Benard Steffen: *Haying*, **1946**

Barley Straw Installation and Water Quality Conditions in Lee Lake, Lakeville, Minnesota, 2008

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Summary

Barley straw has been used in Lee Lake since 2002 with the objective to improve water clarity. Barley straw was installed for the seventh summer in Lee Lake in 2008 and was applied at 350 pounds per acre. Lee Lake is a 25 acre eutrophic lake in the City of Lakeville (Minnesota).

Although the summer water clarity average in 2008 was less compared to 2005, 2006, and 2007, phosphorus concentrations were better in Lee Lake (Figure 1). Water quality summer averages over the years for Lee Lake are shown in Figure 1.

In 2002, the first year of barley straw use, overall water quality was slightly poorer compared to 2001, but better than 8 out of the last 10 years of previously recorded data.

In 2003 and 2004, with the installation of barley straw, water quality was not significantly better compared to conditions from 1994-2001. After 2003, it was speculated that excessive numbers of black bullheads and bluegill sunfish were contributing to may have been responsible for the poor water quality. A fish survey was conducted in August of 2004. Trapnetting results found extremely high numbers of bluegill sunfish and black bullheads. Fish feeding and excretion probably accounted for the high phosphorus levels found in Lee Lake and explain why the barley straw was not more effective.

Fish removal activities began in late 2004 and continued in 2005, 2006, and 2008. With fish removal, the barley straw effects on water quality have been more successful in from 2005 through 2008.

The installation of 8,750 pounds of barley straw in Lee Lake occurred in 2006, 2007, and 2008. Barley bags, weighing 20 pounds, were tied-together in sets and towed to installation sites around the lakeshore and were staked in water depths of 1 to 2 feet.

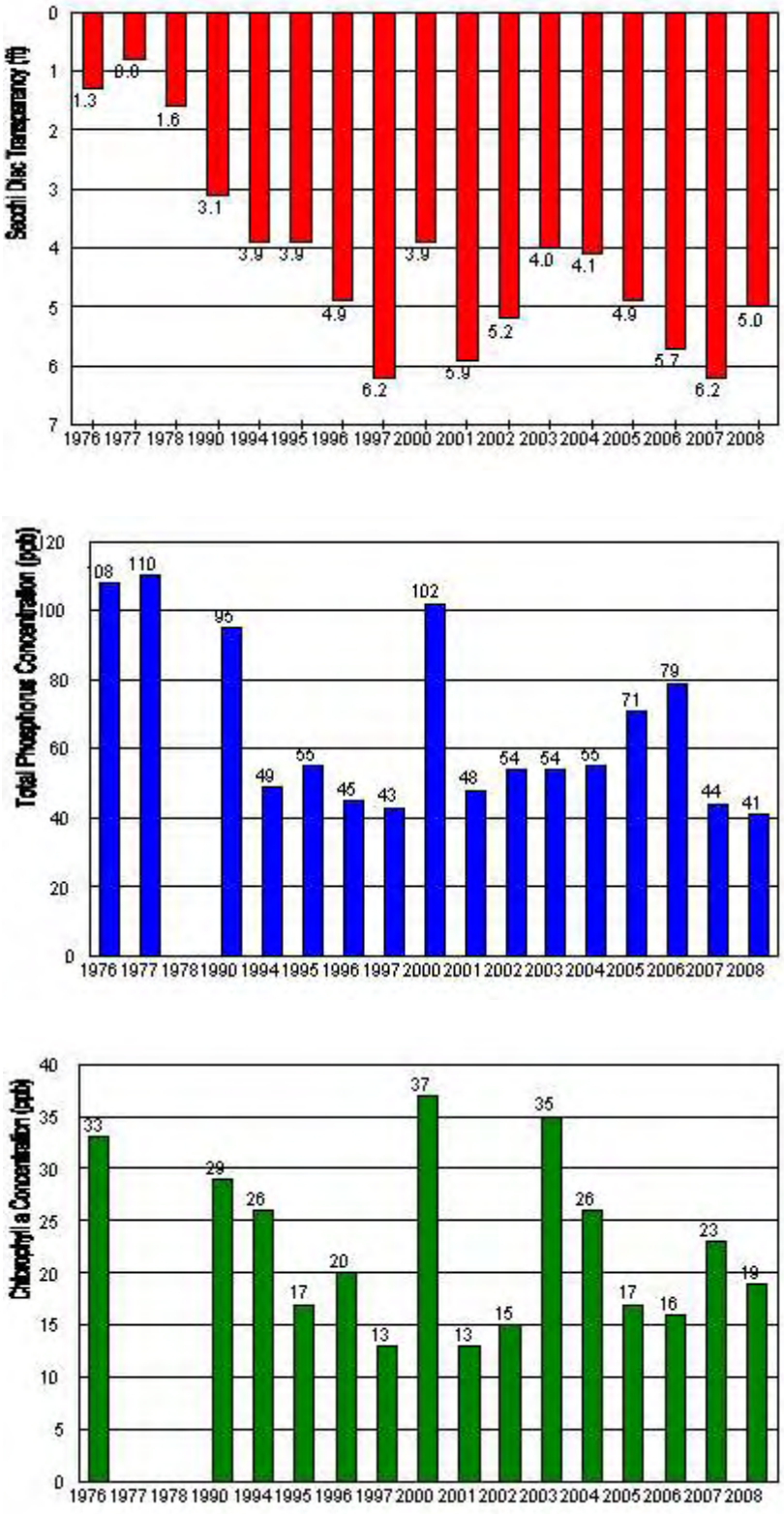

Figure 1. Water quality results for Lee Lake for Secchi disc transparency, total phosphorus, and chlorophyll a. Barley straw has been added to Lee Lake starting in 2002 and fish removal occurred in 2004, 2005, 2006, and 2008. Barley straw and fish removal may have combined to improve water clarity since 2004.

