LITTLE COMFORT LAKE WATERSHED LOAD ASSESSMENT STUDY

Comfort Lake – Forest Lake Watershed District

220 North Lake Street
Forest Lake, MN 55025

JULY 2010

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INTRODUCTION

Project Scope
The emphasis of the Little Comfort Lake watershed load assessment study is to pinpoint the area(s) of loading between the Bone Lake outlet and Little Comfort Lake inlet, in order to better prioritize, and site, potential watershed-based projects to achieve the best load reduction in order to meet the lake's short-term and long-term goals. The short-term goal for Little Comfort Lake is for an in-lake summer mean phosphorus concentration of 40 ug/L. In order for the lake to meet its short-term goal, it would need to reduce its current load (1,255 pounds/yr) phosphorus to 577 pounds (roughly a 65% reduction), and reduce loading by another 161 pounds to meet its long-term goal.

Further, any reduction in the phosphorus load to the lake will provide a reduction in the phosphorus load to the St, Croix River, thus influencing the St. Croix Basin Teams goal of 20% phosphorus load reduction to the St. Croix River.

Background
The Comfort Lake Forest Lake Watershed District (CLFLWD) is a 47 square-mile watershed in the St. Croix River Basin with numerous valuable lakes, streams, and wetlands. The District's proximity to the Twin Cities Metro Area (TCMA) as well as its complex drainage to the St. Croix River makes this an area of great concern for appropriate water resource management. Five (5) of the District lakes are listed as impaired by the MPCA due to excessive nutrients, and although Little Comfort Lake (MNDNR ID# 13-0054) is not currently listed three (3) upstream lakes are (Moody, Bone, and School lakes), and the lake immediately downstream (Comfort Lake) are.

The Little Comfort Lake watershed comprises 4,410 acres (14% of CLFLWD) starting at the Bone Lake Outlet (Figure 1). This area includes three named lakes and their watersheds: Nielson Lake, School Lake and Birch Lake. A recently completed watershed-wide load allocation modeling effort further broke the watershed down into 52 separate subwatersheds (CLFLWD, 2007). The portion of Little Comfort Lake watershed downstream of School Lake encompasses 1,740 acres (6% of CLFLWD). The tributary land use is wetlands (25%), cropland (21%), grassland (21%) and forest (17%). There are two main inlets to Little Comfort Lake; one that receives flows from School Lake, and another one entering Little Comfort Lake along the southern shore (LCL48).

The watershed drains by way of naturally meandering channels (through LCL04, LCL07 and LCL03) from School Lake (over a beaver dam north of a sand and gravel operation) through forest buffered wetlands and through a couple of culverts under road crossings into Little Comfort Lake. The watershed, upland of wetlands and woods, is mostly grassland and cropland with very few residences.

Drainage that collects along the southern shore (LCL48) of Little Comfort Lake is from two drainages. The south drainage originates in a wetland complex at the watershed divide with Forest Lake (LCL47) and drains north to Little Comfort Lake. East of this drainage route is developing residential, while to the west of this drainage route remains cropland. The southwest drainage also originates in a wetland at the watershed divide with Forest Lake (LCL44) and watershed divide with Sunrise River. It drains toward Little Comfort Lake through cropland, by way of the watershed's remaining wetlands.

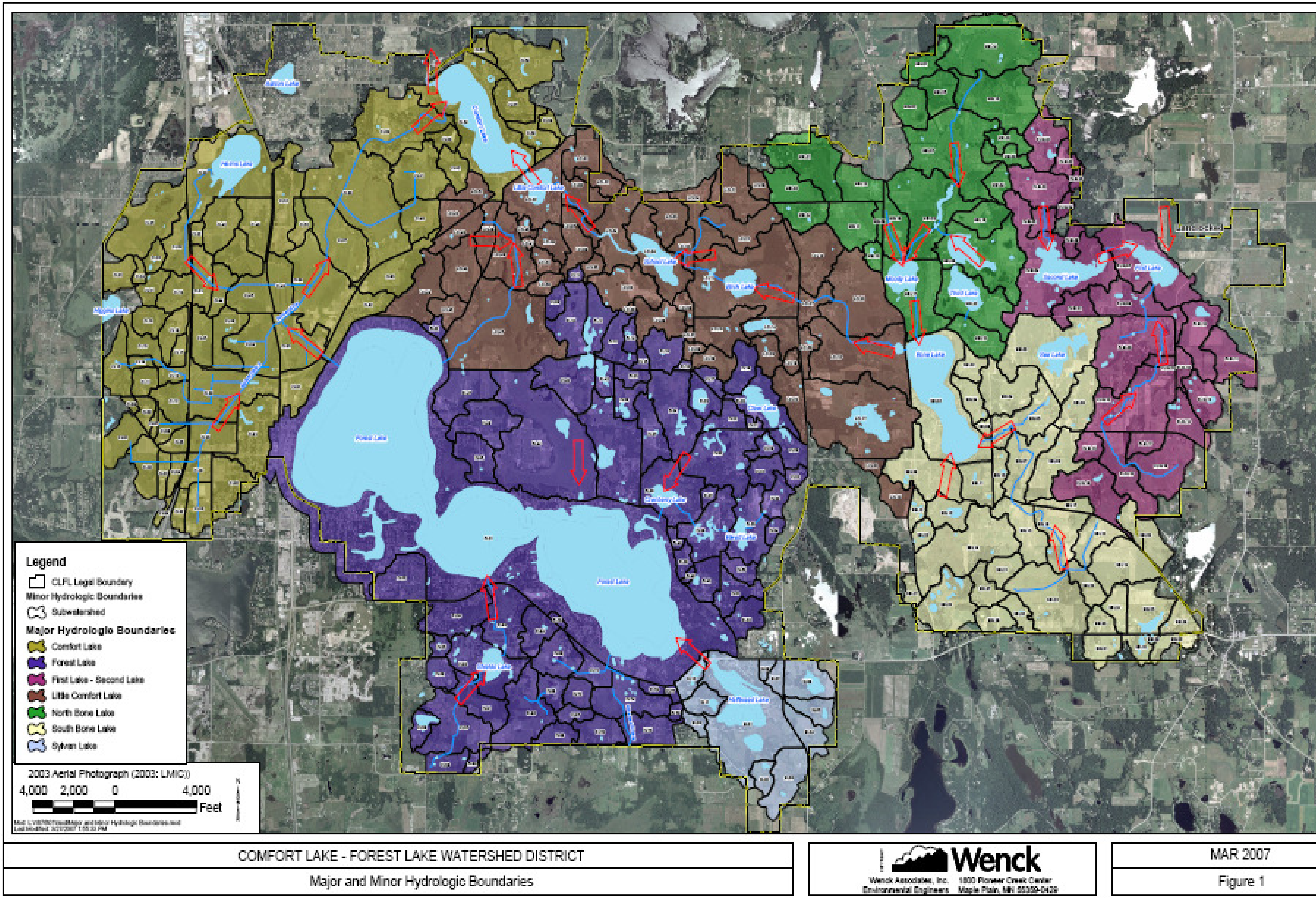


Figure 1. CLFLWD subwatwershed with subwatershed identification numbers by lake drainage districts

Past monitoring, and the recently completed load allocation modeling effort, has revealed increased phosphorus loading between the outlet of Bone Lake to the inlet of Little Comfort Lake (monitored since 2004). The load allocation modeling effort has led to the development of a District-wide Capital Improvement Program (CIP) to address nutrient loading issues (including those along the Bone Lake to Little Comfort Lake stretch). The District's CIP discusses two potential wetland restoration projects, but mentions the need for further study to determine the prioritization and siting of the project(s) in order to address the area where the loading is and provide the most "bang for the buck" in phosphorus load reduction.

Three (3) tributary sites between the Bone Lake Outlet and Little Comfort Lake inlet, as well as three (3) lakes (Bone, School, and Little Comfort), were monitored as part of the load assessment study, in order to help determine and prioritize remedial alternatives to address loadings to Little Comfort Lake. Monitoring locations are shown on Figure 2. The desired outcome of the study is to help prioritize watershed-based projects in the District's CIP in order to help the lake meet its short-term and long-term goals. The success of the assessment and eventual project(s) implementation to meet in-lake goal(s) will be determined through the continual monitoring of system as part of the District's monitoring program.

Methods

As part of the assessment project three (3) continuous flow monitoring sites will be set-up between Bone Lake and the Comfort Lake inlet (one on July Avenue, one on Manning Trail, and one at the inlet to Little Comfort Lake) and the collection of grab samples throughout the year at each of the three (3) sites in order to determine phosphorus and suspended sediment loads. Site set-up and monitoring was completed by the Washington Conservation District (WCD). Water quality samples were collected at each site between April and October during base and storm events, as well as at least twice a month from June to September. Analyses for each included total and dissolved phosphorus, total Kjeldahl nitrogen, nitrate/nitrite, ammonia, total and volatile suspended solids total chloride, and E. coli. There were a total of five (5) E. coli samples collected at each of the three (3) tributary sites (monthly between May and September). In addition, temperature, dissolved oxygen, pH, conductivity and transparency tube measurements will be collected in the field by staff during site visits.

In addition, total phosphorus and total suspended solid loads for each site will be calculated from the collected data, and a report on the sites loading prepared.

Additionally, water quality data was collected for three lakes Bone (MNDNR ID# 82-0054), Little Comfort (MNDNR ID# 13-0054), and School (MNDNR ID# 13-0057). In 2009, the lakes were enrolled in the Metropolitan Council's Citizen-Assisted Monitoring Program (CAMP) and were monitored at pre-determined locations on two week intervals from mid-April to mid-October. During each event, Secchi transparency, water temperature, user perception and climatological information is collected. In addition, surface water samples are collected for lab analyses which include total phosphorus (TP), total Kjeldahl nitrogen (TKN), and chlorophyll-a (CLA). The chemical analyses are performed at the Metropolitan Council Environmental Services (MCES) laboratory, following USEPA approved methods. A full description of each program's methodology can be found at http://www.metrocouncil.org/environment/RiverLakes/Lakes/index.htm.

Each lake has been monitored through CAMP in the past. Historic data are available for Bone Lake (monitored through CAMP since 2001), Little Comfort (annually monitored through CAMP since 2006), and School Lake (monitored through CAMP since 2005 [2008 included just Secchi information]).

The resulting 2009 data for the three (3) tributary sites and three (3) lakes was provided for entry in the STORET system and is included within the Results section of this report.

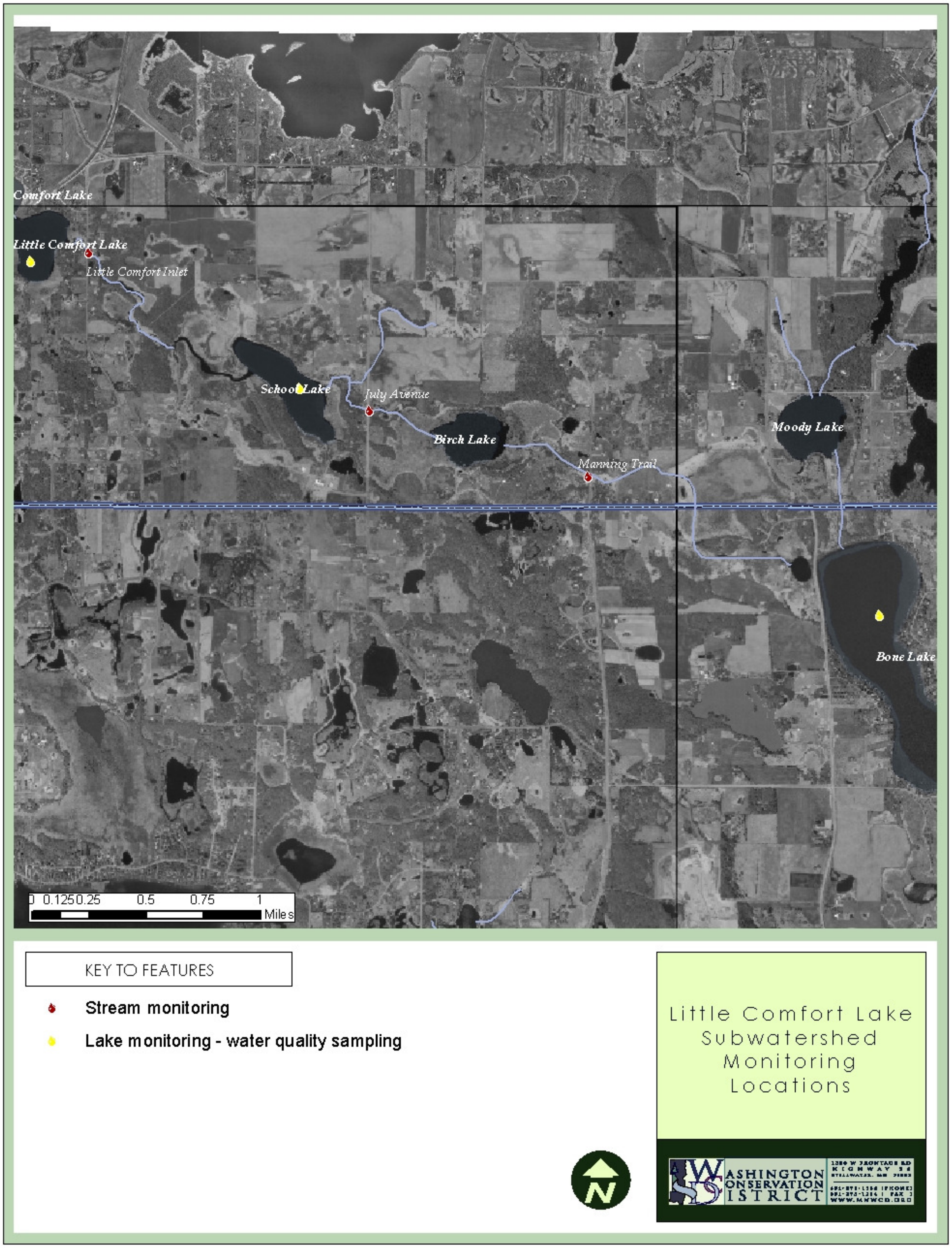


Figure 2. Little Comfort Lake watershed assessment project monitoring locations

RESULTS

Water Quality Analysis

Tributary Monitoring

The unnamed tributary to the Sunrise River that flows from Bone Lake to Comfort Lake was monitored for water quality and discharge at the crossing of Manning Trail, July Avenue, and Little Comfort Lake inlet at Itasca Avenue from mid-March through early November. 2009 was the second year that Manning Trail and July Avenue were monitored and the sixth year that Little Comfort Inlet was monitored. Fifteen minute continuous stage, velocity, and discharge was measured at all three sites, and rainfall data was collected at July Ave. and Little Comfort Inlet. Water quality grab samples were collected at all sites during base flow, storm flow, and snowmelt conditions. Instantaneous dissolved oxygen, temperature, conductivity, pH, and transparency were collected as well. Table 1 below has further descriptions and specific water quality parameters.

