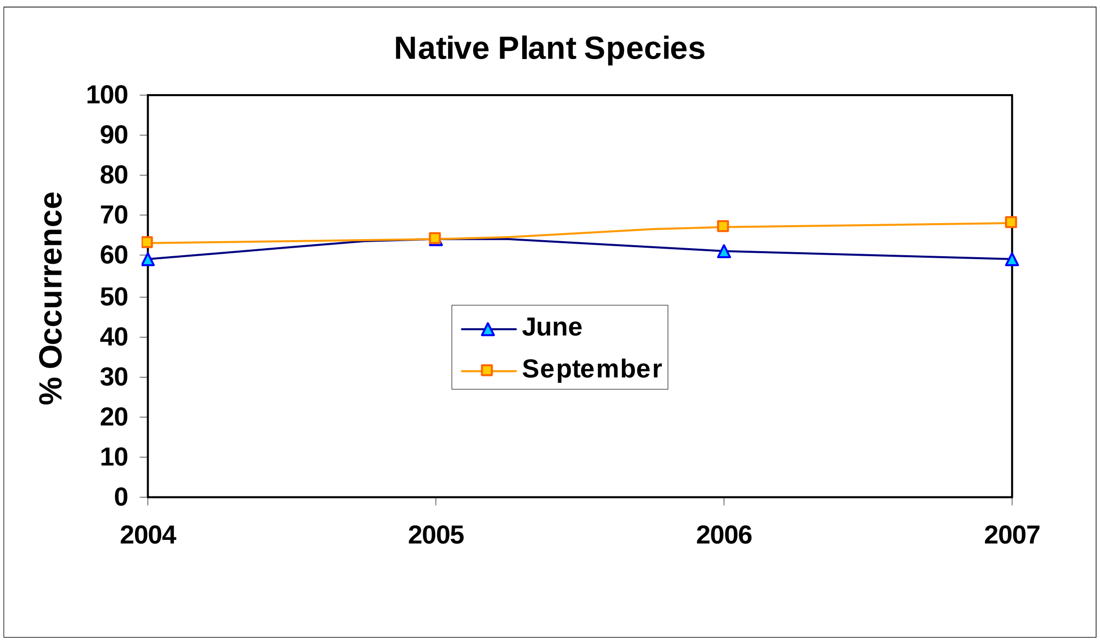


Figure 4: The annual change in the native plant community percent occurrence for Medicine Lake in June and September.

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 and chemically treated 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 in September has increased significantly to 18% in 2005, 70% in 2006 (Table 5). It appears that the percent occurrence of Eurasian watermilfoil stabilized at 70% occurrence in 2007 (Figure 5). The increase in percent occurrence for Eurasian watermilfoil corresponds with the decrease in percent occurrence of curlyleaf pondweed. Based on the point-intercept survey, Eurasian watermilfoil has become the most common aquatic plant specie in Medicine Lake. It is recommended to continue monitoring efforts to determine changes in Eurasian watermilfoil distribution and density.

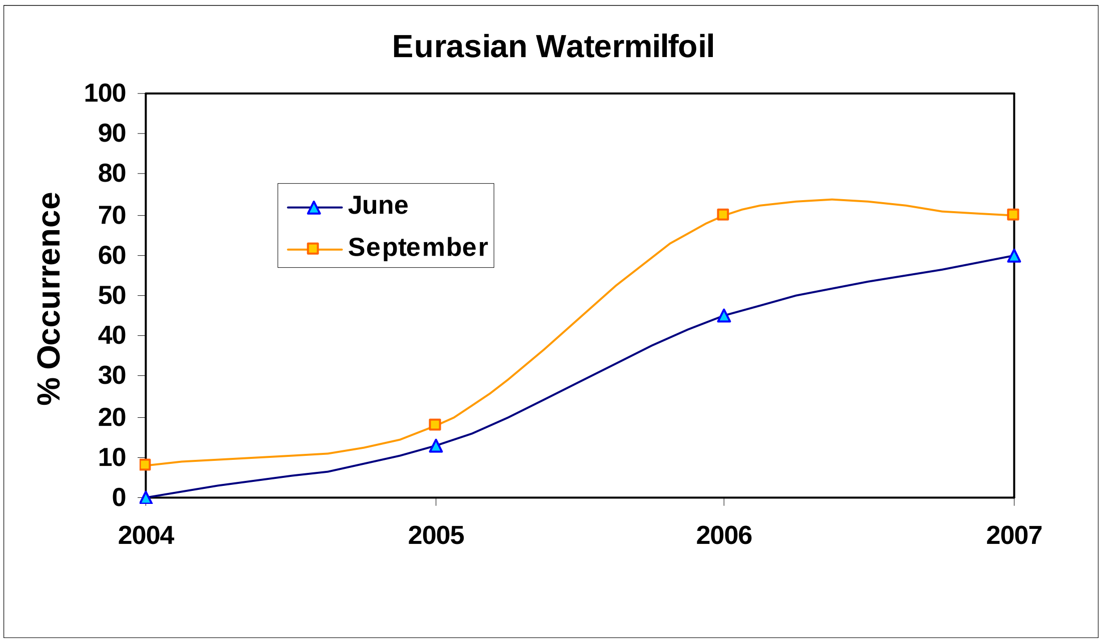


Figure 5: The annual change in Eurasian watermilfoil percent occurrence for Medicine Lake in June and September.

Three Rivers Park District performed a visual survey in 2007 to determine the nuisance growth coverage of Eurasian watermilfoil in Medicine Lake. Three Rivers Park District received several complaints from Medicine Lake lakeshore residents pertaining to nuisance growth of Eurasian watermilfoil in 2006 and 2007. The visual survey indicated that there were approximately 84 acres with nuisance growth of Eurasian watermilfoil that inhibited potential recreational use (Figure 6). Three Rivers Park District contracted with an aquatic herbicide applicator to treat approximately 15 acres to improve recreational opportunities. 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.