Conclusions and Recommendations

Water clarity in Lee Lake showed improvements in 2005, 2006, 2007, and 2008 compared to 2003 and 2004. In 2003 and 2004 it appears high fish densities had a significant adverse influence on Lee Lake water quality.

Fish removal by trapnetting along with the barley installation in 2005 and 2006 may have improved water quality in Lee Lake in from 2005 through 2008.

For 2009, a dose of barley straw at 350 lbs/acre is recommended as well as a modified fish survey. The use of barley as an algal control technique is still evolving and Lee Lake presents an opportunity to evaluate barley's effectiveness.

Lee Lake on September 2, 2008 water quality was good.

Lee Lake: Introduction and Project Setting

Lee Lake is a 25 acre lake (Figure 1) located in the City of Lakeville, Minnesota (MnDNR ID 19-0029). The maximum depth of Lee Lake is 5.2 m (17 feet). The total watershed area is about 313 acres. Lee Lake's water level is maintained by several stormwater inflows. Water leaves Lee Lake through a culvert from a bay in the east side of the lake. The landuse in the direct drainage area to Lee Lake consists of primarily of urban development with a Landscape Supply Company site on an eastern shoreline area.

In the 1970's water clarity was not very good in Lee Lake. The objective of installing barley straw in Lee Lake has been to improve and sustain good water clarity.

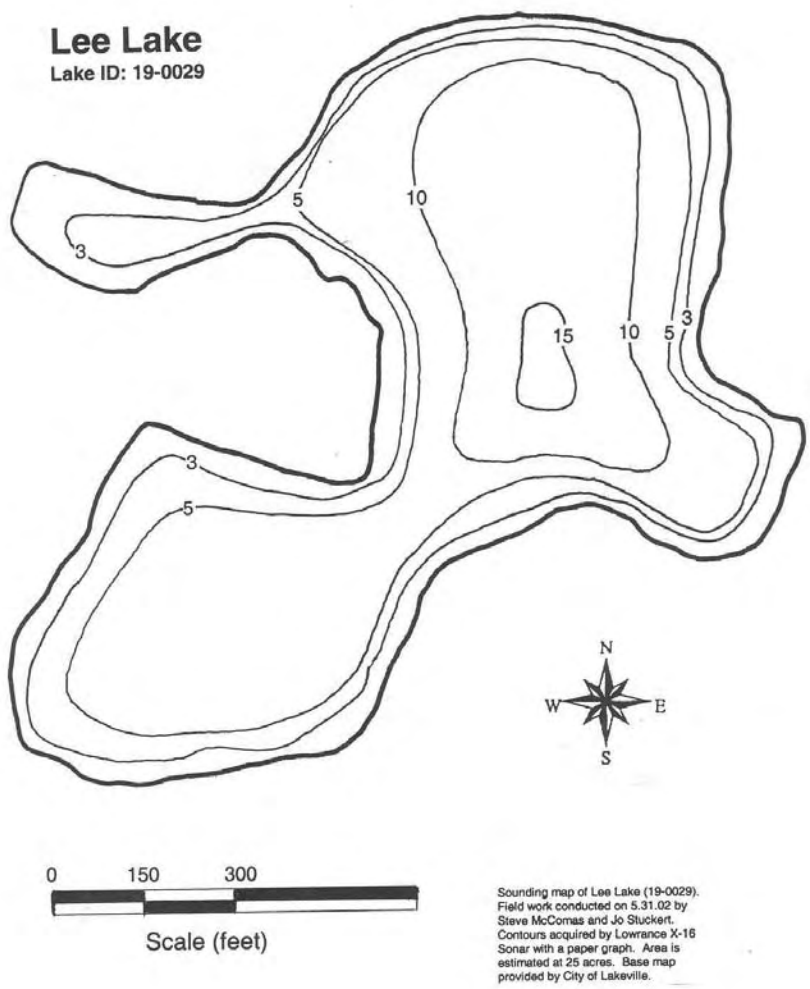

Figure 1. Lee Lake contour map.

Methods of Barley Straw Installation in Lee Lake

In 2008, barley straw was purchased for $0.46/pound (compared to $0.40/pound in 2004) already packed in pellet form in mesh bags measuring 2.5-feet long and 12 inches in diameter and weighing 20 pounds. In May 2008, 8,750 pounds of barley straw were divided into 25 pods and installed in Lee Lake (Figure 2). This represents a dose of 350 pounds of barley per lake acre or 39 g/m^2. It took ½ hour/lake acre using two people to stake the barley bags in the lake at water depths of 2 to 3 feet. Initially, the staked barley bags floated, but after several days the straw became saturated and sank to the bottom. Examples of barley installation are shown in Figure 3.