Table 1. Tributary monitoring site descriptions

Site Description	Full Site Name	Summarized Site Name	General Site Location	Monitoring Site Description	Monitored Parameters
Stream Monitoring	Tributary to Sunrise River at Little Comfort Lake Inlet	Little Comfort Lake Inlet	Itasca Avenue	Flow Monitoring in Natural Cross-Section	Discharge and Water Quality Grab Samples*
Stream Monitoring	Tributary to Sunrise River at Manning Trail	Manning Trail	Manning Trail	Flow Monitoring Through Culvert	Discharge and Water Quality Grab Samples*
Stream Monitoring	Tributary to Sunrise River at July Avenue	July Ave	July Ave	Flow Monitoring Through Culvert	Discharge and Water Quality Grab Samples*

*Stream Monitoring Water Quality Sample Parameters Include: Total Phosphorus, Dissolved Phosphorus, Total Kjeldahl Nitrogen, Nitrate, Nitrite, Ammonia Nitrogen, Total Suspended Solids, Volatile Suspended Solids, Total Chlorides, E. Coli Bacteria

Manning Trail

Two thousand and nine (2009) was the second year that data was collected at the Manning Trail station and flow was recorded from April 2-November 2, 2009. Total discharge for this period was 7,779,360 cf or 179 acre-feet. No automated rain gage was installed at this site to collect continuous rainfall data. Peak discharge of 2.797 cfs occurred on April 4th, which was caused by the remnants of the spring thaw. Figure 3 graphs the flow at the Manning Trail site and rainfall recorded at the July Avenue site.

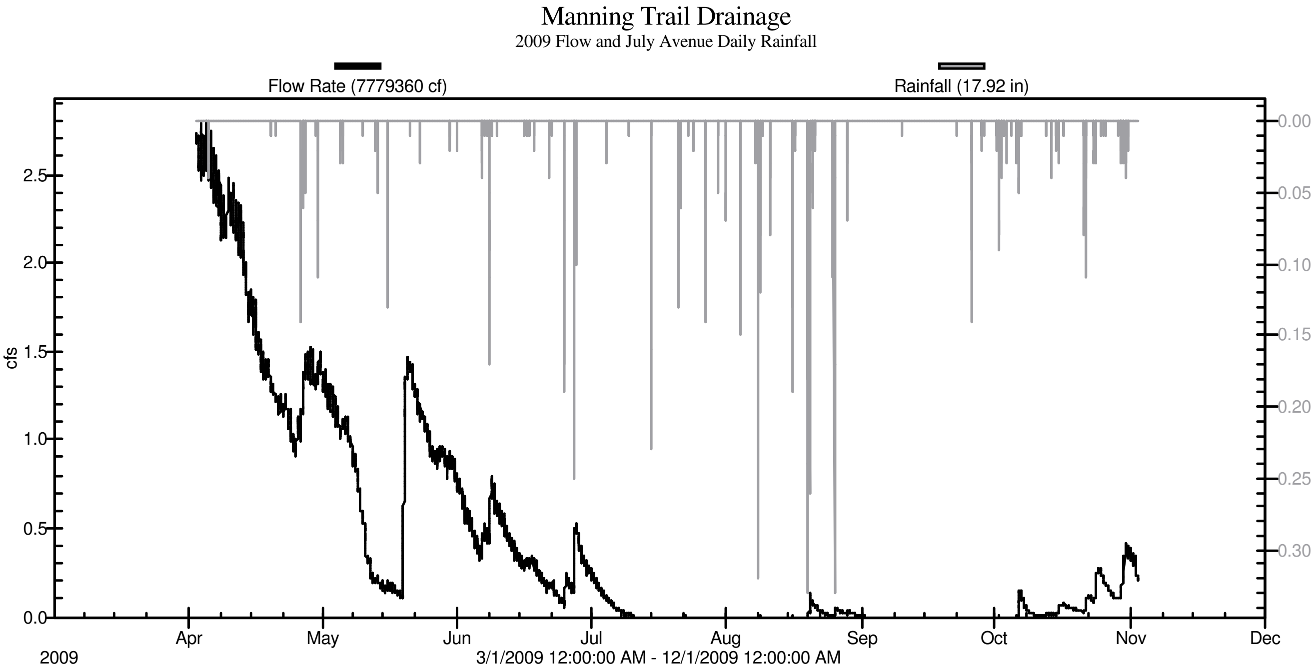


Figure 3. Manning Trail Drainage 2009 Flow and July Avenue Daily Rainfall

Water quality grab samples were collected at the Manning Trail Drainage site in 2009, and chemistry and field water quality measurements are listed Table 2-4 below. The highest concentration of total Kjeldahl nitrogen (TKN) and total phosphorus (TP) were 2 mg\L and 0.337 mg\L, respectively, from a March 17th snowmelt sample. The total suspended solids (TSS) maximum concentration of 15 mg\L was from a June 8th storm grab sample.

Table 2. Manning Trail Drainage 2009 Sample Chemistry Results

Sample Type	Start	End	TSS (mg/L)	VSS (mg/L)	TKN (mg/L)	TP (mg/L)	Dissolved P (mg/L)	Chloride (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia Nitrogen (mg/L)	E. Coli (mpn/100ml)
Snowmelt Grab	3/17/2009 12:30	3/17/2009 12:30	5	4	2	0.337	0.232	16	<0.03	0.12	0.39	
Storm Grab	3/24/2009 10:39	3/24/2009 10:39	4	4	1.4	0.089	~0.013	15	<0.03	0.12	0.38	
Base Grab	5/14/2009 11:25	5/14/2009 11:25	9	4	1.4	0.097	~0.035	20	<0.03	<0.05	0.22	
E. Coli Grab	5/28/2009 8:45	5/28/2009 8:45										58
Storm Grab	6/8/2009 8:13	6/8/2009 8:13	15	6	0.97	0.091	~0.037	16	<0.03	<0.05	~0.05	
E. Coli Grab	6/10/2009 8:10	6/10/2009 8:10										118.7
Base Grab	6/24/2009 8:23	6/24/2009 8:23	4	3	1.3	0.144	0.076	18	<0.03	<0.05	0.08	
Storm Grab	8/20/2009 9:39	8/20/2009 9:39	~2	~2	1.2	0.129	0.091	13	<0.03	<0.05	~0.04	
E. Coli Grab	8/26/2009 8:00	8/26/2009 8:00										>2419.6
Storm Grab	10/6/2009 13:44	10/6/2009 13:44	3	~2	0.94	0.234	0.165	19	<0.03	0.22	~0.02	
Storm Grab	10/22/2009 9:42	10/22/2009 9:42	<1	<1	1	~0.046	~0.048	19	<0.03	<0.05	<0.02	

Table 3. Manning Trail Drainage Field Water Quality Measurements

Date/Time	Transparency (cm)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)	pH
3/17/2009 12:24	69	0.9	9.12	230	7.4
3/24/2009 10:39	86	2.6	9.12	250	7.7
5/14/2009 11:25	75	14.4	8.24		
5/28/2009 8:50	>100	12.4	7.06		
6/8/2009 8:13	>120	12.4	7.03	270	
6/8/2009 9:42	>100	12.4	7.89	289	8.1
6/10/2009 8:11	>100	14.9	6.65		
6/17/2009 9:43	>100	18.7	7.18		
6/24/2009 8:23	>100	22.5	6.10		
8/20/2009 9:39	>100	17.0	7.03	257	7.9
8/26/2009 8:00	>100	14.0	8.40	289	8
10/6/2009 13:44	>100	9.8	9.12	272	8.4
10/22/2009 9:42	>100	6.2	9.82	307	7.8

Table 4. Manning Trail Drainage 2009 Total Phosphorus and Total Suspended Solids Loading

	Sample Collection Time				Loading Interval					
Sample Type	Start	End	TSS (mg/L)	TP (mg/L)	Start	End	Interval Volume (cf)	Interval Volume (ac-ft)	Interval TSS (lb)	Interval TP (lb)
Base**			5	0.146	1/1/09 0:00	3/17/09 7:30	3,254	0.07	1.0	0.03
Snowmelt Grab**	3/17/09 12:30	3/17/09 12:30	5	0.337	3/17/09 7:30	3/18/09 17:30	428,400	9.84	133.7	9.01
Base**			5	0.146	3/18/09 17:30	3/24/09 4:00	939,600	21.58	293.3	8.56
Storm Grab**	3/24/09 10:39	3/24/09 10:39	4	0.089	3/24/09 4:00	3/25/09 4:00	302,400	6.95	75.5	1.68
Base**			5	0.146	3/25/09 4:00	4/2/09 15:00	1,388,520	31.89	433.4	12.66
Base			5	0.146	4/2/09 15:00	5/2/09 15:00	4,477,412	102.84	1397.5	40.81
Base Grab	5/14/09 11:25	5/14/09 11:25	9	0.097	5/2/09 15:00	5/19/09 9:00	833,672	19.15	468.4	5.05
Storm			5	0.146	5/19/09 9:00	5/22/09 5:00	303,023	6.96	94.58	2.76
Base			5	0.146	5/22/09 5:00	6/8/09 5:00	1,144,317	26.28	357.2	10.43
Storm Grab	6/8/09 8:13	6/8/09 8:13	15	0.091	6/8/09 5:00	6/9/09 4:00	58,951	1.35	55.2	0.33
Base			5	0.146	6/9/09 4:00	6/18/09 4:00	330,536	7.59	103.2	3.01
Base Grab	6/24/09 8:23	6/24/09 8:23	4	0.144	6/18/09 4:00	6/25/09 5:00	109,574	2.52	27.4	0.98
Storm			5	0.146	6/25/09 5:00	6/26/09 5:00	17,385	0.40	5.4	0.16
Base			5	0.146	6/26/09 5:00	6/27/09 5:00	14,545	0.33	4.5	0.13
Storm			5	0.146	6/27/09 5:00	6/28/09 2:00	33,231	0.76	10.4	0.30
Base			5	0.146	6/28/09 2:00	7/10/09 17:00	164,006	3.77	51.2	1.49
NoFlow			0	0.000	7/10/09 17:00	8/19/09 12:00	0	0.00	0.0	0.00
Storm Grab	8/20/09 9:39	8/20/09 9:39	2	0.129	8/19/09 12:00	8/21/09 4:00	10,672	0.25	1.3	0.09
Base			5	0.146	8/21/09 4:00	8/25/09 6:00	8,220	0.19	2.6	0.07
Storm			5	0.146	8/25/09 6:00	8/26/09 5:00	3,162	0.07	1.0	0.03
Base			5	0.146	8/26/09 5:00	8/28/09 6:00	4,589	0.11	1.4	0.04
Storm			5	0.146	8/28/09 6:00	8/29/09 0:00	1,823	0.04	0.6	0.02
Base (Intermittent)			5	0.146	8/29/09 0:00	10/6/09 4:00	3,002	0.07	0.9	0.03
Storm Grab	10/6/09 13:44	10/6/09 13:44	3	0.234	10/6/09 4:00	10/7/09 20:00	13,523	0.31	2.5	0.20
Base			5	0.146	10/7/09 20:00	10/15/09 2:00	11,949	0.27	3.7	0.11
Storm			5	0.146	10/15/09 2:00	10/17/09 9:00	11,849	0.27	3.7	0.11
Base			5	0.146	10/17/09 9:00	10/21/09 7:00	13,458	0.31	4.2	0.12
Storm Grab	10/22/09 9:42	10/22/09 9:42	1	0.046	10/21/09 7:00	10/22/09 21:00	13,068	0.30	0.8	0.04
Base			5	0.146	10/22/09 21:00	10/23/09 11:00	4,487	0.10	1.4	0.04
Storm			5	0.146	10/23/09 11:00	10/25/09 9:00	37,152	0.85	11.6	0.34
Base			5	0.146	10/25/09 9:00	10/29/09 10:00	50,402	1.16	15.7	0.46
Storm			5	0.146	10/29/09 10:00	10/31/09 22:00	68,249	1.57	21.3	0.62
Base			5	0.146	10/31/09 22:00	11/2/09 10:00	36,761	0.84	11.5	0.34
Base**			5	0.146	11/2/09 10:00	12/2/09 10:00	388,800	8.93	121.4	3.54
Base**			5	0.146	12/2/09 10:00	1/1/10 0:00	1,278	0.03	0.4	0.01
Snowmelt Average			5	0.337						
Storm Average			5	0.118						
Base Average			7	0.121						
All Average			5	0.146						
Total							**11,231,268**	**258**	**3,718**	**104**
CLFLWD Major Subwatershed Total Acres							7,115			
Total Load										
Total TP/TSS (lb/ac/yr)									0.52	0.01
Total TP/TSS (kg/ha/yr)									0.59	0.02

*Italics indicate estimated concentrations based on average base and storm flow concentrations

** Interval volumes from 1/1/09 to 4/2/09 and 11/3/09 to 1/1/10 where estimated using logged flow conditions and site rating curve

Total phosphorus loading for Manning Trail Drainage in 2009 was estimated at 0.01 lbs/acre (104 lbs.). This site had very little flow for the second half of the monitoring season. This loading is substantially less than what was observed in 2008, most likely due to the overall reduction of runoff in 2009.

July Avenue

Two thousand and nine (2009) was the second year that data was collected at the July Avenue station, and flow was recorded from April 2-November 2, 2009. Total discharge for this period was 19,675,230 cfs or 452 ac/ft. A total of 17.92 inches of rainfall was recorded at the site and a peak flow of 6.788 cfs occurred on April 2nd, due to the remnants of the spring thaw. A second high flow of 6.648 cfs occurred on August 8th, due to a 0.86-inch rainfall event. Figure 4 graphs the flow and rainfall recorded at the July Avenue site.