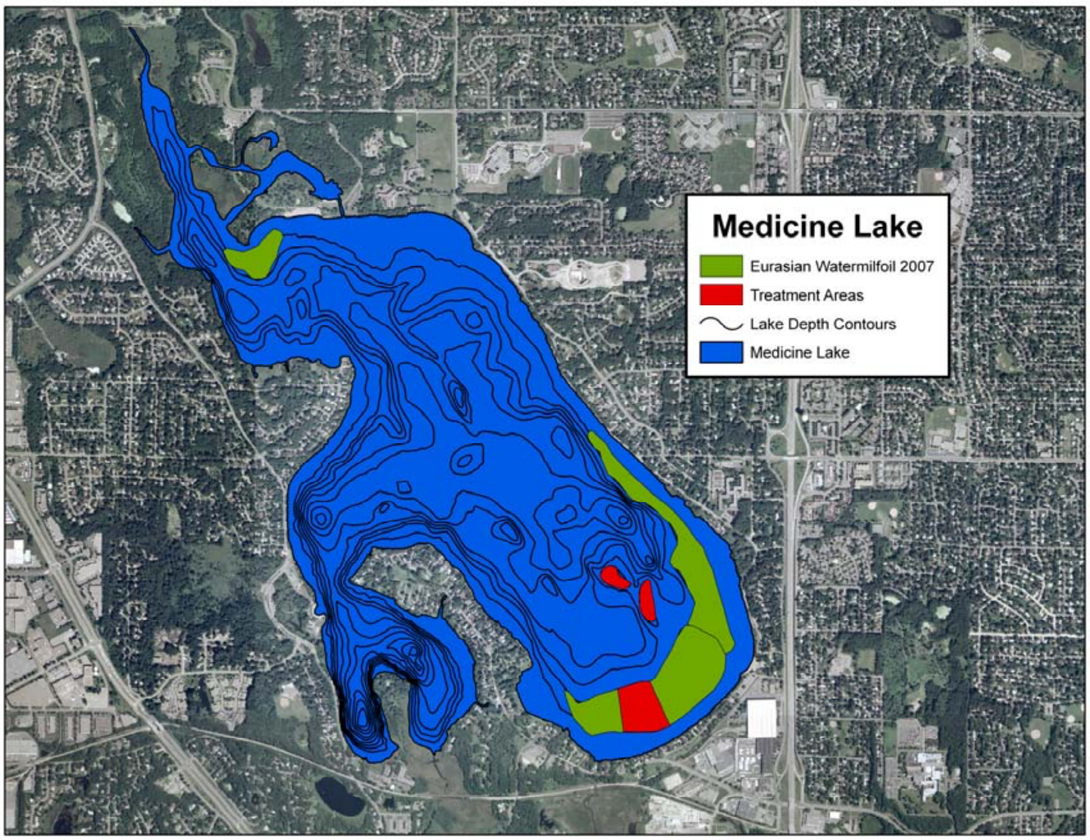


Figure 6: Eurasian watermilfoil growth with nuisance conditions on Medicine Lake in 2007.

Water Quality

Another primary objective of the long-term management approach to control curlyleaf pondweed was to improve in-lake water quality conditions. Medicine Lake was monitored bi-weekly from 1990 through 2007 to determine seasonal changes in water quality. Prior to the herbicide treatments, Medicine Lake had a characteristic total phosphorus spike coinciding with curlyleaf pondweed senescence at the end of June and beginning of July (Figure 7). To estimate the amount of internal loading from curlyleaf pondweed, Three Rivers Park District performed phosphorus analysis on biomass samples collected from the stem density quadrant survey in 2004 to estimate the potential phosphorus loading. The curlyleaf pondweed was collected prior to the initial herbicide treatment. Based on the phosphorus analysis from biomass samples, curlyleaf pondweed potentially released approximately 1,050 pounds of phosphorus in 2004 (Table 7). The data suggests that curlyleaf pondweed senescence may provide a significant source of internal phosphorus loading. The nutrients released from the die-off of curlyleaf pondweed are in a soluble form readily available for algae uptake and potentially can have an impact on water clarity. Typically, Medicine Lake has an algae bloom following curlyleaf pondweed senescence. It was anticipated that management efforts to reduce curlyleaf pondweed abundance would improve water quality conditions by decreasing the internal phosphorus loading and reducing the severity of algae blooms.