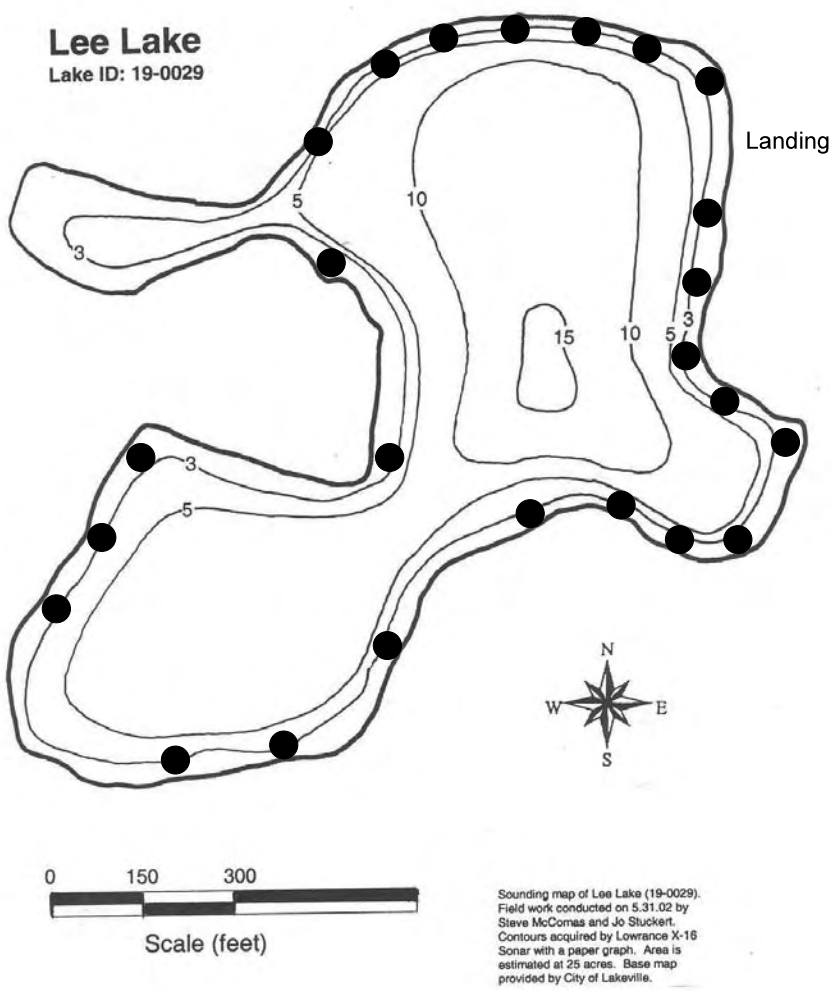

Figure 2. Placement locations of barley straw pods in Lee Lake.

Figure 3. [top] Approximately 8,750 pounds of barley straw was delivered to Lee Lake in 2008.
[middle] Pelletized barley was moved around the lake with a boat.
[bottom] Barley bags were installed in groups of 18 bags per set and were placed around Lee Lake.

Results

Water Clarity Status

The Secchi disc measures lake water clarity. Starting with poor water clarity in Lee Lake in the 1970s, water clarity improved and appeared to peak in 1997 then it was in a declining trend from 1997 through 2004. The summer average water clarity in Lee Lake in 2007 tied with 1997 for the best summer clarity average since records first started in 1976 (Figure 4). There was a slight decline in water quality in 2008, which may be due, in part to construction activities in the direct drainage of the watershed.

The average summer water clarity readings from 1994 through 2008 have been above the impaired lake clarity criteria of 3.3 feet.