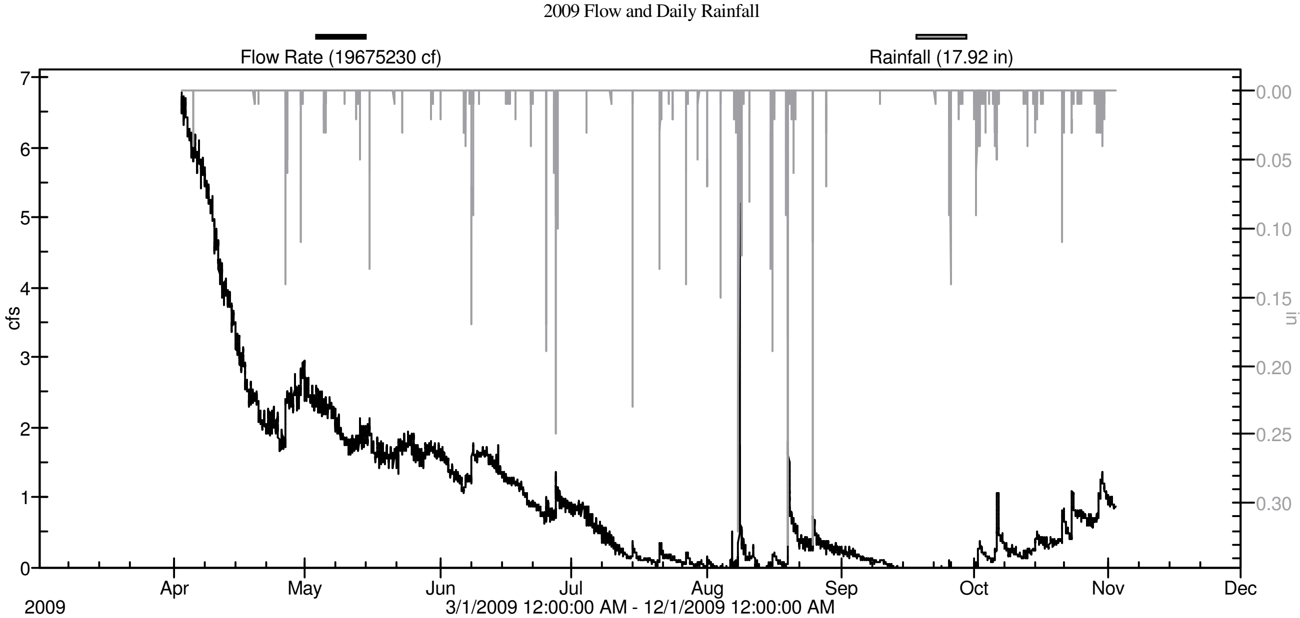


Figure 4. July Avenue Drainage 2009 Flow and Daily Rainfall

Grab samples were collected at the July Avenue site in 2009 and chemistry and field water quality measurements are listed in Tables 5-7 below. The highest concentration of TKN and TP were 1.6 mg/L (June 24th base grab) and 0.352 mg/L (March 17th snowmelt grab), respectively. The highest TSS value recorded was 14 mg/L from a storm grab sample collected on June 8th.

Table 5. July Avenue Drainage 2009 Sample Chemistry Results

Sample Type	Start	End	TSS (mg/L)	VSS (mg/L)	TKN (mg/L)	TP (mg/L)	Dissolved TP (mg/L)	Chloride (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia Nitrogen (mg/L)	E. Coli (mpn/100ml)
Snowmelt Grab	3/17/2009 12:30	3/17/2009 12:30	~2	~2	1.2	0.352	0.268	5	<0.03	0.09	0.16	
Storm Grab	3/24/2009 10:26	3/24/2009 10:26	5	5	0.93	0.077	~0.012	12	<0.03	<0.05	~0.04	
Base Grab	5/14/2009 11:09	5/14/2009 11:09	8	5	1.1	0.055	<0.010	18	<0.03	<0.05	0.06	
E. Coli Grab	5/28/2009 9:00	5/28/2009 9:00										126
Storm Grab	6/8/2009 8:25	6/8/2009 8:25	14	7	1.1	0.086	~0.040	17	<0.03	<0.05	~0.05	
E. Coli Grab	6/10/2009 8:20	6/10/2009 8:20										36.9
Base Grab	6/24/2009 8:33	6/24/2009 8:33	9	~4	1.6	0.134	0.084	18	<0.03	<0.05	0.15	
Base Grab	7/13/2009 9:10	7/13/2009 9:10	~1	~1	1.2	0.084	0.052	17	<0.03	<0.05	0.06	
E. Coli Grab	7/28/2009 8:00	7/28/2009 8:00										579.4
Storm Grab	8/20/2009 9:58	8/20/2009 9:58	4	3	1.2	0.177	0.104	9	<0.03	<0.05	~0.06	
E. Coli Grab	8/26/2009 8:11	8/26/2009 8:11										344.8
Base Grab	9/8/2009 10:21	9/8/2009 10:21	~2	~1	1	0.062	~0.019	13	<0.03	<0.05	~0.06	
Storm Grab	10/2/2009 9:31	10/2/2009 9:31	4	~2	1.1	0.221	0.158	27	<0.03	0.08	0.09	
Storm Grab	10/6/2009 13:53	10/6/2009 13:53	~2	~2	0.98	0.154	0.132	20	<0.03	<0.05	~0.05	
Storm Grab	10/22/2009 10:12	10/22/2009 10:12	~2	~2	1.1	0.083	0.072	13	<0.03	<0.05	<0.02	

Table 6. July Avenue Drainage 2009 Field Water Quality Measurements

Date/Time	Transparency (cm)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)	pH
3/17/2009 12:33	94	0.8	9.51	108	6.9
3/24/2009 10:26	86	1.9	12.84	234	8
5/14/2009 11:09	>100	15.0	5.17		
5/28/2009 8:57	>100	14.3	4.95		
6/8/2009 8:25	>120	12.9	5.25	220	
6/8/2009 9:56	>100	12.4	5.08	238	7.8
6/10/2009 8:20	>100	15.7	6.14		
6/24/2009 8:33	>100	24.1	1.28		
7/13/2009 9:10	>100	16.1	2.73	239	8.2
8/20/2009 9:58	>100	17.0	1.81	207	7.6
8/26/2009 8:11	>100	15.2	1.66	241	7.3
9/8/2009 10:21	>100	16.3	2.44	240	7.06
10/2/2009 9:31	>100	9.0	5.60	282	8.3
10/6/2009 13:53	>100	9.3	6.44	250	7.9
10/22/2009 10:12	>100	6.1	7.16	244	7.4

Total phosphorous loading for July Avenue in 2009 was estimated at 0.02 lbs/acre (151 lbs). Compared to the Manning Trail site, the total discharge at July Ave is over double and the TP load is slightly higher. The load compared to 2008 is substantially lower and is due in large part to the overall reduction in flow in 2009 when compared to 2008.

Table 7. July Avenue Drainage 2009 Total Phosphorus and Total Suspended Solids Loading

	Sample Collection Time				Loading Interval					
Sample Type	**Start**	**End**	**TSS (mg/L)**	**TP (mg/L)**	**Start**	**End**	**Interval Volume (cf)**	**Interval Volume (ac-ft)**	**Interval TSS (lb)**	**Interval TP (lb)**
*Base***			5	0.084	1/1/09 0:00	3/17/09 5:00	32,490	0.75	10.1	0.17
Snowmelt Grab**	3/17/09 12:30	3/17/09 12:30	2	0.352	3/17/09 5:00	3/18/09 17:00	648,000	14.88	80.9	14.24
*Base***			5	0.084	3/18/09 17:00	3/24/09 4:00	1,980,720	45.49	618.2	10.39
Storm Grab**	3/24/09 10:26	3/24/09 10:26	5	0.077	3/24/09 4:00	3/25/09 12:00	576,000	13.23	179.8	2.77
*Base***			5	0.084	3/25/09 12:00	4/2/09 15:30	2,955,960	67.89	922.6	15.50
Base			5	0.084	4/2/09 15:30	4/26/09 10:30	7,775,086	178.58	2426.8	40.77
Storm			5	0.133	4/26/09 10:30	4/27/09 0:30	120,722	2.77	37.7	1.00
Base Grab	5/14/09 11:09	5/14/09 11:09	8	0.055	4/27/09 0:30	5/16/09 0:30	3,585,154	82.35	1790.46	12.31
Base			5	0.084	5/16/09 0:30	6/8/09 5:30	3,144,339	72.22	981.4	16.49
Storm Grab	6/8/09 8:25	6/8/09 8:25	14	0.086	6/8/09 5:30	6/8/09 17:30	70,630	1.62	61.7	0.38
Base			5	0.084	6/8/09 17:30	6/17/09 17:30	1,128,953	25.93	352.4	5.92
Base Grab	6/24/09 8:33	6/24/09 8:33	9	0.134	6/17/09 17:30	6/27/09 2:30	749,184	17.21	420.9	6.27
Storm			5	0.133	6/27/09 2:30	6/27/09 20:30	66,449	1.53	20.7	0.55
Base			5	0.084	6/27/09 20:30	7/7/09 20:30	701,339	16.11	218.9	3.68
Base Grab	7/13/09 9:10	7/13/09 9:10	1	0.084	7/7/09 20:30	7/14/09 21:30	183,380	4.21	11.4	0.96
Storm			5	0.133	7/14/09 21:30	7/15/09 8:30	10,346	0.24	3.2	0.09
Base			5	0.084	7/15/09 8:30	7/21/09 1:30	51,861	1.19	16.2	0.27
Storm			5	0.133	7/21/09 1:30	7/21/09 20:30	15,898	0.37	5.0	0.13
Base			5	0.084	7/21/09 20:30	7/27/09 10:30	50,240	1.15	15.7	0.26
Storm			5	0.133	7/27/09 10:30	7/27/09 23:30	8,131	0.19	2.5	0.07
Base			5	0.084	7/27/09 23:30	8/8/09 7:30	27,337	0.63	8.5	0.14
Storm			5	0.133	8/8/09 7:30	8/8/09 21:30	47,514	1.09	14.8	0.39
Base			5	0.084	8/8/09 21:30	8/11/09 11:30	41,793	0.96	13.0	0.22
Storm			5	0.133	8/11/09 11:30	8/11/09 23:30	8,675	0.20	2.7	0.07
Base			5	0.084	8/11/09 23:30	8/16/09 1:30	4,375	0.10	1.4	0.02
Storm			5	0.133	8/16/09 1:30	8/17/09 0:30	12,202	0.28	3.8	0.10
Base			5	0.084	8/17/09 0:30	8/19/09 12:30	8,875	0.20	2.8	0.05
Storm Grab	8/20/09 9:58	8/20/09 9:58	4	0.177	8/19/09 12:30	8/20/09 17:30	89,605	2.06	22.4	0.99
Base			5	0.084	8/20/09 17:30	8/25/09 6:30	160,812	3.69	50.2	0.84
Storm			5	0.133	8/25/09 6:30	8/25/09 22:30	33,832	0.78	10.6	0.28
Base Grab	9/8/09 10:21	9/8/09 10:21	2	0.062	8/25/09 22:30	9/15/09 22:30	285,204	6.55	35.6	1.10
Base (Intermittent)			5	0.084	9/15/09 22:30	10/2/09 1:30	2,393	0.05	0.7	0.01
Storm Grab	10/2/09 9:31	10/2/09 9:31	4	0.221	10/2/09 1:30	10/2/09 22:30	19,308	0.44	4.8	0.27
Base			5	0.084	10/2/09 22:30	10/5/09 16:30	34,424	0.79	10.7	0.18
Storm Grab	10/6/09 13:53	10/6/09 13:53	2	0.154	10/5/09 16:30	10/7/09 21:30	85,891	1.97	10.7	0.83
Base			5	0.084	10/7/09 21:30	10/21/09 6:30	322,353	7.40	100.6	1.69
Storm Grab	10/22/09 10:12	10/22/09 10:12	2	0.083	10/21/09 6:30	10/22/09 4:30	51,400	1.18	6.4	0.27
Base			5	0.084	10/22/09 4:30	10/23/09 9:30	50,934	1.17	15.9	0.27
Storm			5	0.133	10/23/09 9:30	10/24/09 5:30	57,895	1.33	18.1	0.48
Base			5	0.084	10/24/09 5:30	10/29/09 12:30	322,354	7.40	100.6	1.69
Storm			5	0.133	10/29/09 12:30	10/31/09 1:30	151,409	3.48	47.3	1.26
Base			5	0.084	10/31/09 1:30	11/2/09 10:30	194,164	4.46	60.6	1.02
*Base***			5	0.084	11/2/09 10:30	12/2/09 12:00	1,246,752	28.64	389.1	6.54
*Base***			5	0.084	12/2/09 12:00	1/1/10 0:00	12,744	0.29	4.0	0.07
Snowmelt Average			2	0.352						
Storm Average			5	0.133						
Base Average			5	0.084						
All Average			5	0.135						
Total							**27,127,126**	**623**	**9,112**	**151**
CLFLWD Major Subwatershed Total Acres							7,902			
Total Load										
Total TP/TSS (lb/ac/yr)									1.15	0.02
Total TP/TSS (kg/ha/yr)									1.29	0.02

*Italics indicate estimated concentrations based on average base and storm flow concentrations, with intervals before 7/29/08 based on all samples taken before that date, and respectivly for intervals after that date

** Interval volumes from 1/1/09 to 4/2/09 and 11/2/09 to 1/1/10 where estimated based upon base and storm flow

Inlet to Little Comfort Lake

The station for the Little Comfort Lake Inlet site recorded flow between April 9 and November 2, 2009. Total discharge during this period was 72,160,360 cf or 1,657 acre-ft. Total rainfall recorded during the monitoring season was 17.34 inches. Peak discharge of 55.10 cfs occurred on April 17th. The cause of this high flow is unknown, but potentially could have been caused by the removal of a beaver dam upstream of the site. Figure 5 graphs the flow and rainfall recorded at the Little Comfort Lake Inlet site.