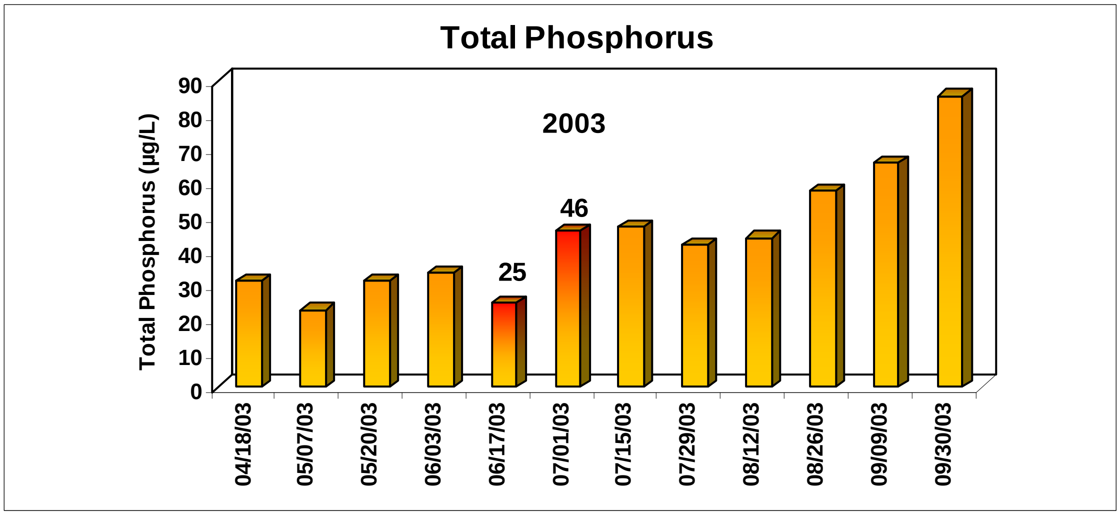


Figure 7: Seasonal changes in total phosphorus concentration for Medicine Lake in 2003.

Table 7: 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 significant improvement in water quality conditions after the herbicide treatment in 2004. There was an increase in phosphorus concentration coinciding with the time period of the initial herbicide treatment (Figure 8). The increase in phosphorus concentration was due to the amount of phosphorus released (previously estimated from biomass samples) from the die-off of curlyleaf pondweed after the herbicide treatment. However, an algae bloom did not develop despite the increase in total phosphorus concentration (Figure 9). 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. After the herbicide treatment, the phosphorus concentrations continued to increase throughout the remainder of 2004. Algae blooms developed in early summer when water temperatures were warmer. It was unreasonable to assume that a significant improvement in water quality would occur immediately following the herbicide treatment because of the major nutrient release from the curlyleaf pondweed. A significant change in water quality conditions most likely would not become apparent until there was a reduction in curlyleaf pondweed.

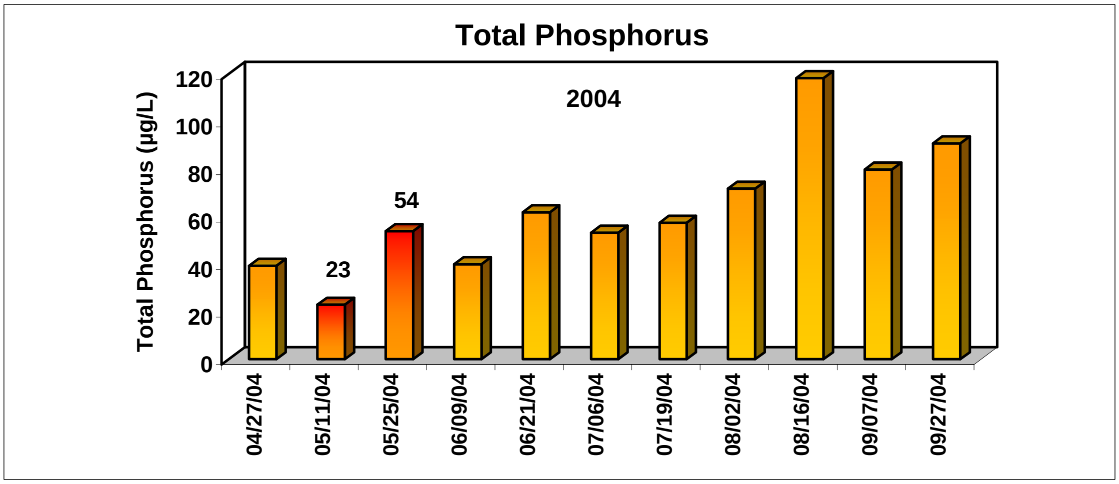


Figure 8: Seasonal changes in total phosphorus concentration for Medicine Lake in 2004.

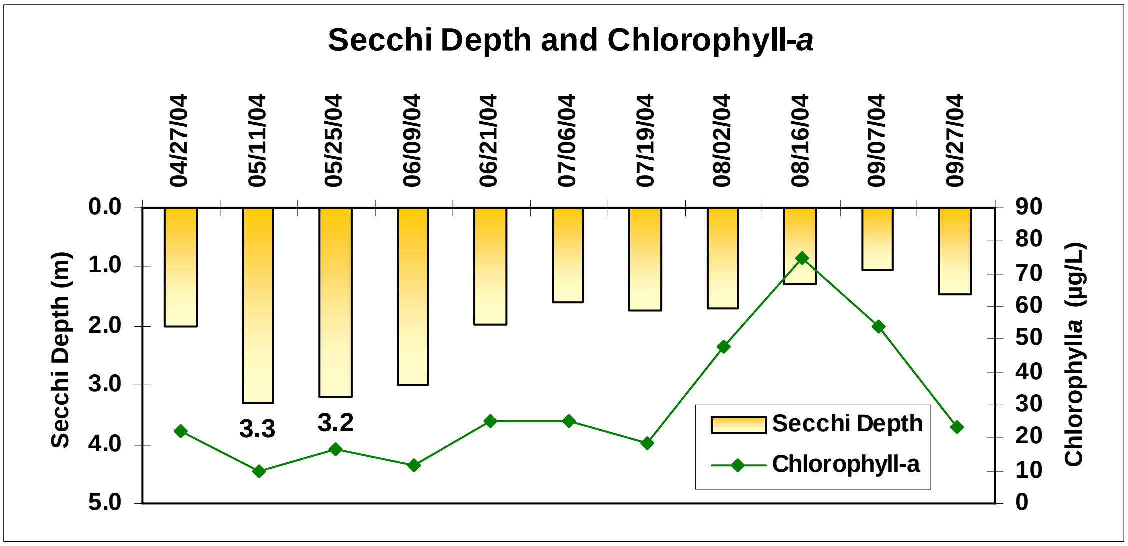


Figure 9: Seasonal changes in chlorophyll-a and secchi depth for Medicine Lake in 2004.