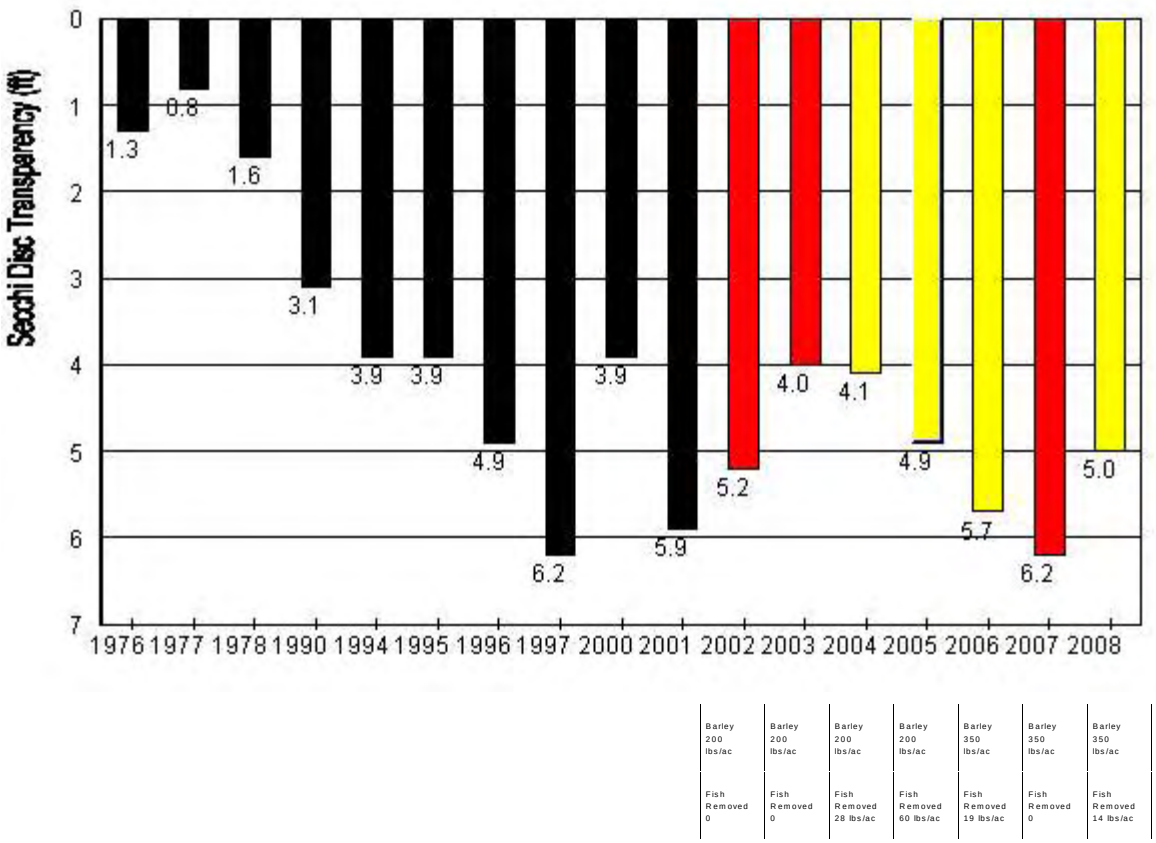

Figure 4. Lee Lake average summer transparencies for 1976 through 2008. Black bars indicate no organic carbon amendments. The red bars represent a dose of barley straw and no fish removal. The yellow bars represent years with barley straw and fish removal.

Phosphorus Status

Phosphorus levels in Lee Lake put it in the eutrophic range. Summer concentrations for 1976 through 2008 are shown in Figure 5. Except for 2000, summer phosphorus concentrations from 1994 through 2008 have been lower compared to phosphorus from 1976 to 1990. Barley straw did not significantly decrease average lake phosphorus concentrations from 2002 - 2006 compared to the non-barley years of 1994 through 2001. However, phosphorus levels were low in 2007 and 2008. Other than 2005 and 2006, the average summer phosphorus concentration from 2001 through 2008 has been less than the 60 ppb-TP nutrient criteria for an impaired lake.

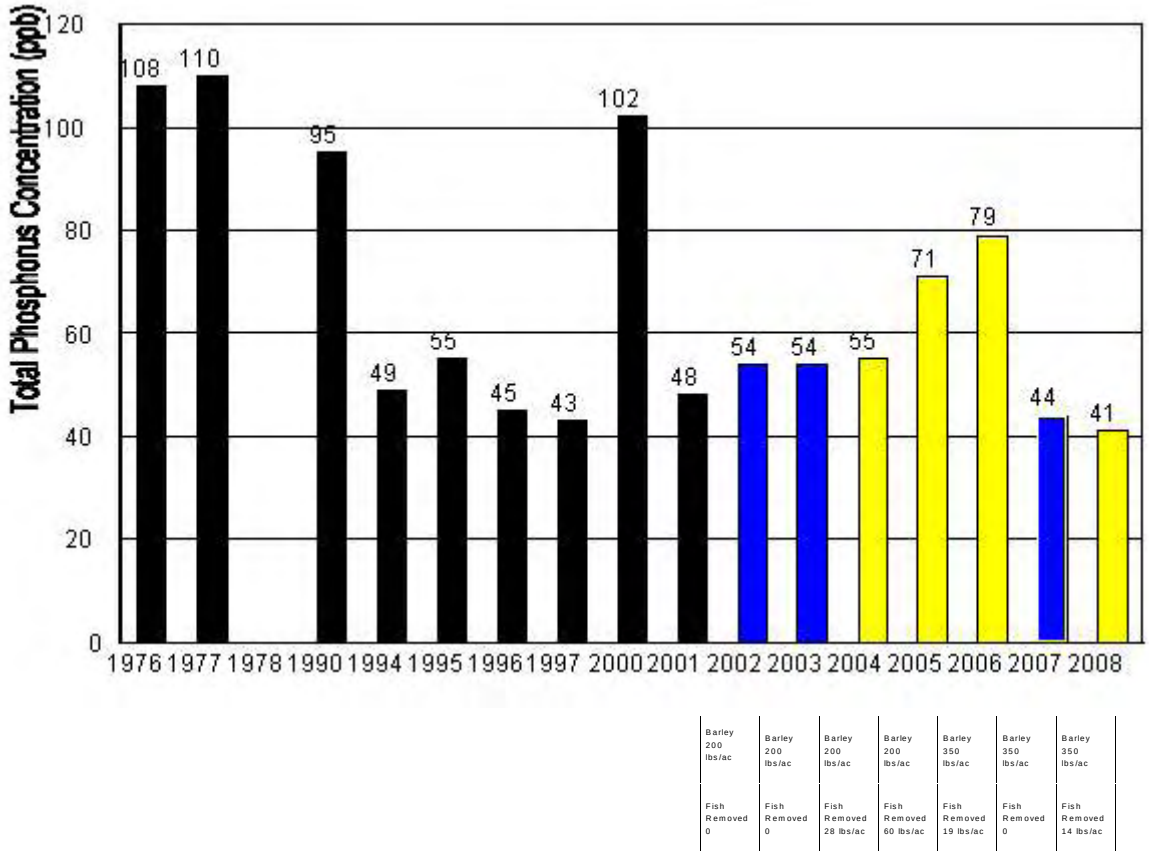

Figure 5. Lee Lake average summer total phosphorus for 1976 through 2008. Black bars indicate no organic carbon amendments. The blue bars represent a dose of barley straw and no fish removal. The yellow bars represent years with barley straw and fish removal.