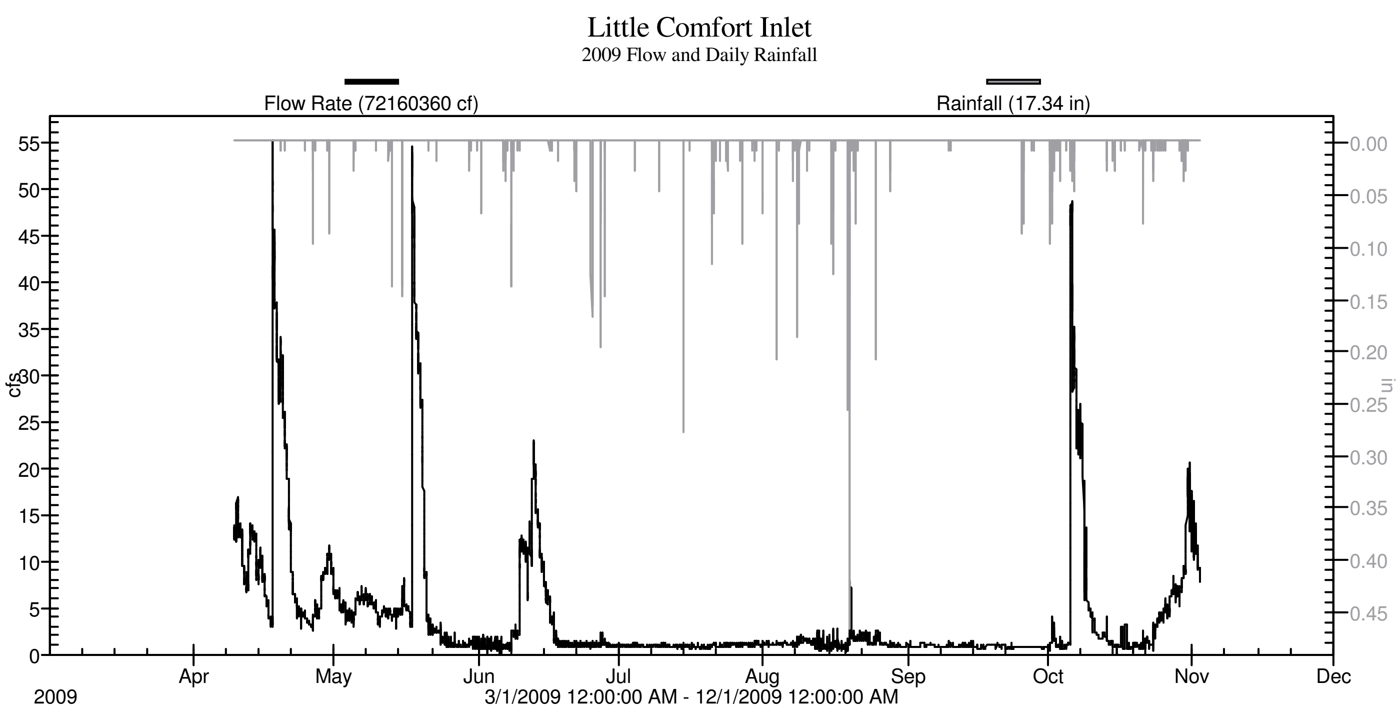


Figure 5. Little Comfort Lake Inlet 2009 Flow and Daily Rainfall

Grab samples were collected at the Little Comfort Lake Inlet site in 2009 and chemistry and field water quality measurements are listed in Tables 8-10 below. The highest concentrations of TKN and TP were 1.1 mg/L (June 8th storm grab, June 24th base sample, October 6th storm sample) and 0.159 mg/L (October 2nd storm sample), respectively. The TSS maximum concentration of 21 mg/L was from a June 8th storm grab sample.

Table 8. Little Comfort Lake Inlet 2009 Sample Chemistry Results

Sample Type	Start	End	TSS (mg/L)	VSS (mg/L)	TKN (mg/L)	TP (mg/L)	Dissolved P (mg/L)	Chloride (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Ammonia Nitrogen (mg/L)	E. Coli (mpn/100ml)
Storm Grab	3/24/2009 10:14	3/24/2009 10:14	11	7	0.81	0.072	~0.021	8	<0.03	0.1	0.13	
Base Grab	5/14/2009 10:56	5/14/2009 10:56	4	~2	0.82	0.08	~0.014	14	<0.03	0.06	0.09	
Storm Grab	6/8/2009 8:40	6/8/2009 8:40	21	8	1.1	0.114	~0.018	9	<0.03	0.14	0.44	
E. Coli Grab	6/10/2009 8:30	6/10/2009 8:30										547.5
Base Grab	6/24/2009 8:46	6/24/2009 8:46	~2	~2	1.1	0.087	~0.049	12	0.12	0.21	0.25	
Base Grab	7/15/2009 8:30	7/15/2009 8:30	9	~3	0.52	0.059	~0.037	13	<0.03	<0.05	~0.04	
E. Coli Grab	7/28/2009 8:10	7/28/2009 8:10										201.4
Storm Grab	8/20/2009 10:18	8/20/2009 10:18	~1	~1	0.91	0.077	0.053	10	<0.03	0.06	~0.03	
Storm Grab	10/2/2009 9:46	10/2/2009 9:46	~2	~1	0.56	0.159	0.148	11	<0.03	0.12	<0.02	
Storm Grab	10/6/2009 14:04	10/6/2009 14:04	10	4	1.1	~0.026	~0.027	14	<0.03	<0.05	0.23	
Base Grab	10/22/2009 10:34	10/22/2009 10:34	~1	~1	0.8	~0.041	~0.018	10	<0.03	<0.05	~0.04	

Table 9. Little Comfort Lake Inlet 2009 Field Water Quality Measurements

Date/Time	Transparency (cm)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (umhos/cm)	pH
3/24/2009 10:14	56	4.6	13.05	266	8
4/24/2009 9:13	>100	13.7	5.54		
5/14/2009 10:56	>100	14.9	9.93		
6/8/2009 8:40	39	11.6	7.60	350	
6/10/2009 8:31	>100	15.8	6.50		
6/24/2009 8:46	>100	22.7	3.96		
7/13/2009 9:33	>100	16.4	5.49	379	8.4
7/15/2009 8:32	58	19.1	4.10	394	8.6
8/20/2009 10:18	>100	17.1	5.83	348	7.9
10/2/2009 9:46	>100	9.3	8.43	361	8.1
10/6/2009 14:04	>100	11.1	6.12	351	7.9
10/22/2009 10:34	>100	6.3	8.14	400	8

Total phosphorus loading for Little Comfort Lake Inlet for 2009 was estimated at 0.04 lb/ac (418 lbs). Compared to the July Ave. site, the higher TP load at Little Comfort Inlet is due in large part to the much higher total discharge that occurred at that site. However, the overall load is much lower when compared to 2008, again due to the reduction in total flow.

Table 10. Little Comfort Lake Inlet 2009 Total Phosphorus and Total Suspended Solids Loading

	Sample Collection Time				Loading Interval					
Sample Type	**Start**	**End**	**TSS (mg/L)**	**TP (mg/L)**	**Start**	**End**	**Interval Volume (cf)**	**Interval Volume (ac-ft)**	**Interval TSS (lb)**	**Interval TP (lb)**
Base**			4	0.061	1/1/09 0:00	3/24/2009 5:00	355,140	8.16	89	1.4
Storm Grab**	3/24/09 10:14	3/24/09 10:14	11	0.072	3/24/09 5:00	3/25/2009 17:00	1,425,600	32.74	979	6.4
Base**			4	0.061	3/25/09 17:00	4/9/09 15:00	11,599,200	266.42	2896	44.2
Base Grab	5/14/09 10:56	5/14/09 10:56	4	0.080	4/9/09 15:00	5/17/09 15:00	29,053,090	667.32	7255	145.1
Base			4	0.061	5/17/09 15:00	6/8/09 5:00	10,254,040	235.52	2560	39.0
Storm Grab	6/8/09 8:40	6/8/09 8:40	21	0.114	6/8/09 5:00	6/14/09 6:00	5,371,105	123.37	7041	38.2
Base			4	0.061	6/14/09 6:00	6/20/09 6:00	1,978,225	45.44	494	7.5
Base Grab	6/24/09 8:46	6/24/09 8:46	2	0.087	6/20/09 6:00	6/25/09 5:00	391,077	8.98	49	2.1
Storm			9	0.090	6/25/09 5:00	6/25/09 18:00	45,800	1.05	26	0.3
Base			4	0.061	6/25/09 18:00	6/27/09 3:00	108,160	2.48	27	0.4
Storm			9	0.090	6/27/09 3:00	6/28/09 3:00	113,395	2.60	64	0.6
Base			4	0.061	6/28/09 3:00	7/13/09 3:00	1,112,992	25.56	278	4.2
Base Grab	7/15/09 8:30	7/15/09 8:30	9	0.059	7/13/09 3:00	7/21/09 1:00	505,856	11.62	284	1.9
Base			4	0.061	7/21/09 1:00	8/8/09 6:00	1,541,870	35.41	385	5.9
Storm			9	0.090	8/8/09 6:00	8/9/09 19:00	193,820	4.45	109	1.1
Base			4	0.061	8/9/09 19:00	8/15/09 19:00	545,023	12.52	136	2.1
Storm			9	0.090	8/15/09 19:00	8/16/09 15:00	83,648	1.92	47	0.5
Base			4	0.061	8/16/09 15:00	8/19/09 3:00	172,079	3.95	43	0.7
Storm Grab	8/20/09 10:18	8/20/09 10:18	1	0.077	8/19/09 3:00	8/20/09 20:00	373,781	8.59	23	1.8
Base			4	0.061	8/20/09 20:00	8/25/09 7:00	627,006	14.40	157	2.4
Storm			9	0.090	8/25/09 7:00	8/26/09 0:00	133,327	3.06	75	0.7
Base			4	0.061	8/26/09 0:00	10/1/09 10:00	2,568,569	59.00	641	9.8
Storm Grab	10/2/09 9:46	10/2/09 9:46	2	0.159	10/1/09 10:00	10/2/09 14:00	174,029	4.00	22	1.7
Base			4	0.061	10/2/09 14:00	10/5/09 17:00	257,966	5.93	64	1.0
Storm Grab	10/6/09 14:04	10/6/09 14:04	10	0.026	10/5/09 17:00	10/8/09 22:00	7,594,310	174.43	4741	12.3
Base			4	0.061	10/8/09 22:00	10/19/09 22:00	1,914,027	43.96	478	7.3
Base Grab	10/22/09 10:34	10/22/09 10:34	1	0.018	10/19/09 22:00	10/30/09 16:00	3,752,074	86.18	234	4.2
Storm			9	0.090	10/30/09 16:00	10/31/09 20:00	1,631,490	37.47	917	9.2
Base			4	0.061	10/31/09 20:00	11/2/09 13:00	1,663,605	38.21	415	6.3
Base**			4	0.061	11/2/09 13:00	12/2/09 13:00	15,552,000	357.21	3883	59.2
Base**			4	0.061	12/2/09 13:00	1/1/10 0:00	127,260	2.92	32	0.5
Storm Average			9	0.090						
Base Average			4	0.061						
All Average			7	0.077						
Total							**101,219,564**	**2,325**	**34,444**	**418**
CLFLWD Major Subwatershed Total Acres										
Total Load							10,513			
Total TP/TSS (lb/ac/yr)									3.28	0.04
Total TP/TSS (kg/ha/yr)									3.67	0.04

*Italics indicate estimated concentrations based on average base and storm flow concentrations

** Interval volumes from 1/1/09 to 4/9/09 and 11/2/09 to 1/1/10 where estimated based upon base flow

Tributary Monitoring Loads and Discussion

The TP and TSS loadings and the total discharge at the Manning Trail, July Ave., and Little Comfort Lake inlet monitoring stations increased in 2009 as you move further down the watershed, which is to be expected. These results were all lower when compared to the results in 2008, due in large part to lower lake levels, lack of rainfall/snowmelt, and less runoff events. The total discharge, TP load, and TSS load at Little Comfort Lake inlet were the lowest monitored in 2009 in the last six years. Historically, this monitoring station has shown that nutrient loadings have responded similarly to total discharge, with the exception of 2006 and 2007. Higher base flow conditions and higher or lower individual nutrient results during specific sampling periods are possible causes for the nutrient loadings and total discharge not tracking well together.

Proportionally, the 2008 and 2009 tributary monitoring data show that the highest phosphorus load increase was found to be between the July Avenue site and the inlet to Comfort Lake site as compared to the loads from the Manning Trail and July Avenue sites. The increase in loading between the sites for 2008 and 2009 are shown in Table 11 and Figures 6 and 7.

Table 11. Percent Increase in Phosphorus loading between Tributary Monitoring Sites

Site	2008	2009
Manning Trail to July Avenue	-15%	45%
July Avenue to Little Comfort Inlet	161%	175%

The water quality flow chart (figures 6 and 7) shows the summer (June 1 – September 30) total phosphorus mean concentrations in lakes and annual total phosphorus loadings collected at stream monitoring locations. The largest nutrient loading is found between School Lake and Little Comfort Lake. This is possibly due to a larger amount of discharge flowing into Little Comfort Lake compared to what's flowing into School Lake, and/or nutrient loadings from School Lake coupled with other contributions between School and Little Comfort Lake.

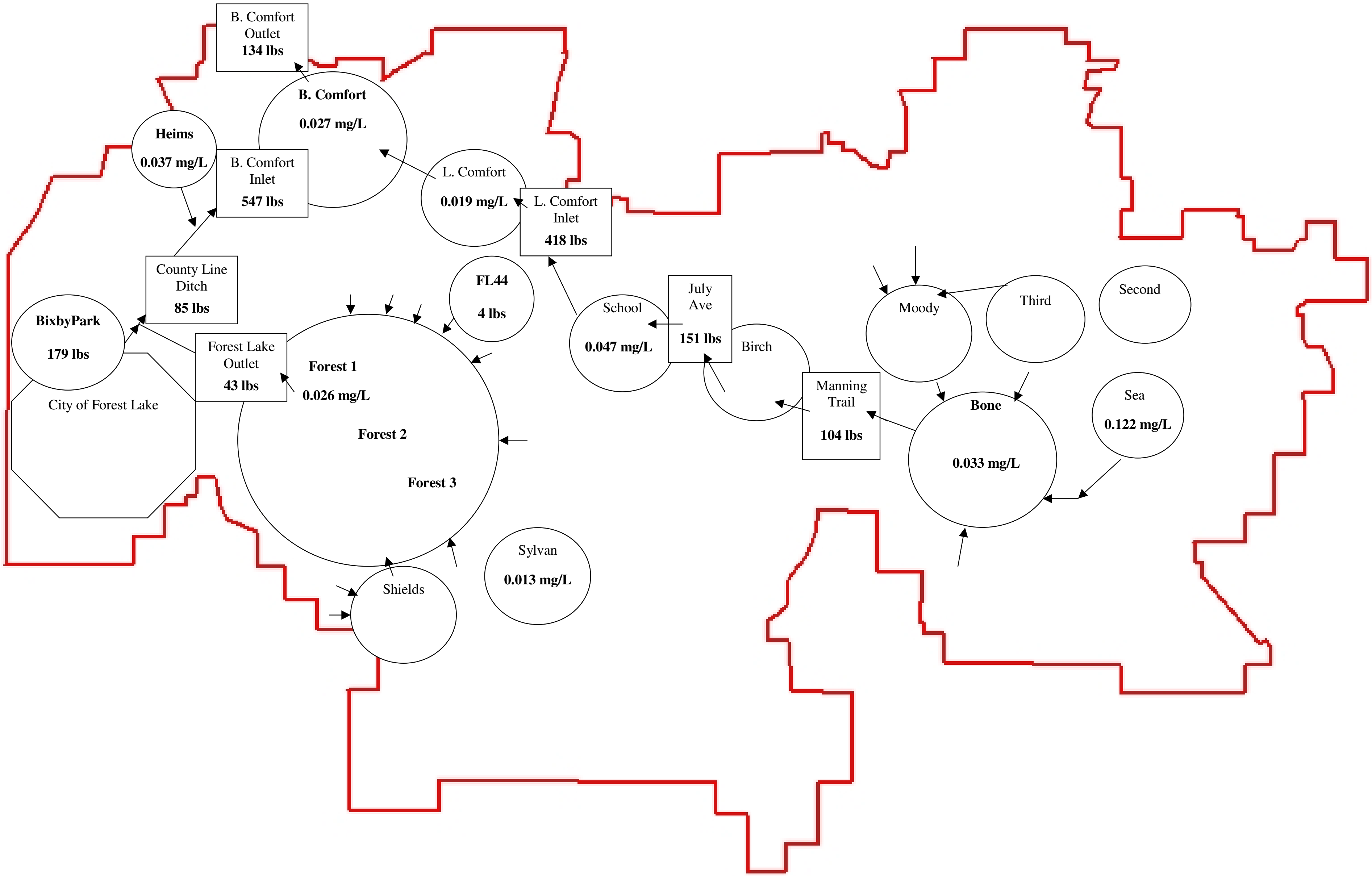


Figure 6. 2009 monitored tributary phosphorus loads and summer lake phosphorus means