There was no increase in phosphorus concentration that coincided with the herbicide treatment in 2005. The reduced amount of curlyleaf pondweed in 2005 may account for the absence of a phosphorus spike. However, a total phosphorus spike did occur in 2005 at the beginning of July (Figure 10). The increase in phosphorus concentrations was not due to senescence because the early herbicide application in April effectively eliminated the curlyleaf pondweed. 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. Consequently, an algae bloom developed following the increase in phosphorus from the internal mixing event (Figure 11). Medicine Lake has the potential to mix several times each year due to the prevailing northerly and southerly winds. However, these mixing events typically occur at the end of August and the beginning of September as water temperatures begin to decrease. 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. After the mixing event, the phosphorus concentrations continued to gradually increase with corresponding algae blooms that persisted throughout the summer.

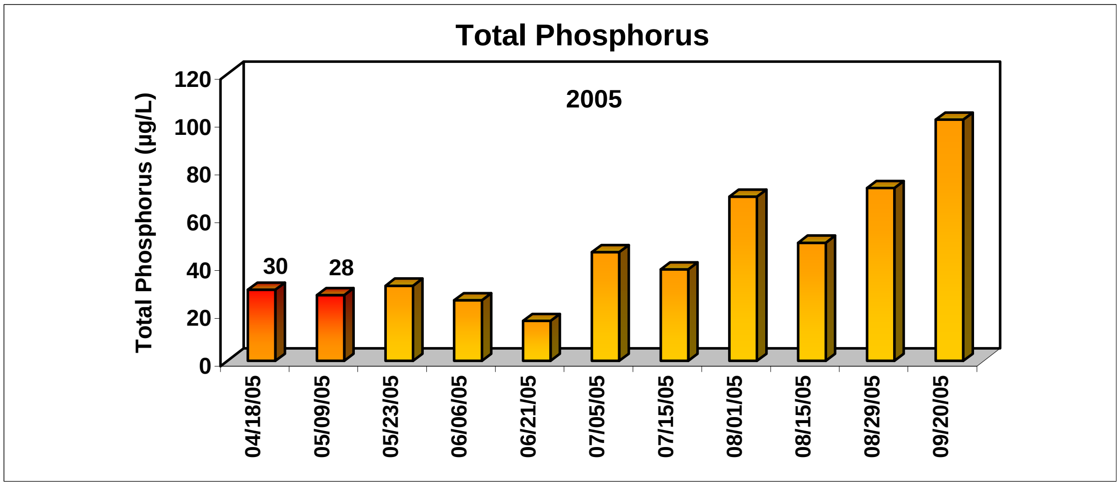


Figure 10: Seasonal changes in total phosphorus concentrations for Medicine Lake in 2005.

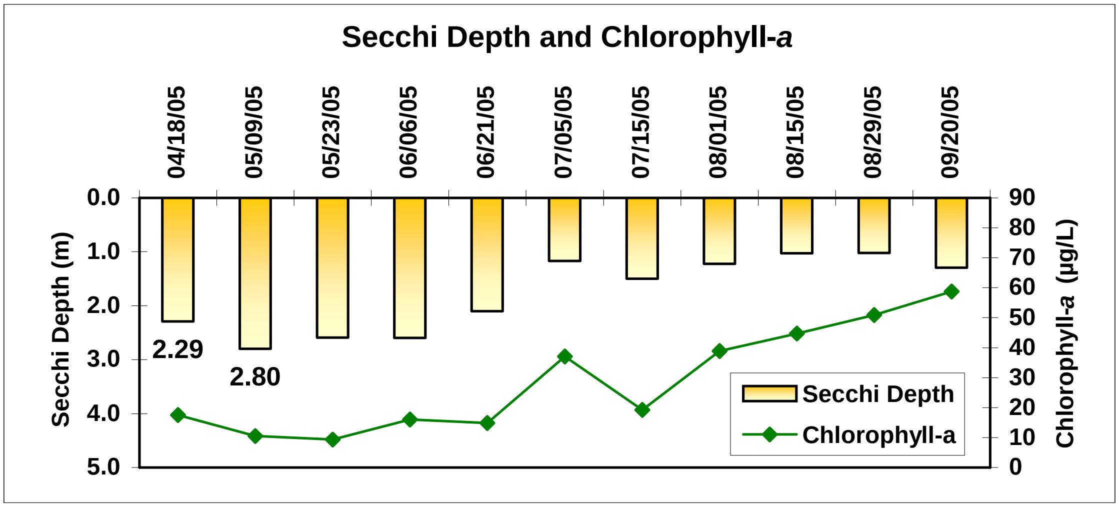


Figure 11: Seasonal changes in secchi depth and chlorophyll-*a* concentration for Medicine Lake in 2005.

There was an improvement in the bi-weekly phosphorus concentrations for Medicine Lake in 2006. The phosphorus concentrations were similar to 2005 in which there was no increase that corresponded with the herbicide treatment in 2006 (Figure 12). The in-lake phosphorus concentrations remained very low (below 40 µg/L) from June through mid to late July. There was no increase in the total phosphorus concentration corresponding to the typical curlyleaf pondweed senescence at the end of June and the beginning of July. This was most likely due to the decrease in curlyleaf pondweed biomass from the consecutive herbicide treatments. Despite a decrease in phosphorus concentrations, the water clarity conditions were similar to previous years. An algae bloom occurred at the end of June and water clarity remained poor for the remainder of the season (Figure 13). Medicine Lake continues to have excessive amounts of phosphorus available for algae uptake even though concentrations have decreased. Based on the 2006 data, it appears that seasonal water clarity conditions are influenced by factors other than phosphorus concentrations (i.e. zooplankton and/or weather conditions). Although water clarity conditions have not significantly improved, it is encouraging that in-lake phosphorus concentrations were lower for a significant portion of the season.