Algae Status

Algae levels put Lee Lake in the eutrophic range meaning the lake is fertile. Average summer chlorophyll concentrations for 1976 through 2008 are shown in Figure 6. Barley straw is supposed to reduce excessive algae growth. Chlorophyll was not reduced in 2003 and 2004, but from 2005 through 2008 summer chlorophyll concentrations have been below the 24 ppb-Chla threshold for a nutrient impaired lake.

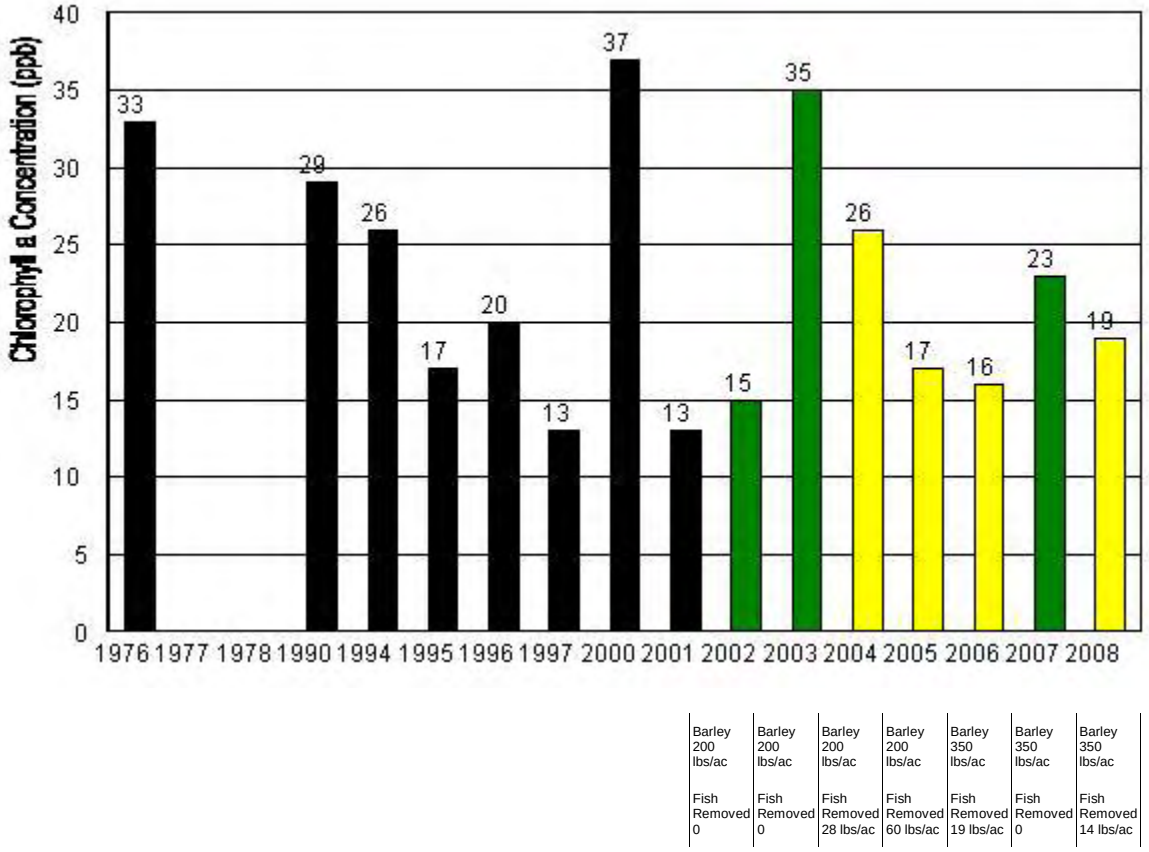

Figure 6. Lee Lake average summer chlorophyll a for 1976 through 2008. Black bars indicate no organic carbon amendments. The green bars represent a dose of barley straw and no fish removal. The yellow bars represent years with barley straw and fish removal.

Water Quality Summary: Water quality data are summarized in Table 1. In 2008, water clarity, phosphorus, and chlorophyll all met nutrient criteria for unimpaired shallow lakes, based on MPCA criteria. Water clarity was slightly more turbid in 2008 compared to 2007, but phosphorus and chlorophyll levels were lower.

Table 1. Lee Lake summer averages for water quality indicators (May-September). Number of data points is in parenthesis.