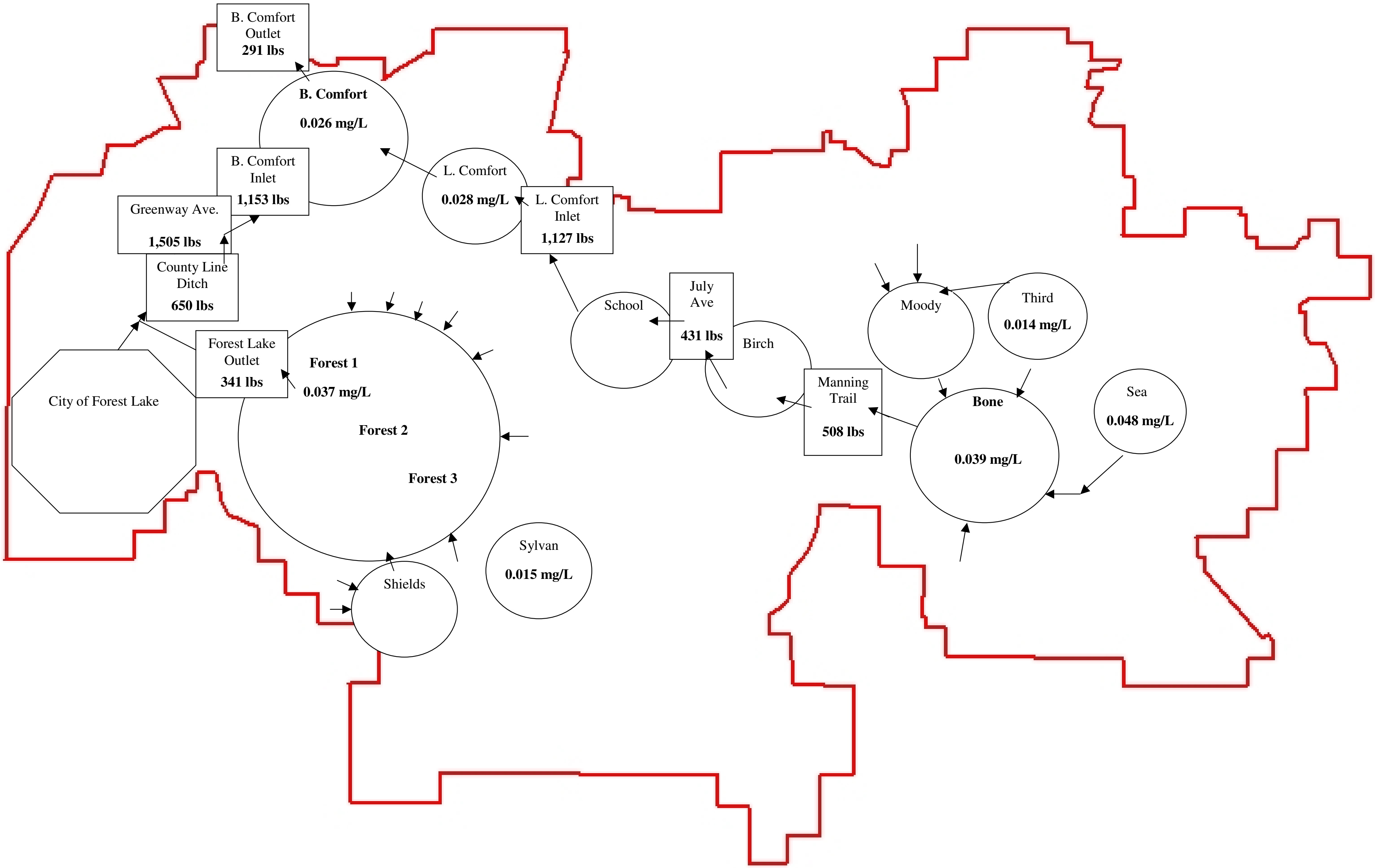


Figure 7. 2008 monitored tributary phosphorus loads and summer lake phosphorus means

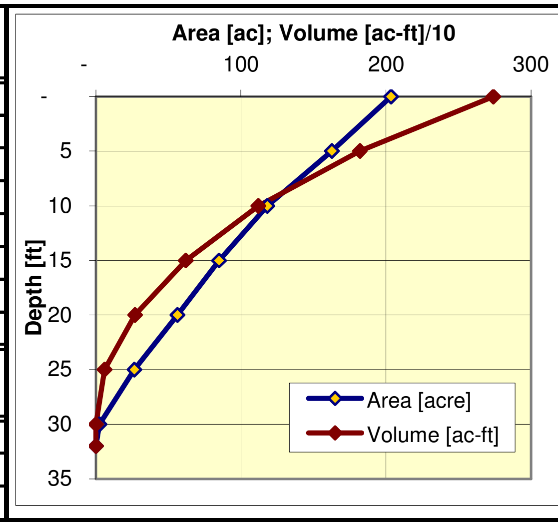
Lake Monitoring

Bone, School, and Little Comfort Lakes were monitored as part of this study from mid-April to mid-October 2009. All three lakes have been monitored by the CLFLWD in the past. Lake information, lakeshed loading calculations and reduction needs determined through the District's watershed-wide load allocation modeling effort (CLFLWD 2007), and current and historic water quality information are presented in this section.

Bone Lake

Bone Lake (MNDNR ID# 82-0054) is considered a deep lake, although it shares some character of a shallow lake due to its significant littoral area of 58%. Its 32-foot maximum depth ensures that it remains thermally stratified through the growing season. The lake's depth and volume are summarized below:

Depth [ft]	Area [acre]	Volume [ac-ft]
-	204	2,740
5	163	1,820
10	118	1,120
15	85	620
20	56	270
25	27	60
30	2	-
32	-	
13	Average Depth	
32	Maximun Depth	
58%	Littoral	



Present Conditions, Trends

Bone Lake is listed as impaired by the Minnesota Pollution Control Agency (MPCA) due to excessive nutrients.

Bone Lake Basin was monitored 12 times from early-May through late-September. Each monitoring event resulted in the analysis of a water sample for total phosphorus (TP), chlorophyll-a (CLA), total Kjeldahl nitrogen (TKN), and Secchi transparency, as well as the volunteer's perception of the lake's physical condition and recreational suitability. Collected water samples were submitted to the Metropolitan Council Environmental Services laboratory for analysis. Results are presented on graphs and data tables below.

Table 12. Bone Lake, 2009 summer (June-September) data summary

Parameter	*Mean*	*Minimum*	*Maximum*	*Grade*
TP (µg/l)	33.0	28.0	97.0	C+
CLA (µg/l)	17.0	5.4	73.0	B
Secchi (m)	1.7	1.1	3.5	C
TKN (mg/l)	1.20	0.96	1.5	
			Overall Grade	C+

Data are available for Bone Lake from 1975 to 2009; the average (since 1990, not continuous) total phosphorus is 51 ug/L. This is slightly above typical values for North Central Hardwood Forest (NCHF) ecoregion (23-50 ug/L), and is indicative of eutrophic conditions. When looking at the lake's whole database, there is not a statistically significant trend (improving or deteriorating) for surface total phosphorus between 1975 and 2009. However, phosphorus has ranged from a low of 33 ug/L in 2009 to a high of 103 ug/L in 1991.

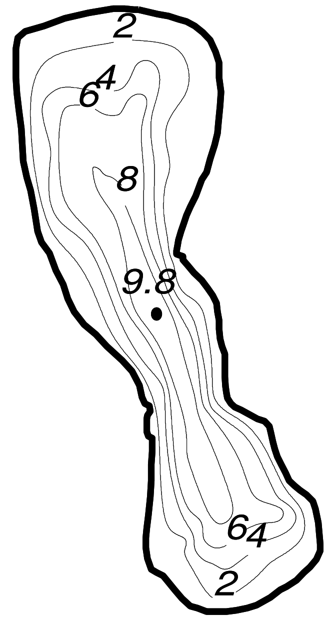
That said, total phosphorus and chlorophyll-*a* data collected shows improved conditions over the past four years, with growing season averages decreasing each year. The 2009 observation of 17 ug/L (the lowest measured) is at the upper range of values typical for NCHF ecoregion (5-22 ug/L), but it has ranged from 17 to 52 ug/L.

Secchi depth also shows no significant trend, although it has fluctuated from 0.9 to 1.7 meters, with a growing season average around 1.3 meters. Data collected indicates that Bone Lake isn't as clear as typical lakes found in the NCHF ecoregion (1.5 to 3.2 meters).

BONE LAKE

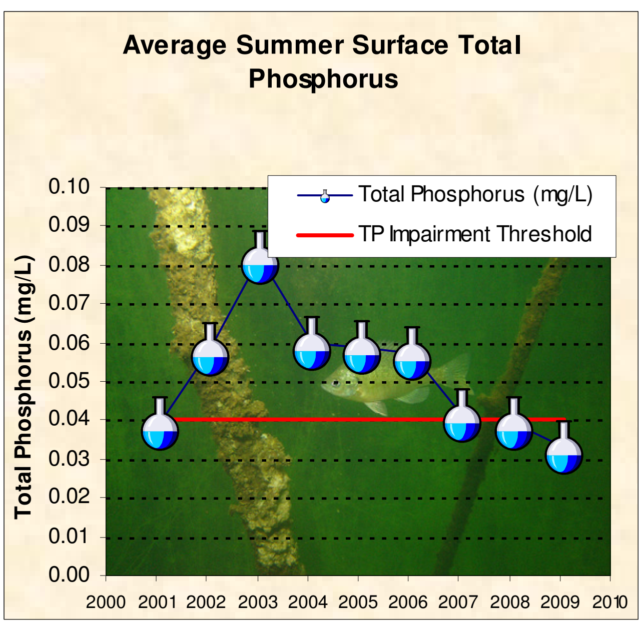
2009 Lake Grade: C+

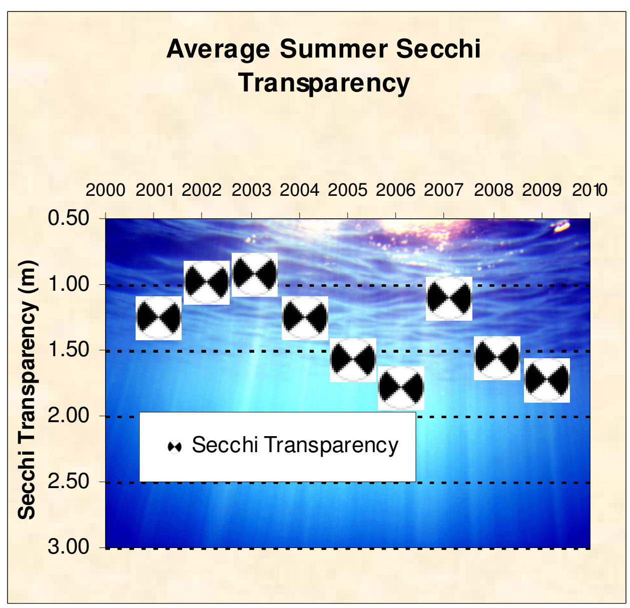
- DNR ID #: 820054
- Municipality: City of Scandia
- Location: Section 5 T32N-R20W
- Lake Size: 210 Acres
- Maximum Depth: 32 ft
- Ordinary High Water Mark: 909.1 ft
- 58% Littoral
  Note: Littoral area is the portion of the lake <15 ft and dominated by aquatic vegetation.



Summary Points

- Bone Lake was considered a eutrophic lake in 2009, based on the Carlson Trophic State Index (similar to 2006-2008).
- Bone Lake's summer phosphorus mean was lower than that experienced in 2003-2008.
- **Bone Lake is listed on the MPCA's Impaired Waters List for excessive nutrients.**
- **Eurasian Milfoil and Curly leaf pondweed (invasive aquatic plants) are extensive in this lake.**
- The major land use is rural/agricultural.
- The lake does stratify throughout the summer months.





Date	Total Phosphorus (mg/L)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Secchi Disk Depth (m)
5/11/09	0.097	6.3	1.4	2.4
5/18/09	0.044	14	1.3	2
5/28/09	0.031	27	1.2	1.7
6/9/09	0.04	10	1.5	1.8
6/15/09	0.033	7.7	1.2	2
6/20/09	0.036	5.4	1.2	2.1
7/1/09	0.031	8.2	1.3	3.5
7/19/09	0.031	14	0.96	1.2
8/2/09	0.036	17	0.98	1.2
9/6/09	0.036	73	1.4	1.1
9/15/09	0.03	11	1.3	1.3
9/26/09	0.028	6.4	0.96	1.4
2009 Summer Average	0.033	16.967	1.200	1.733

Water Quality threshold is 0.04 mg/L TP or higher*

Shallow Lake water quality threshold is 0.06 mg/L or higher*

	High	High Date	Low	Low Date	Average
2009 Elevation (ft)	NA	NA	NA	NA	NA

*MPCA description of Impaired Lake's Listing criteria: “At a minimum, a decision that a given lake is impaired for the 303(d) list due to excessive nutrients will be supported by data for both causal and response factors. Data requirements for 303(d) listing consist of 12 or more TP measurements collected from June through September over the most recent 10-year period. Ideally this should represent 12 separate visits to the lake over the course of two summers; however it might also reflect four monthly samples over the course of three years (a typical sampling regimen for many lake monitoring programs). In addition to exceeding the TP guideline thresholds, lakes to be considered for 303(d) listing should have at least 12 Secchi measurements and 12 chlorophyll-a measurements. This amount of data will allow for at least one season (preferably more) of paired TP, chlorophyll-a, and Secchi disk data and provide a basis for evaluating their interrelationships and hence the trophic status of the lake.”