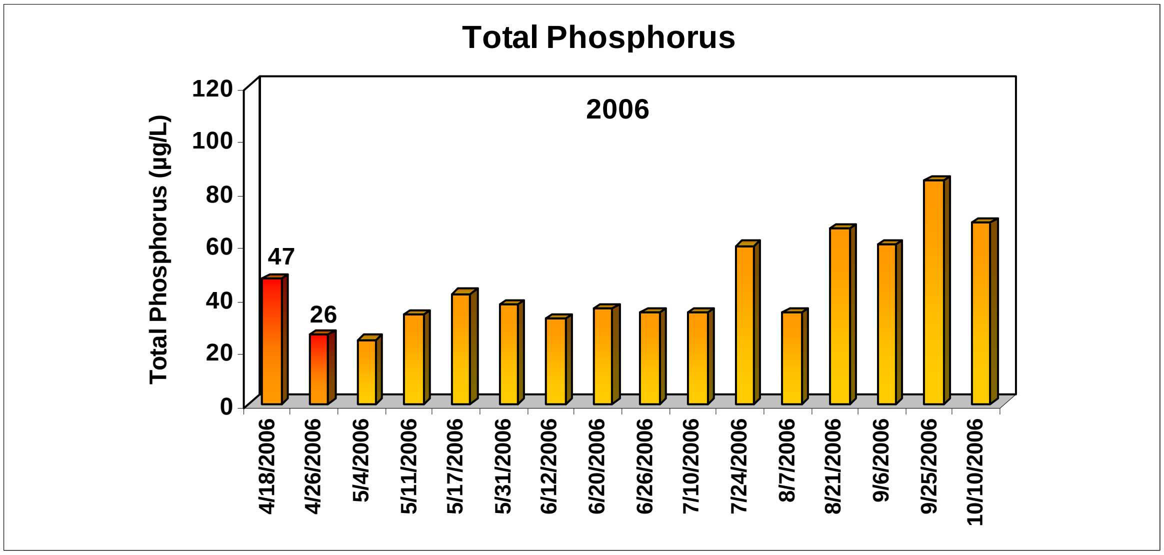


Figure 12: Seasonal changes in total phosphorus concentration for Medicine Lake in 2006.

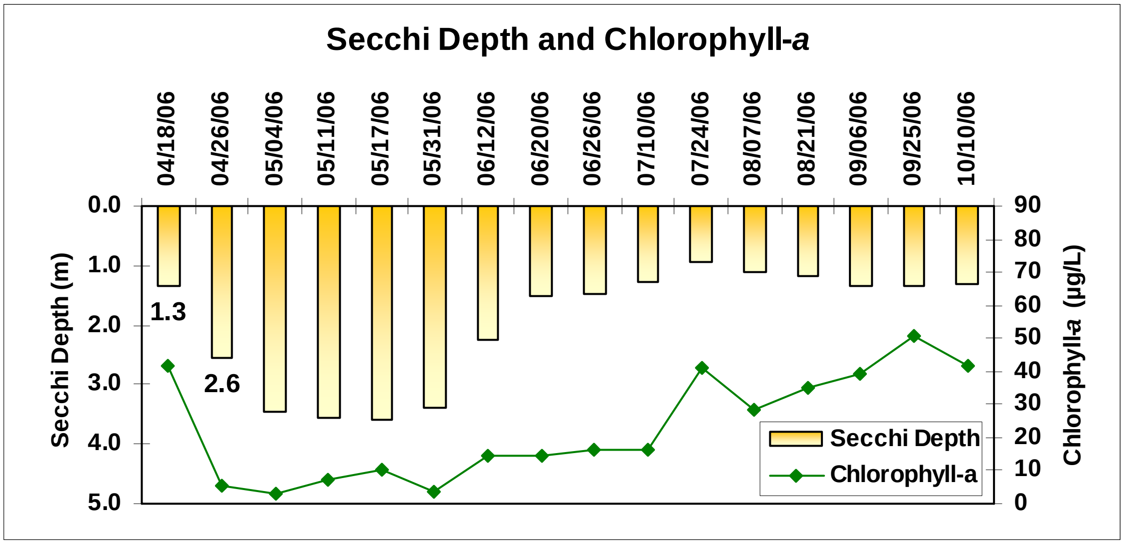


Figure 13: Seasonal changes in secchi depth and chlorophyll-*a* concentration for Medicine Lake in 2006.

The water quality conditions in 2007 were considerably different in comparison to 2006. The aquatic vegetation surveys indicated there was a significant increase in the abundance of curlyleaf pondweed in 2007. Since there was no early season herbicide treatment, curlyleaf pondweed developed turions and senescence occurred at the end of June through the beginning of July. A characteristic phosphorus spike coincided with the time period of senescence (Figure 14). This abrupt increase in the phosphorus concentration for 2007 was similar to the phosphorus spike that typically occurred prior to the herbicide treatments. An algae bloom developed following the total phosphorus increase that corresponded with curlyleaf pondweed senescence. The algae bloom contributed to a decrease in water clarity conditions for Medicine Lake (Figure 15). The water quality conditions continued to degrade throughout the remaining portion of the summer.