	Secchi Disc Transparency (m)	Total Phosphorus (ppb)	Chlorophyll a (ppb)
1976	0.4 (3)	108 (4)	33 (2)
1977	0.25 (2)	110 (2)	
1978	0.5 (6)		
1990	0.95 (6)	95 (6)	29 (6)
1994	1.2 (14)	49 (14)	26 (14)
1995	1.2 (15)	55 (15)	17 (15)
1996	1.5 (14)	45 (14)	20 (14)
1997	1.9 (13)	43 (13)	13 (13)
2000	1.2 (12)	102 (12)	37 (12)
2001	1.8 (10)	48 (10)	13 (10)
2002	1.6 (9)	54 (9)	15 (10)
2003	1.2 (7)	54 (7)	35 (7)
2004	1.2 (12)	55 (12)	26 (12)
2005	1.5 (8)	71 (8)	17 (8)
2006	1.7 (11)	79 (11)	16 (11)
2007	1.9 (11)	44 (11)	23 (11)
2008	1.5 (10)	41 (10)	19 (10)

On June 29, 2007, filamentous algae was present on Lee Lake.

By July 25, 2007 the filamentous algae had died off and the lake surface was clear and water clarity was good. Lee Lake has experienced a wide variety of water quality conditions over the years.

Factors Influencing Water Quality in Lee Lake

The installation of barley straw in Lee Lake from 2002 - 2004 did not improve water quality as well as it has in 2005, 2006, 2007, and 2008. It appears there must have been one or more factors that kept the barley from improving Lee Lake water quality in 2002, 2003, and 2004.

Data collected on fish density and on fish feeding habits in Lee Lake in 2004 seem to indicate that high densities of fish could inhibit the improvement of water quality when barley straw is used in Lee Lake (Table 2).

The results from the Lee Lake fish survey in 2004 and from Lee Lake fish stomach contents indicated there was a potential for the high fish density in Lee Lake to contribute to excessive nutrient loading which could overwhelm the effects of barley straw. Results from other fish studies in lakes with installations of barley straw or its equivalent, crushed corn, found that in lakes with high densities of bluegill sunfish, their stomach contents were dominated by detritus which is really just lake sediments. Stomach content analysis of bluegill sunfish from Lee Lake found all fish had detritus and 70% of the fish had stomach contents with greater than 50% detritus.

It appears that in lakes with low densities of bluegills, they feed in the water column, and thus recycle existing water column phosphorus. In lakes with high densities of bluegills, they deplete food options in the water column and feed in the sediments to acquire necessary nutrition. In the process of feeding in this manner, the fish ingest sediments and excrete them as well. Therefore, sediment phosphorus is introduced into the water column that normally would have stayed in the sediments and would have been unavailable to algae. This is “new” phosphorus compared to the “recycled” phosphorus that comes from feeding on zooplankton in the water column.

Table 2. Lee Lake trapnet results for the fish survey conducted in September 2004 are based on 15 trapnet lifts and data are represented as fish per trapnet lift (source: McComas 2004).

Bluegill (fish/net)	Black Bullhead (fish/net)	Black Crappie (fish/net)	Largemouth Bass (fish/net)	Yellow Perch (fish/net)	Northern Pike (fish/net)
465	97	31	3	<1	<1

Fish Removal Efforts Combined with Barley Straw Installation May Have Improved Water Quality

Based on the 2004 fish survey (summarized in Table 2), it appeared there were excessive numbers of bluegill sunfish and black bullheads that could be contributing to poor water quality in Lee Lake. From 2004 through 2008, over 120 pounds of fish/acre have been removed from Lee Lake. Fish removal combined with barley straw installation is correlated with better water quality compared to most of the years prior to the installation of barley, which started in 2002 (Figure 7).

Prior to 2002, there have been several years where water clarity was good (for example 1997 and 2001). It is likely these were years of winterkill impacts where the fish community density was reduced and the result was improved water clarity.

Table 3. Summary of pounds of fish removed from Lee Lake from 2004-2008.

	Bluegill (pounds)	Black Bullhead (pounds)	Black Crappie (pounds)	Total (pounds)	Pounds/Acre
2004	479	223	0	702	28
2005	922	584	0	1,506	60
2006	298	120	58	476	19
2008	125	163	57	345	14
Total	1,824	1,090	115	3,029	121