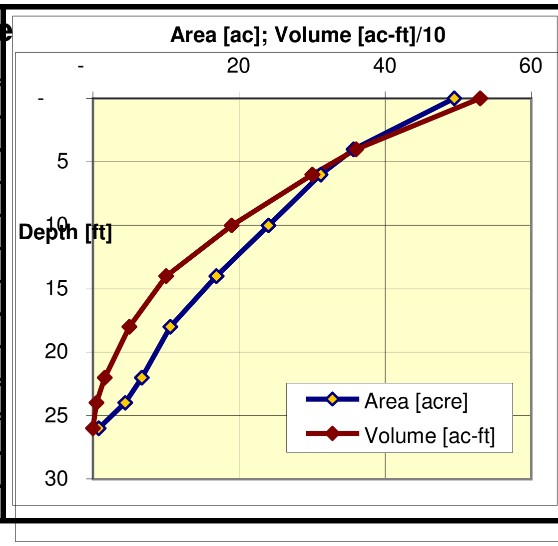
Lake Water Quality Summary

	Trophic Status	Lake Grades									
	2009	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
Total Phosphorus (mg/l)	Eutrophic	C	C	C	C	C	C	D	C	C	C
Chlorophyll-*a* (ug/l)	Eutrophic	B	B	B	B	C+	C	C	C	C	C
Secchi depth (ft)	Eutrophic	C	C	C	C	C	C	C	C	B	C
Overall	Eutrophic	C+	C+	C+	C+	C	C	C-	C	C+	C

School Lake

School Lake (MNDNR ID# 13-0057) is considered a deep lake; 66% of the area is littoral. Its maximum depth ensures that it remains thermally stratified through the growing season. The lake's depth and volume are summarized below:

Depth [ft]	Area [acre]	Volume [ac-ft]
-	49	530
4	36	360
6	31	300
10	24	190
14	17	100
18	11	50
22	7	16
24	4	5
26	1	-
11	Average Depth	
26	Maximun Depth	
66%	Littoral	



Present Conditions, Trends

School Lake is listed as impaired by the MPCA due to excessive nutrients

In 2009, School Lake was monitored six (6) times between late-May and mid-August. Each monitoring event resulted in the analysis of a water sample for total phosphorus (TP), chlorophyll-a (CLA), total Kjeldahl nitrogen (TKN), and Secchi transparency, as well as the volunteer's perception of the lake's physical condition and recreational suitability. Collected water samples were submitted to the Metropolitan Council Environmental Services laboratory for analysis. Results are presented on graphs and data tables on the following page.

Table 13. School Lake, 2009 summer (June-September) data summary

Parameter	*Mean*	*Minimum*	*Maximum*	*Grade*
TP (µg/l)	47.0	44.0	52.0	C
CLA (µg/l)	29.4	28.0	30.0	B
Secchi (m)	1.4	1.1	1.7	C
TKN (mg/l)	0.89	0.82	0.98	
			Overall Grade	C+

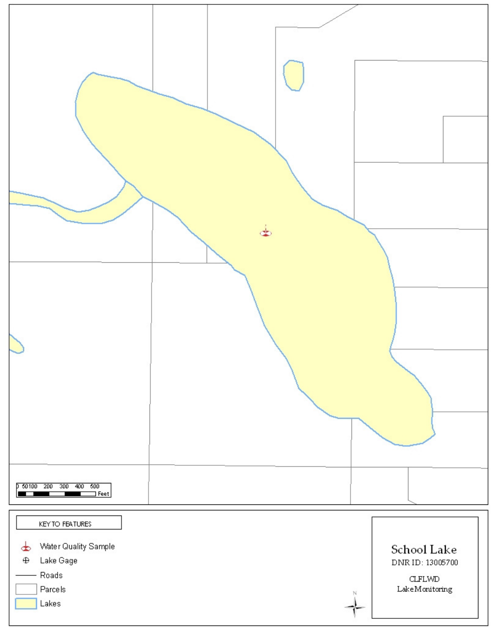
The four-year average total phosphorus average for School Lake is 61 ug/L. This is above typical values for North Central Hardwood Forest Ecoregion (23-50 ug/L), and is indicative of eutrophic conditions.

With just four years of water quality monitoring, no statistically significant trends in water quality can be identified for School Lake. That said the lake's TP and Secchi means have gotten better each year the lake has been monitored.

SCHOOL LAKE

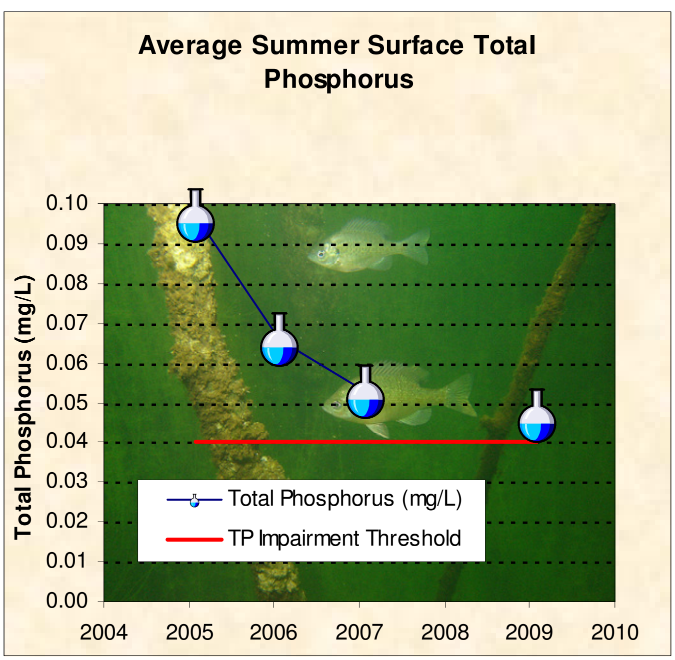
2009 Lake Grade: C+

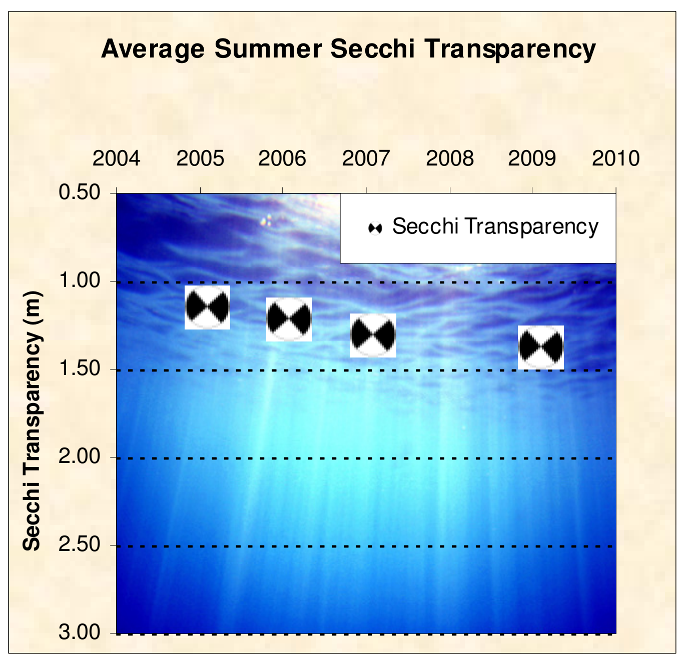
- DNR ID #: 130057
- Municipality: Chisago City
- Location: SE$^{1/4}$ Section 36 T33N-R21W
- Lake Size: 47 Acres
- Maximum Depth: 26 ft
- Ordinary High Water Mark: N/A
- 66% Littoral
  Note: Littoral area is the portion of the lake <15 ft and dominated by aquatic vegetation.



Summary Points

- School Lake was considered a eutrophic lake in 2009, based on the Carlson Trophic State Index.
- **A limited amount of Curly Leaf Pondweed (An invasive aquatic plant) is present.**
- **School Lake is listed on the MPCA's Impaired Waters List for excessive nutrients.**
- At this time, there are not enough years of data to determine a statistically significant trend in overall water quality but the water quality appears to be improving slightly.
- The major land use is rural/agricultural.
- The lake does stratify throughout the summer months.





Date	Total Phosphorus (mg/L)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Secchi Disk Depth (m)	
5/24/09	0.052	29	0.95	1.5	
6/13/09	0.047	30	0.82	1.7	
6/28/09	0.047	29	0.87	1.4	
7/10/09	0.049	30	0.95	1.2	
7/25/09	0.046	28	0.84	1.1	
8/11/09	0.044	30	0.98	1.5	
2009 Summer Average	0.047	29.400	0.892	1.380	
Water Quality threshold is 0.04 mg/L TP or higher*					
Shallow Lake water quality threshold is 0.06 mg/L or higher*					
	High	**High Date**	**Low**	**Low Date**	**Average**
2009 Elevation (ft)	NA	NA	NA	NA	NA

*MPCA description of Impaired Lake's Listing criteria: "At a minimum, a decision that a given lake is impaired for the 303(d) list due to excessive nutrients will be supported by data for both causal and response factors. Data requirements for 303(d) listing consist of 12 or more TP measurements collected from June through September over the most recent 10-year period. Ideally this should represent 12 separate visits to the lake over the course of two summers; however it might also reflect four monthly samples over the course of three years (a typical sampling regimen for many lake monitoring programs). In addition to exceeding the TP guideline thresholds, lakes to be considered for 303(d) listing should have at least 12 Secchi measurements and 12 chlorophyll-a measurements. This amount of data will allow for at least one season (preferably more) of paired TP, chlorophyll-a, and Secchi disk data and provide a basis for evaluating their interrelationships and hence the trophic status of the lake."

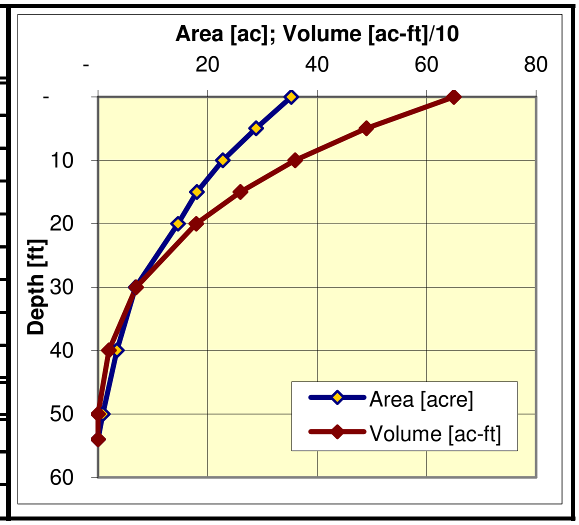
Lake Water Quality Summary

	Trophic Status	Lake Grades									
	2009	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
Total Phosphorus (mg/l)	Eutrophic	C		C	C	D					
Chlorophyll-*a* (ug/l)	Eutrophic	B		C	C	C					
Secchi depth (ft)	Eutrophic	C		C	C	C-					
Overall	Eutrophic	C+		C	C	C-					

Little Comfort Lake

Little Comfort Lake (MNDNR ID# 13-0054) is considered a deep lake with 49% of the area being littoral. Its maximum depth ensures that it remains thermally stratified through the growing season. The lake's depth and volume are summarized below:

Depth [ft]	Area [acre]	Volume [ac-ft]
-	35	650
5	29	490
10	23	360
15	18	260
20	15	180
30	7	70
40	3	20
50	1	-
54	-	-
18	Average Depth	
54	Maximun Depth	
49%	Littoral	



Present Conditions, Trends

In 2009, School Lake was monitored 12 times between mid-April and early-October. Each monitoring event resulted in the analysis of a water sample for total phosphorus (TP), chlorophyll-a (CLA), total Kjeldahl nitrogen (TKN), and Secchi transparency, as well as the volunteer's perception of the lake's physical condition and recreational suitability. Collected water samples were submitted to the Metropolitan Council Environmental Services laboratory for analysis. Results are presented on graphs and data tables on the following page.

Table 14. Little Comfort Lake, 2009 summer (June-September) data summary

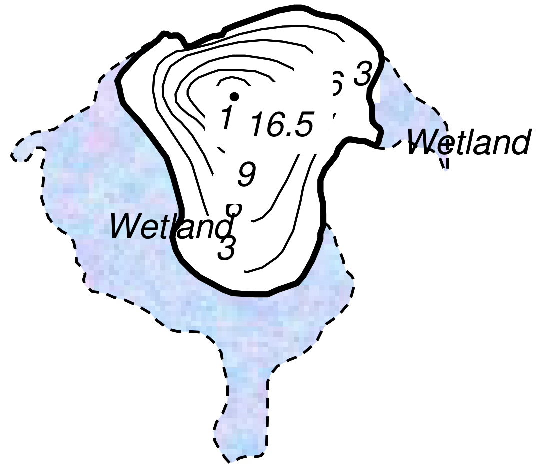
Parameter	*Mean*	*Minimum*	*Maximum*	*Grade*
TP (µg/l)	19.0	16.0	52.0	A
CLA (µg/l)	7.8	3.5	24.0	A
Secchi (m)	2.0	0.8	2.4	C
TKN (mg/l)	0.80	0.74	1.10	
			Overall Grade	B+

Data were available for Little Comfort Lake in 1994 and 2006-2009; the five-year average (not continuous) total phosphorus average is 44 ug/L. This is typical values for North Central Hardwood Forest Ecoregion (23-50 ug/L), and is indicative of eutrophic conditions. Considering just 2006-2009, the surface total phosphorus average of 42 ug/L is indicative of eutrophic conditions. The five-year average Secchi transparency average is 1.7 meters. With just five years of water quality monitoring, no statistically significant trends in water quality can be identified for Little Comfort Lake, however, the total phosphorus and chlorophyll-*a* data collected shows better summer means over the past three years, with growing season averages decreasing each year