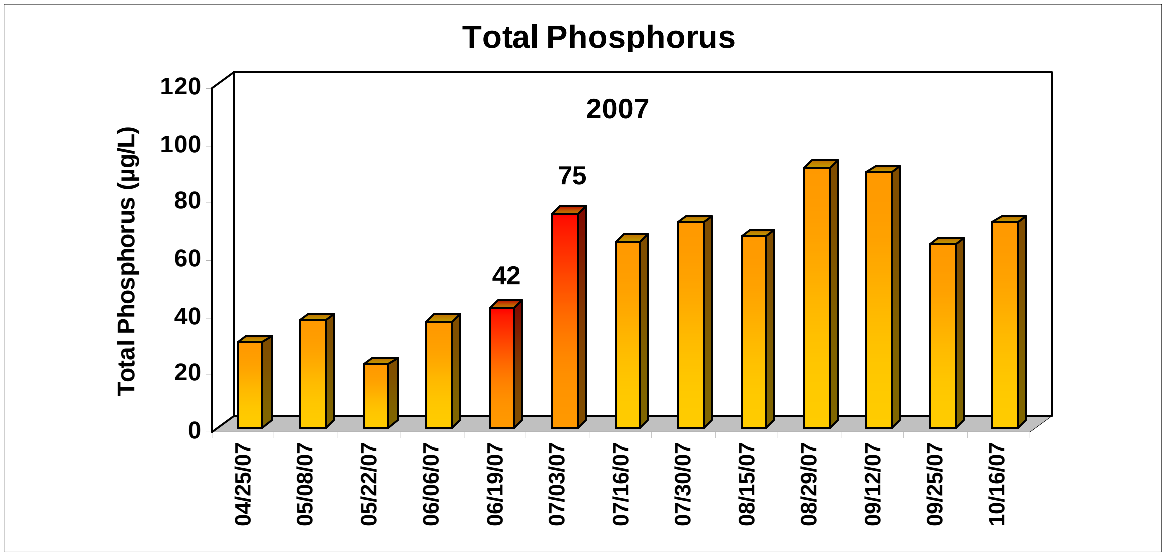


Figure 14: Seasonal changes in total phosphorus for Medicine Lake in 2007.

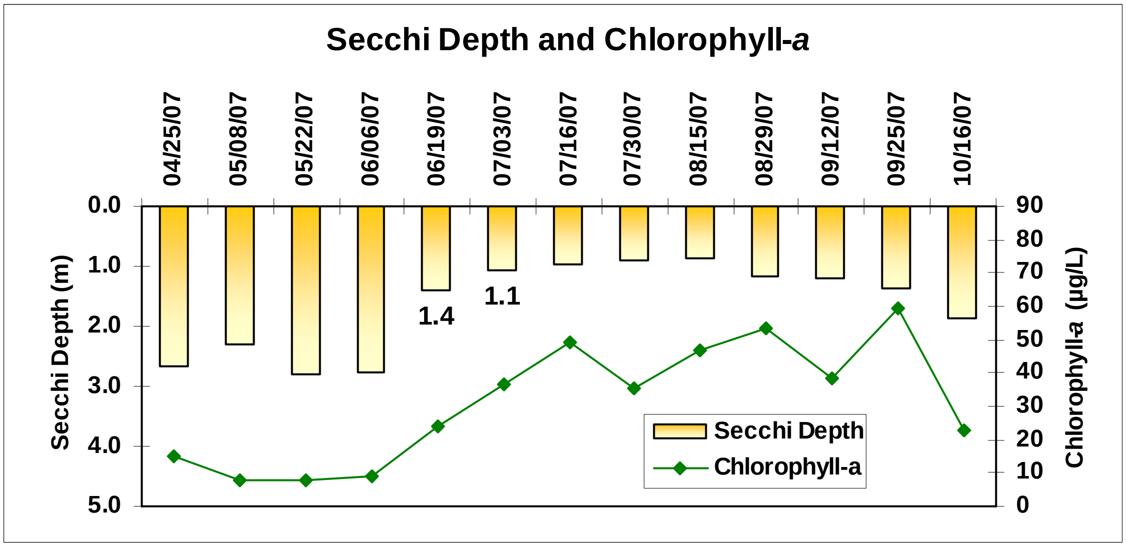


Figure 15: Seasonal changes in secchi depth and chlorophyll-*a* concentration for Medicine Lake in 2007.

It appears that the amount of curlyleaf pondweed may have had an influence on average annual phosphorus concentrations within Medicine Lake. In 2005 and 2006, a reduction in the amount of curlyleaf pondweed eliminated the characteristic phosphorus spike that previously corresponded with senescence. It appears that phosphorus concentrations were lower throughout a major portion of the summer after the characteristic phosphorus spike was eliminated. The decrease in phosphorus concentrations during the summer should contribute to a lower average annual phosphorus concentration for Medicine Lake. Preliminary analysis of water quality data indicated that average phosphorus concentrations were lower in 2005 and 2006 when curlyleaf pondweed abundance was reduced by consecutive herbicide treatments (Figure 16). 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 and senescence of curlyleaf pondweed contributed to phosphorus loading. Despite an improvement in phosphorus concentrations in 2005 and 2006, the average annual phosphorus concentration increased substantially in 2007 (Figure 16). The increase in phosphorus concentration corresponded to the re-establishment of curlyleaf pondweed for Medicine Lake in 2007. It was anticipated that the three consecutive years of herbicide treatments would reduce the viable turion seed bank to achieve long-term control of curlyleaf pondweed. However, the expected long term control of curlyleaf pondweed was not achieved. The amount of curlyleaf pondweed appears to have had an impact on total phosphorus concentrations.