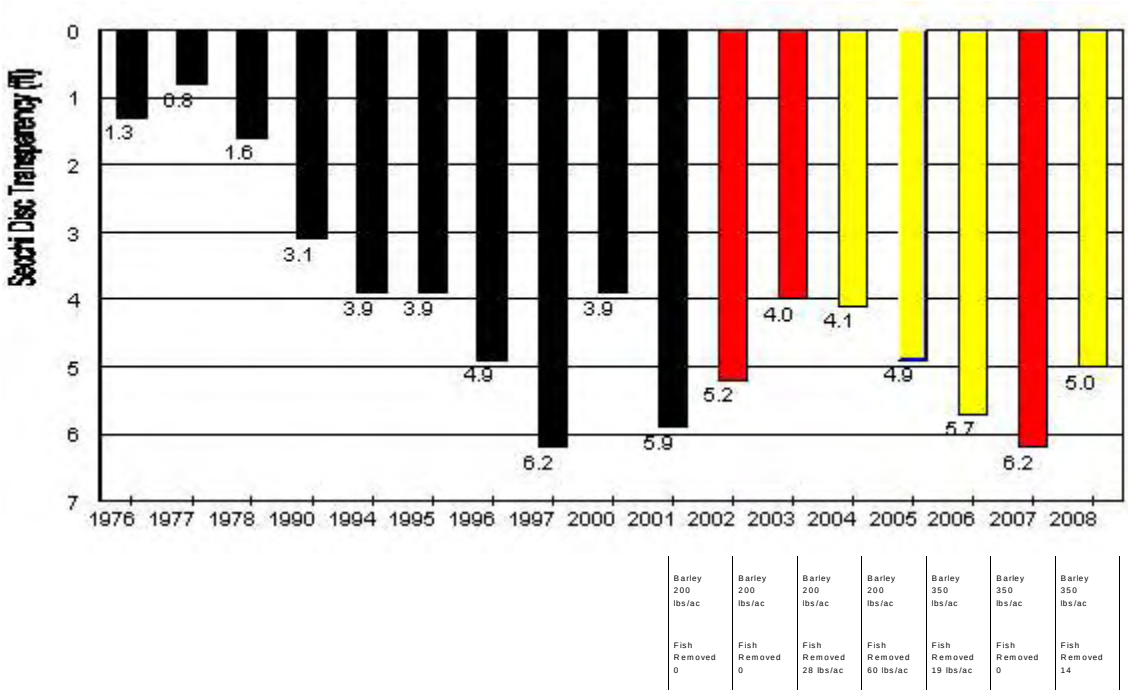

Figure 7. Lee Lake summer water clarity from 1976 through 2008. Black bars indicate no barley straw additions or fish removal. The red bars represent barley additions and yellow bars represent years with barley additions and fish removal.

Conclusions and Recommendations

Water clarity in Lee Lake showed improvements in from 2005 through 2008 compared to 2003 and 2004. In 2003 and 2004 it appears high fish densities had a significant adverse influence on Lee Lake water quality.

Fish removal by trapnetting along with the barley installation may have improved water quality in Lee Lake from 2005 through 2008.

For 2009, a dose of barley straw at 350 lbs/acre is recommended as well as a modified fish survey to check the status of bluegill sunfish, black bullheads, and predator fish, like largemouth bass. The use of barley as an algal control technique is still evolving and Lee Lake presents an opportunity to evaluate barley's effectiveness.

Figure 8. Significant construction in the Lee Lake watershed occurred in 2008 and runoff from the construction site may have had an impact on water clarity.

Appendix

A. Fish Removal
B. Water Quality Data
C. Installation Methods

A combination of fish removal and barley straw installation has seemed to improve water clarity in Lee Lake.

APPENDIX A: Fish Removal

2004

	Bluegill	Black Bullhead	Total	Removal/acre
Weight of fish removed (lbs)	479	223	702	28 lbs/ac
Number of fish	5,154	1,453	6,607	264
Number of fish per pound	10.8	6.5	--	--

2005

	Bluegill	Black Bullhead	Total	Removal/acre
Weight of fish removed (lbs)	922	584	1,506	60 lbs/ac
Number of fish	7,856	3,854	11,710	468 lbs/ac
Number of fish per pound	8.5	6.6	--	--

2006

	Bluegill	Black Bullhead	Black Crappies	Total	Removal/acre
Weight of fish removed (lbs)	298	120	57.5	476	19 lbs/ac
Number of fish	2,179	792 (est)	158	3,129	125 lbs/ac
Number of fish per pound	7.3	6.6 (est)	2.7	--	--

2008

	Bluegill	Black Bullhead	Black Crappies	Total	Removal/acre
Weight of fish removed (lbs)	125	163	57	345	14 lbs/ac
Number of fish	1,145	505	175	2,155	86 lbs/ac
Number of fish per pound	11.8	3.1	3.1	--	--

APPENDIX B: Water Quality Data

Secchi disc transparency for Lee Lake. Results are shown in meters.

Month		1976	1977	1978	1990	1994	1995	1996	1997	2000	2001	2002	2003	2004	2005	2006	2007	2008
April	1		0.5										1.4					
	2													2.7				
	3					1	1.1		1.7		1	1.4				2.0	3.1	
	4						1.2	2	1.5	1.7				2.4	1.6			1.7
May	1					1.1					1.3	1.8	2.3			2.4	2.1	
	2			0.7			1.1	1.9	1.2	1.8				1.8	2.8			1.8
	3					1.4				1.8	3	1.5	1.8			1.9	2.9	
	4					2	1.4	2.5	2.5					1.3	1.7	2.6	2.3	2.4
June	1			0.5			1.5			1.1	3.2	1.6		1.6				
	2	0.5				1.7		2	3						1.2			1.3
	3						1.45				2.4	1.4		1.7	0.9	1.7	2.1	
	4					1.6		2.1	2.4	1.3		1.1	0.5			1.2	1.7	1.4
July	1			0.47	1.4		1.4		1.6					1.0				
	2					1.7		1.8			2					1.5	1.5	1.2
	3						1.2			1.8		1.4		0.8	1.9			1.7
	4				1.3	1.2		1.2	1.4		1.6			1.2	0.9	1.6	1.4	
August	1						1	0.7	2.5	0.4				1.1				
	2		0.25	0.35		0.8	1.1				1	1.7			0.9	1.6	1.4	1.5
	3				0.8			0.7	1.2	0.35			1.4		1.1			1.2
	4					0.5	1.2			0.5	1.5	1.5				1.6	1.0	
September	1			0.5		0.5		0.9	2.1				1.0	0.8			1.2	1.0
	2	0.25					0.9			0.3	0.9			0.8		1.6		
	3					0.7		0.9	1.3				0.8	0.8		1.2	1.1	1.6
	4				0.7		0.9			0.9	0.7	1.7	0.8	0.95				
October	1			0.75		1.5		1.1	1.5							1.9	1.1	1.5
	2				0.6		1.1	1.1		1.3			1.3	1.6				
	3					0.8					1.3	0.9				3.1		1.1
	4										1.4						1.4	
November	1	0.7		0.75	0.8													
AVERAGE (m) (May - September)		0.4	0.25	0.5	0.95	1.2	1.2	1.5	1.9	1.2	1.8	1.6	1.2	1.2	1.5	1.7	1.7	1.5
(n)		3	2	6	6	14	15	14	13	12	10	9	7	12	8	11	11	10
Average (ft)		1.3	0.8	1.6	3.1	3.9	3.9	4.9	6.2	3.9	5.9	5.2	4.0	4.0	4.8	5.7	5.6	5.0
Minimum (m)		0.25	--	0.35	0.7	0.5	0.9	0.7	1.2	0.3	0.7	1.1	0.5	0.8	0.9	1.2	1.0	1.0
maximum (m)		0.50	--	0.7	1.4	2.0	1.5	2.5	3.0	1.8	3.2	1.8	2.3	1.8	2.8	2.6	2.9	2.4