LITTLE COMFORT LAKE

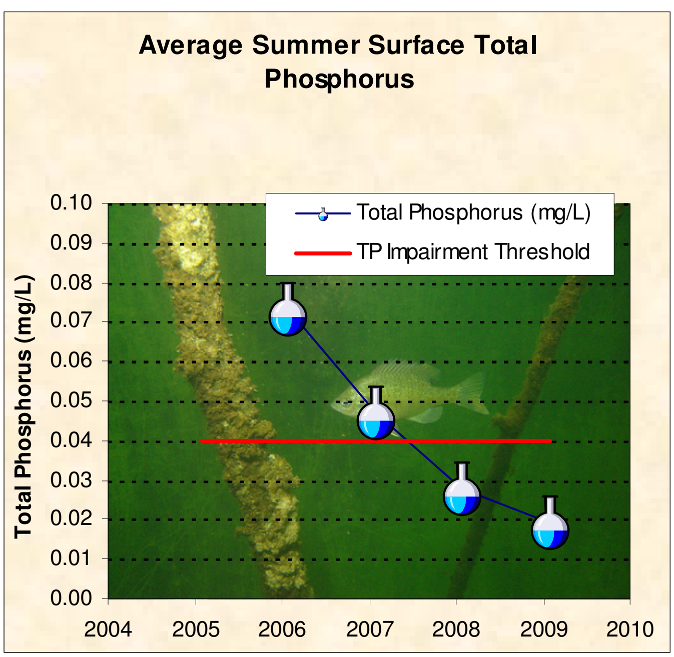
2009 Lake Grade: B+

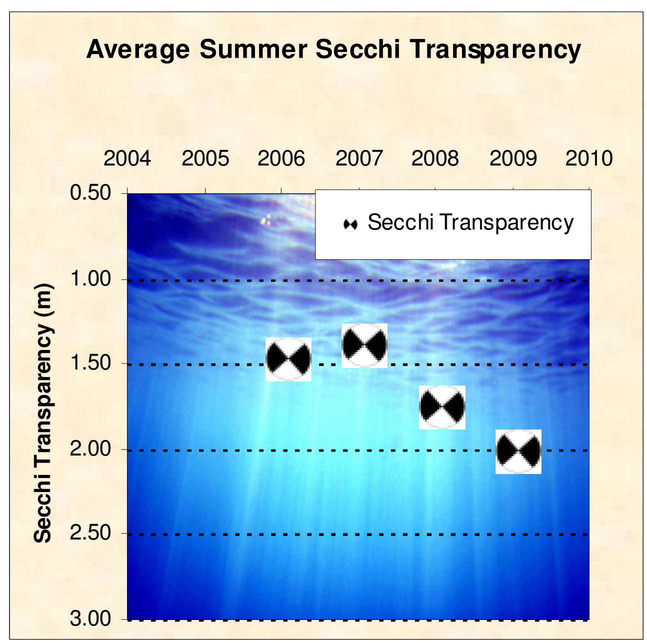
- DNR ID #: 130054
- Municipality: Chisago City
- Location: Section 27 T33N-R21W
- Lake Size: 36 Acres
- Maximum Depth: 56 ft
- Ordinary High Water Mark: 887.2 ft
- 49% Littoral
  Note: Littoral area is the portion of the lake <15 ft and dominated by aquatic vegetation.



Summary Points

- Little Comfort Lake was considered a mesotrophic lake in 2009, based on the Carlson Trophic State Index.
- 2009 represents the best monitored water quality for Little Comfort Lake to date.
- **Curly leaf pondweed (invasive aquatic plants) are extensive in this lake.**
- The major land use is rural/agricultural.
- The lake does stratify throughout the summer months.





Date	Total Phosphorus (mg/L)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Secchi Disk Depth (m)
4/16/09	0.052	24	1.1	0.8
5/1/09	0.024	11	0.84	1
5/13/09	0.03	7.3	0.92	1.4
6/1/09	0.017	3.5	0.74	2.4
6/10/09	0.018	3.6	0.81	3
6/22/09	0.014	6.6	0.85	2.2
7/12/09	0.017	9.8	0.75	1.7
7/27/09	0.016	10	0.82	1.6
8/23/09	0.022	10	0.78	1.9
9/5/09	0.019	7.8	0.86	1.7
9/16/09	0.029	11	0.87	1.6
10/4/09	0.031	5.8	0.87	1.5
2009 Summer Average	0.019	7.788	0.810	2.013

Water Quality threshold is 0.04 mg/L TP or higher*

Shallow Lake water quality threshold is 0.06 mg/L or higher*

	High	High Date	Low	Low Date	Average
2009 Elevation (ft)	NA	NA	NA	NA	NA

*MPCA description of Impaired Lake's Listing criteria: "At a minimum, a decision that a given lake is impaired for the 303(d) list due to excessive nutrients will be supported by data for both causal and response factors. Data requirements for 303(d) listing consist of 12 or more TP measurements collected from June through September over the most recent 10-year period. Ideally this should represent 12 separate visits to the lake over the course of two summers; however it might also reflect four monthly samples over the course of three years (a typical sampling regimen for many lake monitoring programs). In addition to exceeding the TP guideline thresholds, lakes to be considered for 303(d) listing should have at least 12 Secchi measurements and 12 chlorophyll-a measurements. This amount of data will allow for at least one season (preferably more) of paired TP, chlorophyll-a, and Secchi disk data and provide a basis for evaluating their interrelationships and hence the trophic status of the lake."

Lake Water Quality Summary

	Trophic Status	Lake Grades									
	2009	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
Total Phosphorus (mg/l)	Mesotrophic	A	B	C	D						
Chlorophyll-*a* (ug/l)	Mesotrophic	A	C	A	C						
Secchi depth (ft)	Mesotrophic	C	C	C	C						
Overall	Mesotrophic	B+	B-	B-	C						

CONCLUSION

The Little Comfort Lake watershed comprises 4,410 acres (14% of CLFLWD) starting at the Bone Lake Outlet. This area includes three named lakes and their watersheds: Nielson Lake, School Lake and Birch Lake (described in previous sections).

The portion of Little Comfort Lake watershed downstream of School Lake encompasses 1,740 acres (6% of CLFLWD). The tributary land use is wetlands (25%), cropland (21%), grassland (21%) and forest (17%). There are two main inlets to Little Comfort Lake; one that receives flows from School Lake, and another one entering Little Comfort Lake along the southern shore (LCL48).

The watershed drains by way of naturally meandering channels (through LCL04, LCL07 and LCL03) from School Lake (over a beaver dam north of a sand and gravel operation) through forest buffered wetlands and through a couple of culverts under road crossings into Little Comfort Lake. The watershed, upland of wetlands and woods, is mostly grassland and cropland with very few residences.

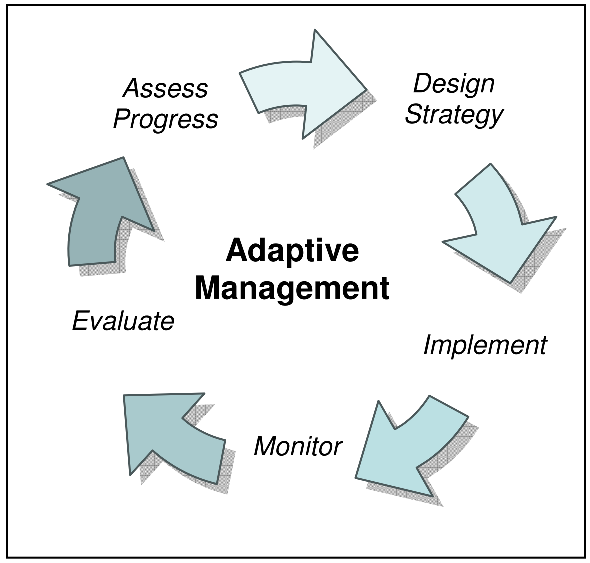
Drainage that collects along the southern shore (LCL48) of Little Comfort Lake is from two drainages. The south drainage originates in a wetland complex at the watershed divide with Forest Lake (LCL47) and drains north to Little Comfort Lake. East of this drainage route is developing residential, while to the west of this drainage route remains cropland. The southwest drainage also originates in a wetland at the watershed divide with Forest Lake (LCL44) and watershed divide with Sunrise River. It drains toward Little Comfort Lake through cropland, by way of the watershed's remaining wetlands.

Ultimately, by reducing the nutrient load to Little Comfort Lake, it will result in the lake continuing to meet its short-term and long-term goals and will result in load reductions to water resources downstream (i.e. Comfort Lake [listed as impaired for excessive nutrients by the MPCA] and the St. Croix River).

Ultimately, by reducing the nutrient load to Little Comfort Lake, it will result in the lake continuing to meet its short-term and long-term goals and will result in load reductions to water resources downstream (i.e. Comfort Lake [listed as impaired for excessive nutrients by the MPCA] and the St. Croix River).

Remedial Alternatives
The District emphasizes adaptive management principles supported by sound scientific technologies and methods to develop uniform, fiscally responsible and integrated approaches to water management in an ongoing effort to protect and improve the District's water resources. In addition, the District stresses education and outreach to increase the awareness of Stakeholders as to water resource issues and their roles in protecting and improving the quality of our water resources

Adaptive management is an iterative approach of implementation, evaluation, and course correction. While nutrient load reductions and eventual lake responses to District projects have been modeled, actual results are difficult to predict. Further, future conditions and technological advances may alter the specific course of actions detailed in the District's Capital Improvement Plan (CIP). Therefore, continued monitoring and course corrections responding to monitoring results offer the best opportunity for meeting the various management goals. Through adaptive management the success of, and in-lake response to, Best Management Practices (BMPs) and capital improvement projects can be determined.



To evaluate the possible means to reduce nutrient loads within the Little Comfort Lake watershed, between the outlet of Bone Lake and the inlet of Little Comfort Lake, two potential capital projects were identified; Birch Lake Wetland Restoration and the School Lake Outlet Structure and Wetland Restoration projects. The following section provides narrative, expected load reductions, costs, and preliminary design drawings with supporting information. Due to results from the 2008 and 2009 tributary monitoring, the highest loading seems to come between the School Lake outlet and Little Comfort Lake Inlet, as opposed to between Birch Lake and School Lake. Therefore, findings from this report point toward the School Lake outlet and wetland restoration project as being the project that should be undertaken first and the need for the Birch Lake Wetland Restoration project will be determined through the District's ongoing baseline monitoring program as part of the District's ongoing support of adaptive management approaches to the management of its water resources.

School Lake Outlet Structure and Wetland Restoration

Monitoring conducted at the main inlet to Little Comfort Lake has shown significantly higher loading than would be predicted from the School Lake phosphorus concentration and loading from the intervening subwatersheds. The phosphorus concentrations leaving School Lake are around 60 ug/L – too low to expect common treatment options to be effective. However, the excess phosphorus load in the intervening watershed between School and Little Comfort is estimated at 200 pounds.

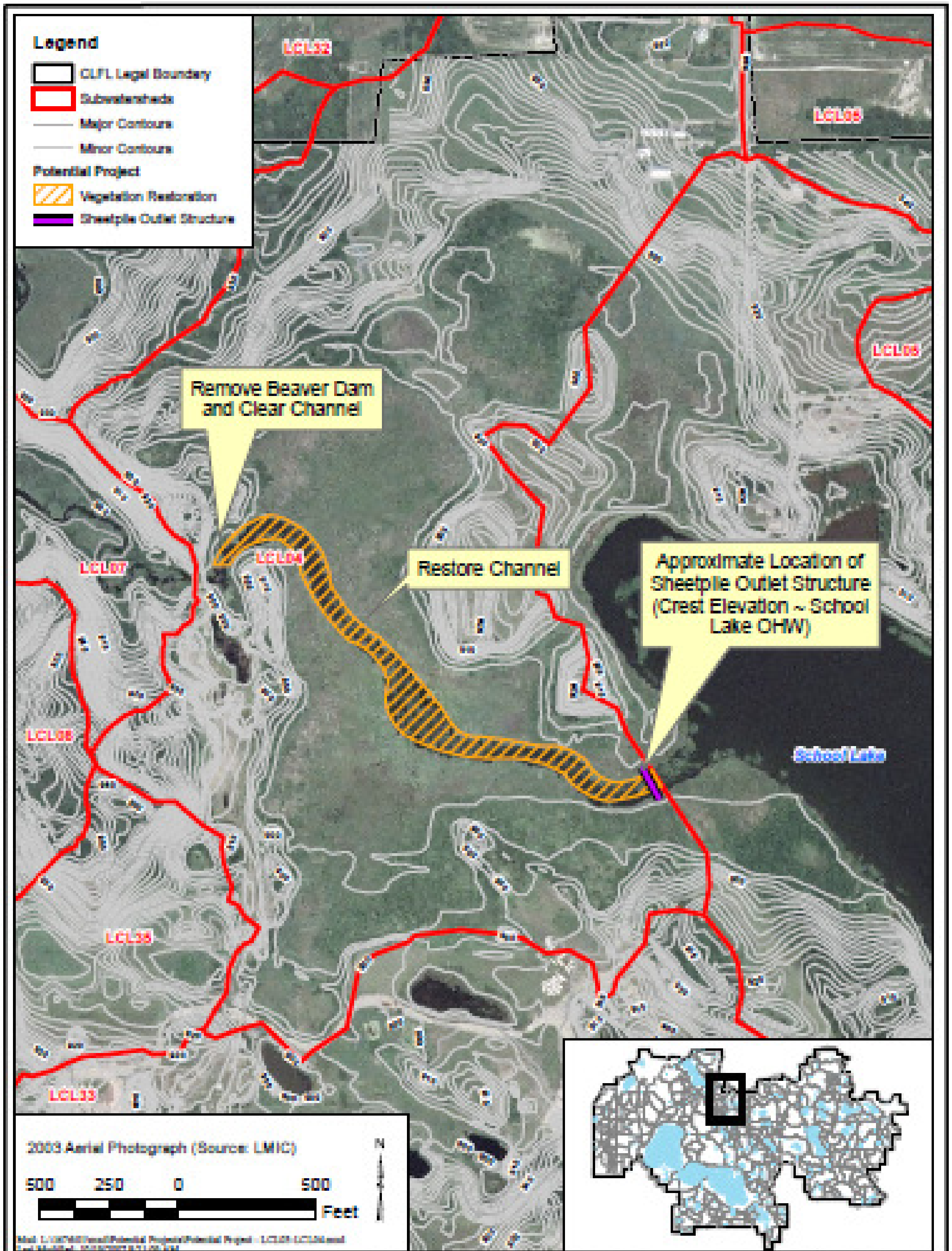
Inspection of aerial photographs indicates that the hydraulic control for the School Lake discharge is located about 2,500 feet downstream of the lake; in this reach (Subwatershed LCL04) the stream appears impounded and about 70 feet wide. Downstream from there the channel is much narrower, usually less than 10 feet wide, and follows a much more meandering and natural planform. A site inspection in September 2007 found that there is a service road crossing the stream at that location; a beaver dam with a fall of about 1.5 feet is located about 100 feet upstream. Together they are responsible for impounding this segment of stream, which flows through a large cattail wetland and is covered to a large extent by lily pads. The impoundment appears to affect phosphorus exchange along the stream, although it cannot be reasoned just what the effect might be. Given the available information, it is not possible to state what a more natural state might be for the School Lake outlet. Therefore, a series of synoptic surveys of the phosphorus concentration profile along the length of the stream is recommended to help identify phosphorus sources and sinks that may be worth treating. A geomorphic assessment of the reach between School Lake and Little Comfort Lake may also provide information necessary for properly restoring the reach to natural conditions.