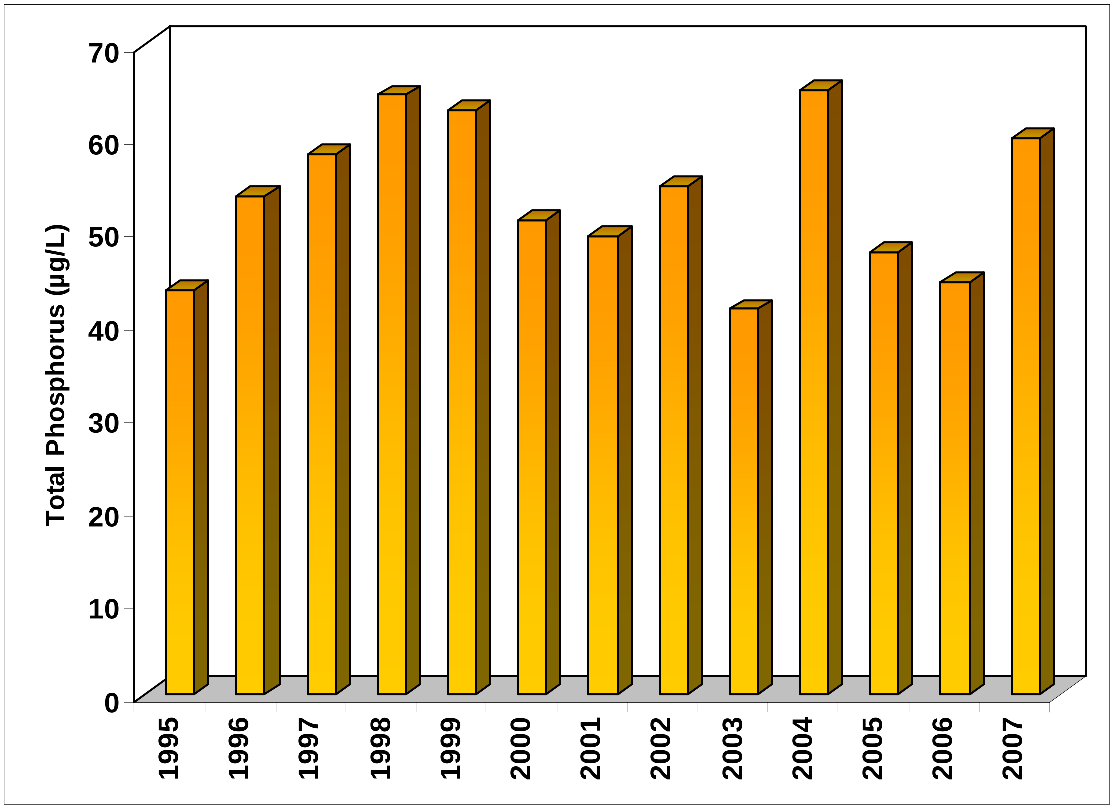


Figure 16: Medicine Lake average total phosphorus concentration from May through September.

The decrease in total phosphorus concentration from the reduction of curlyleaf pondweed may be offset by increases in watershed and internal loading processes. Medicine Lake receives a considerable amount of nutrient loading from watershed and internal loading sources that potentially inhibits improvements in water quality. To determine watershed nutrient loading to Medicine Lake, there were 11 monitoring stations installed with automated samplers/flow data loggers (Figure 17). The watershed monitoring program was a collaborative effort between 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. However, the in-lake total phosphorus concentration did not correspond with watershed nutrient loading following the initial herbicide treatment in 2004. The in-lake total phosphorus concentration decreased from 2004 through 2006 despite an increase in the watershed loading in 2006; and the in-lake total phosphorus concentration increased despite a decrease in the watershed loading for 2007 (Figure 18). The changes in total phosphorus concentration do not appear to be exclusively related to watershed loading and may be partially attributed to internal loading processes. It is extremely difficult to measure the amount of internal loading that is attributed to the physical processes of mixing the water column. However, the annual number of mixing events has not significantly changed in comparison to previous years prior to the herbicide treatments. This would suggest that physical internal loading processes may not be the dominate factor influencing the recent change in total phosphorus concentrations. It appears that the reduced amount of internal loading as a consequence of controlling curlyleaf pondweed may have contributed to the in-lake total phosphorus improvements. Although these improvements may be related 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.

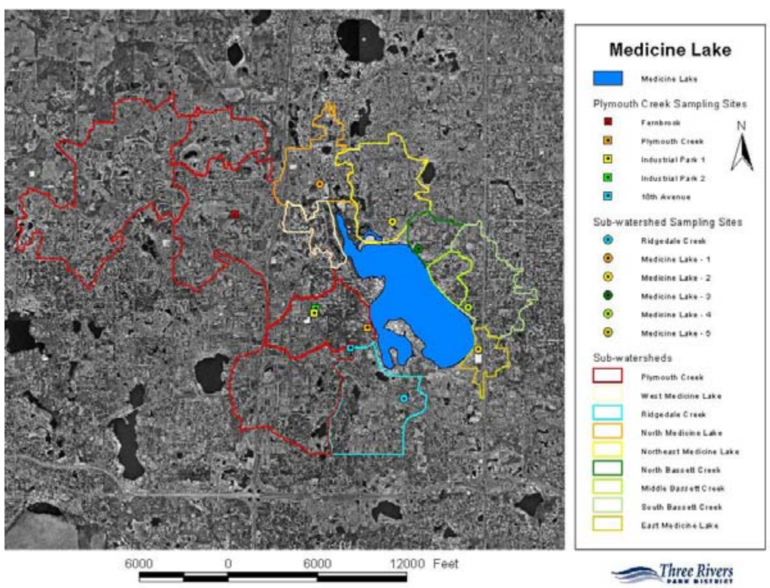


Figure 17: Medicine Lake watershed monitoring sites.