Total Phosphorus concentrations for Lee Lake. Results are shown in ug/l.

Month		1976	1977	1978	1990	1994	1995	1996	1997	2000	2001	2002	2003	2004	2005	2006	2007	2008
April	1	110	110										74					
	2													40				
	3					40	40		70		60	44				37	30	
	4						20	35	50	30				32	43			42
May	1					40					50	54	40			37	31	
	2						30	40	40	40				34	47			36
	3					30				40	30	59	41			61	35	
	4					30	40	30	20					30	30	38	35	26
June	1	100					30			110	30	69		52				
	2					40		40	20						62			34
	3						65				80	103		60	45	123	31	
	4				80	30		40	20	80		78	44			92	41	44
July	1						40		30					61				
	2					40		40			40					129	50	32
	3				70		60			100		65		68	45			37
	4					40		40	40		40			48	105	88	38	
August	1		110				60	60	40	90				55				
	2					50	50				80	44			63	51	35	41
	3				120*			60	60	120			56		165			
	4					60	60			110	40	27				81	54	
September	1	115				90		50	60				88	62		62	57	66
	2									170	40			83				
	3					70		50	100				63	90		106	73	54
	4				110		90				50	23	75	65				
October	1					50		60	100							47	104	62
	2						70	50		70			52	55				
	3				70	110					30	50				64		68
	4				80						40						43	
November	1	100																
AVERAGE		108	110		1	49	55	45	43	102	48	54	54	55	71	79	44	41
(n)		4	2		6	14	15	14	13	12	10	9	7	12	8	11	11	9

*assuming 120 ug/l, but was reported as 1.2 mg/l.

Chlorophyll a concentrations for Lee Lake. Results are shown in ug/l.

Month		1976	1977	1978	1990	1994	1995	1996	1997	2000	2001	2002	2003	2004	2005	2006	2007	2008
April	1		4										9					
	2													7				
	3					8	12		14		34	5.7				7.7	5.2	
	4						6	4	8	1				5	11			8.4
May	1					8					23	9.8	9			12	5.4	
	2						9	14	12	3				6	4.2			5.5
	3					6				5	3	7.5	3			4.6	5.9	
	4					2	5	4	2					12	5.9	3.2	9.3	5
June	1						5			7	5	6		11				
	2					5		2	3						4.4			9.1
	3										8	26		17	8.3	23	7.4	
	4				8	7	7	11	8	10		13	89			18	16	17
July	1						18		9					18				
	2					13		13			17					12	29	13
	3				9		15			38		12		43	7.3			27
	4					34		17	13		5			7	26	16	26	
August	1						15	30	9	55				30				
	2					32	20				26	14			36	19	19	22
	3				30			37	18	65			20		44			17
	4					44	25			68	12	16				23	81	
September	1					71		32	10				61	54		19	21	47
	2	33					40			110	20			64				
	3					43		34	43				9	66		21	41	29
	4				71		30			36	9	24	56	36				
October	1					18		25	11							9.8	68	29
	2						22	21		4			21	30				
	3				47	93					16					7.4		270
	4				47						17						21	
November	1	7																
AVERAGE		33			29	26	17	20	13	37	13	15	35	26	17	16	23	19
(n)		2	1		6	14	15	14	13	12	10	10	7	12	8	11	11	10

APPENDIX C: Installation Methods

2004 Barley Installation

[top] Barley straw was delivered to Lee Lake from a farm in Cambridge, Minnesota.
[middle] Twenty-pound barley bags were tied-together in sets of 100 pounds (5 bags).
[bottom] Barley sets were then towed to their installation sites.

Barley Installation: 2005 - 2008

[top] Approximately 5,000 pounds of barley straw were delivered to Lee Lake in 2005. Here are some of the bags.
[bottom] Barley straw bags were tied together in sets of about 200 pounds and towed to installation sites.

Barley Installation: 2005 - 2008

[top] Approximately 8,750 pounds of barley straw per year were installed in Lee Lake from 2006 - 2008. Barley bags were installed in groups of 18 bags per set.
[bottom] The pelletized barley expanded in the bags. Two weeks after installation the bags were cut open and removed from Lee Lake, leaving the barley behind.