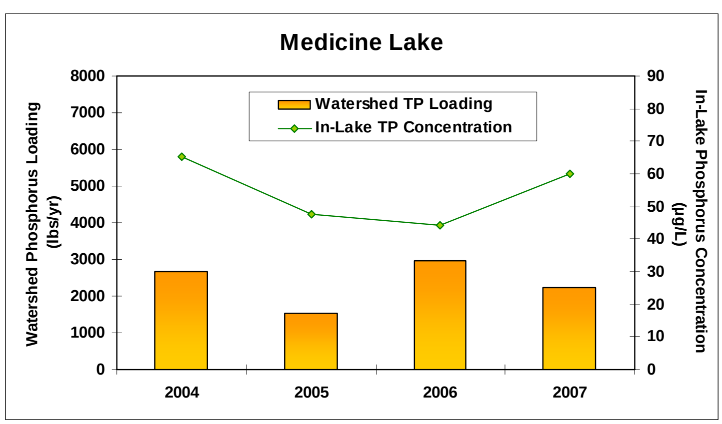


Figure 18: Changes in total watershed phosphorus loading and in-lake phosphorus concentrations.

Typically, the in-lake phosphorus concentration influences the severity of potential algae blooms for a particular lake. It was anticipated that a decrease in phosphorus concentrations would reduce the severity of algae blooms and improve water clarity conditions. However, there was no relationship between the average annual total phosphorus concentrations and water clarity conditions for Medicine Lake. Despite a decrease in average phosphorus concentrations for 2005 and 2006, there were no significant differences in the average annual chlorophyll-*a* concentrations or secchi depth transparency (Figure 19). In 2007, there was an increase in the average annual total phosphorus concentration, but a decrease in the average annual chlorophyll-*a* concentrations and an increase in secchi depth transparency (Figure 19). The changes in annual water clarity conditions are similar to the seasonal variations that were observed for each year from 2004 through 2007. Medicine Lake continues to have an excessive amount of soluble phosphorus available for the development of algae blooms despite any reductions in total phosphorus concentrations. The data suggests that water clarity conditions may be influenced by other factors when nutrients are not a limiting. Medicine Lake typically develops poor water clarity conditions in the summer after water temperatures are warmer. Prior to warmer water temperatures, the amount of zooplankton may have a significant influence on water clarity conditions. However, an increase in water temperatures during the summer becomes more conducive for the development of algae blooms. Consequently, zooplankton were less likely to have an influence on water clarity conditions due to the excessive algae that persists throughout the summer. It is speculated that further reductions in total phosphorus concentrations are required to significantly improve water quality conditions.

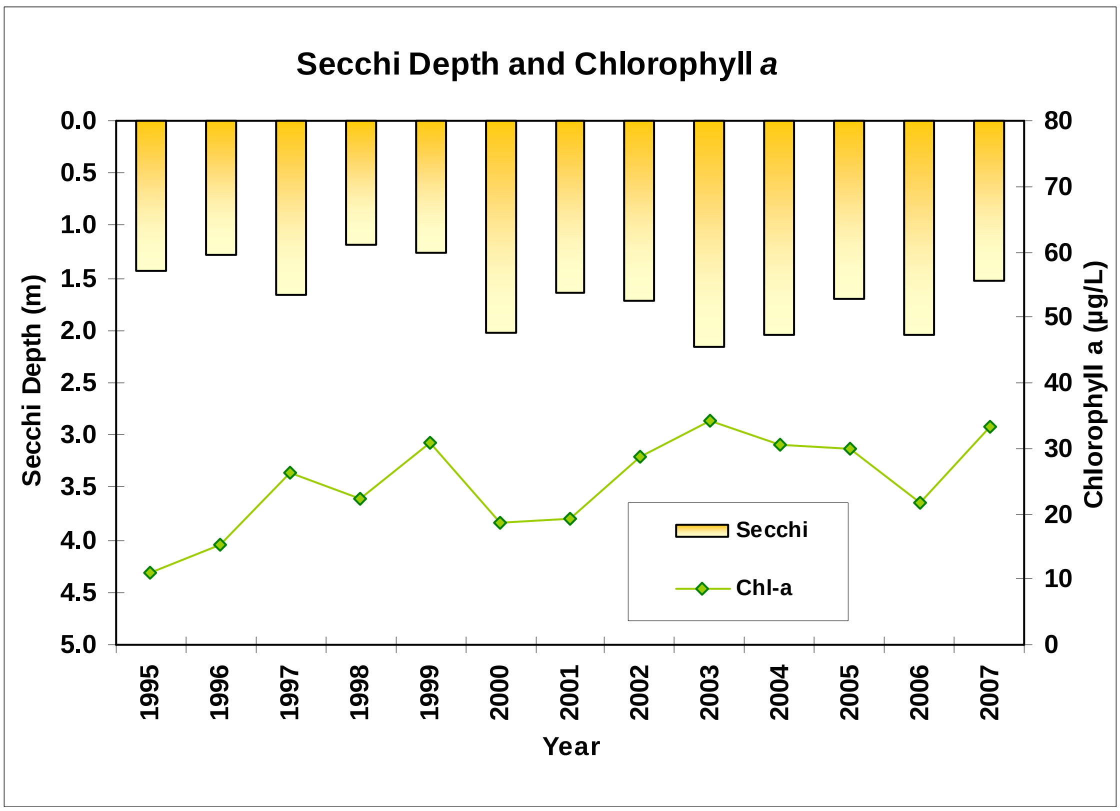


Figure 19: Annual changes in secchi depth and chlorophyll-*a* concentrations for Medicine Lake.