For the preliminary design and cost estimate, it has been assumed that the phosphorus source is the impounded channel in the large wetland of LCL04. One hypothetical cause of loading may be the sluggish water in the channel and anoxic sediments which could release phosphorus to the overlying water, where it is transported downstream. Based on the available information and assumptions, the preliminary project concept (to be used as a placeholder until the problem can be further diagnosed) includes the following:

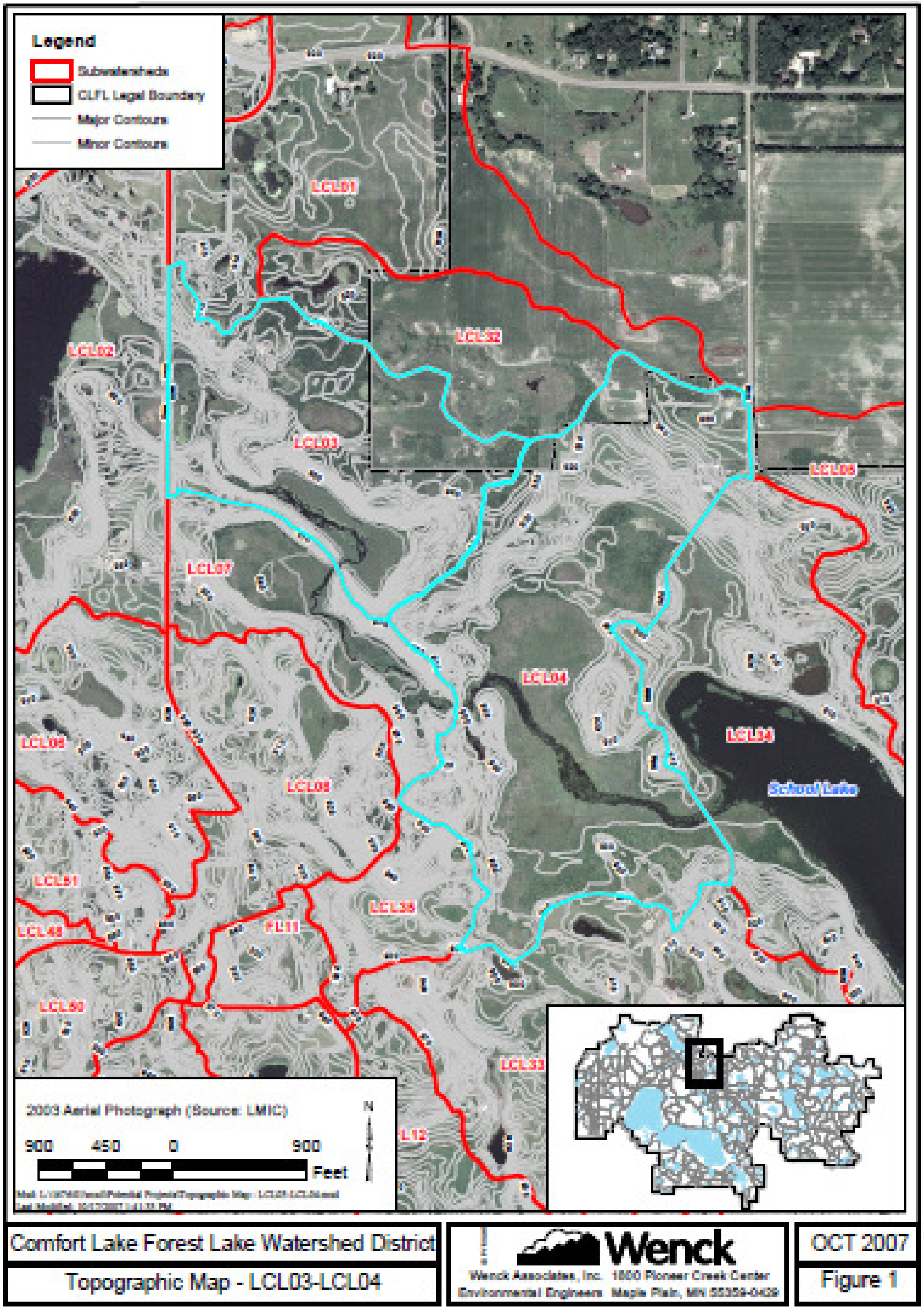
Construction of a sheet pile weir to maintain the present elevation of School Lake close to the lake.

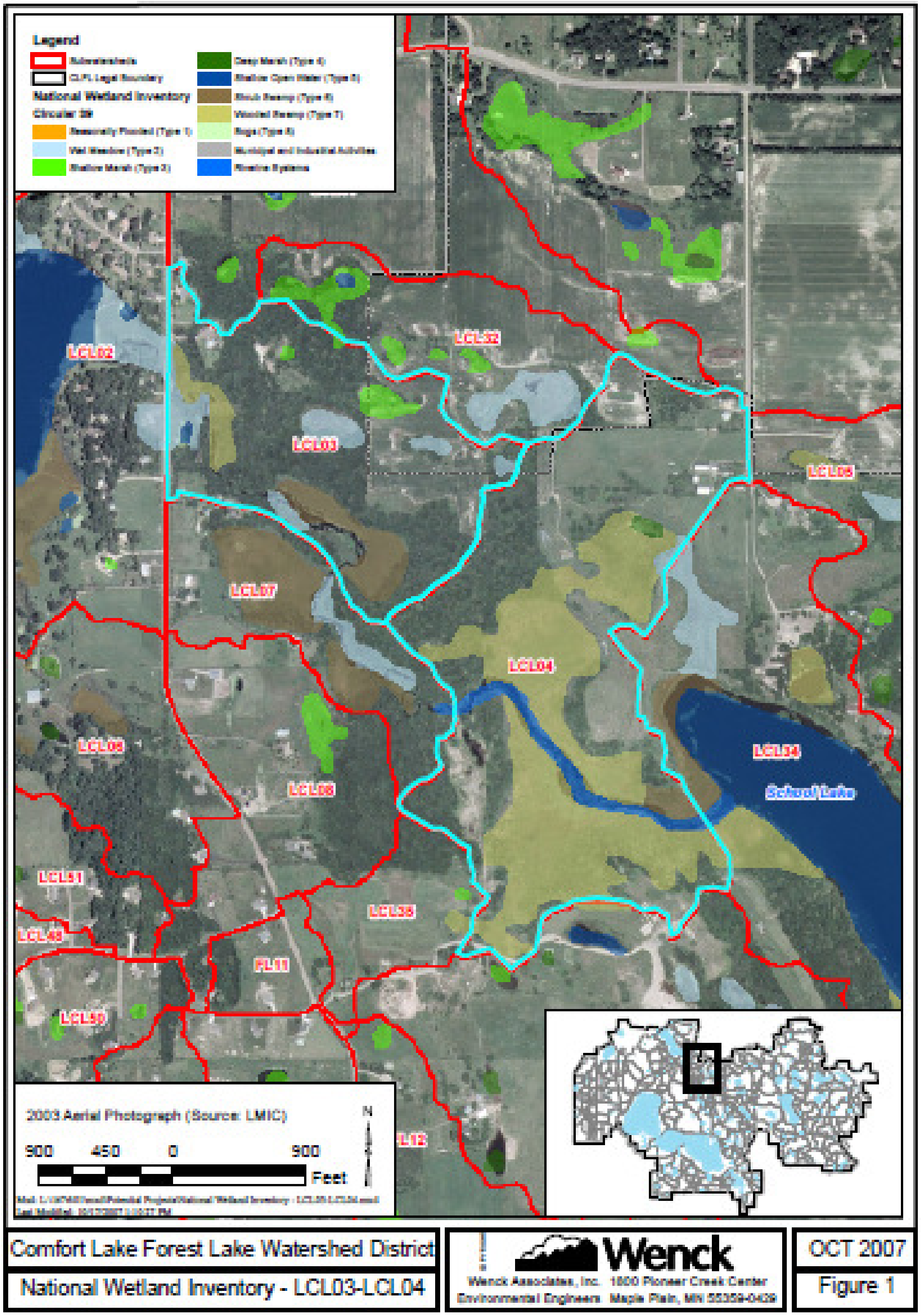
- Removal of the beaver dam and replacement of the culvert at the service road. This would allow the stream to flow freely from the lake downstream.
- The culvert would be oversized to allow its invert to be set below the stream bed and filled partly with sediment similar to that of the stream bed. This would provide continuous stream habitat substrate, but more importantly, it would allow the erosion and deposition processes to determine the stream thalweg elevation at this point, rather than having it controlled by the invert.
- Restoration of the channel between the culvert and the new School Lake outlet. The channel would be defined partly by planting vegetation that would help stabilize the new channel banks.

The targeted benefit of the project would be reduction of approximately 50 pounds of phosphorus load to Little Comfort Lake. The estimated outflow load from School Lake is 475 pounds. The outflow load from Subwatershed LCL04 is 523 pounds which is approximately 50 pounds greater than the School Lake outflow. The goal of the wetland restoration is to restore a net zero (i.e., inflow equals outflow) discharge of phosphorus, which would result in a reduction of 50 pounds of phosphorus. The estimated present-value cost for this project (including engineering, property easements, construction and operation and maintenance costs) is $290,000. The estimated annual load reduction is expected to be 50 pounds per year; with an annualized cost of $23,000 per year, the cost-effectiveness over twenty years is $460 per pound. The design concept and cost estimate are shown in following pages. Feasibility and design investigations specific to the restoration project would include the above-mentioned diagnostic investigations. The cost estimate includes a large contingency for the case that the diagnostic investigations lead to a different project type.



Comfort Lake Forest Lake Watershed District	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359-0429	OCT 2007
School Lake Outlet and Wetland Restoration		Plan


Legend
Subwatersheds
CLFL Legal Boundary
Major Contours
Minor Contours
LCL01
LCL02
LCL03
LCL32
LCL07
LCL04
LCL34
School Lake
LCL08
LCL51
FL11
LCL35
LCL33
2003 Aerial Photograph (Source: LMIC)
N
900 450 0 900
Feet
Comfort Lake Forest Lake Watershed District
Topographic Map - LCL03-LCL04
Wenck
Wenck Associates, Inc. 1800 Pioneer Creek Center
Environmental Engineers Maple Plain, MN 55359-0429
OCT 2007
Figure 1


Legend
National Wetland Inventory
LCL02
LCL32
LCL03
LCL05
LCL07
LCL04
LCL09
LCL34
School Lake
LCL08
LCL51
LCL35
LCL48
FL11
LCL50
L12
2003 Aerial Photograph (Source: LMIC)
N
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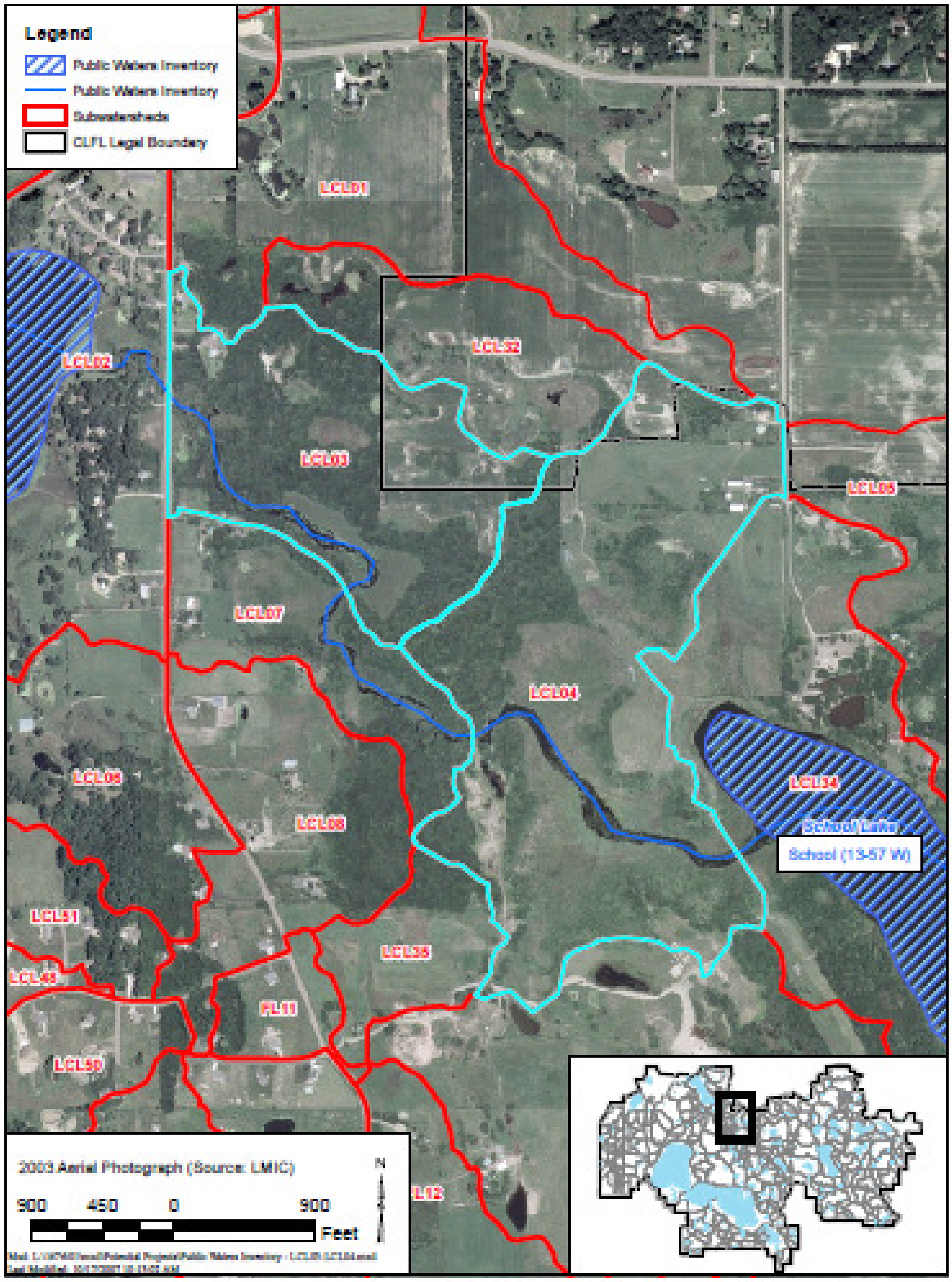
Feet
Comfort Lake Forest Lake Watershed District
National Wetland Inventory - LCL03-LCL04
Wenck
Wenck Associates, Inc. Environmental Engineers
1800 Pioneer Creek Center Maple Plain, MN 55359-0429
OCT 2007
Figure 1



Comfort Lake Forest Lake Watershed District

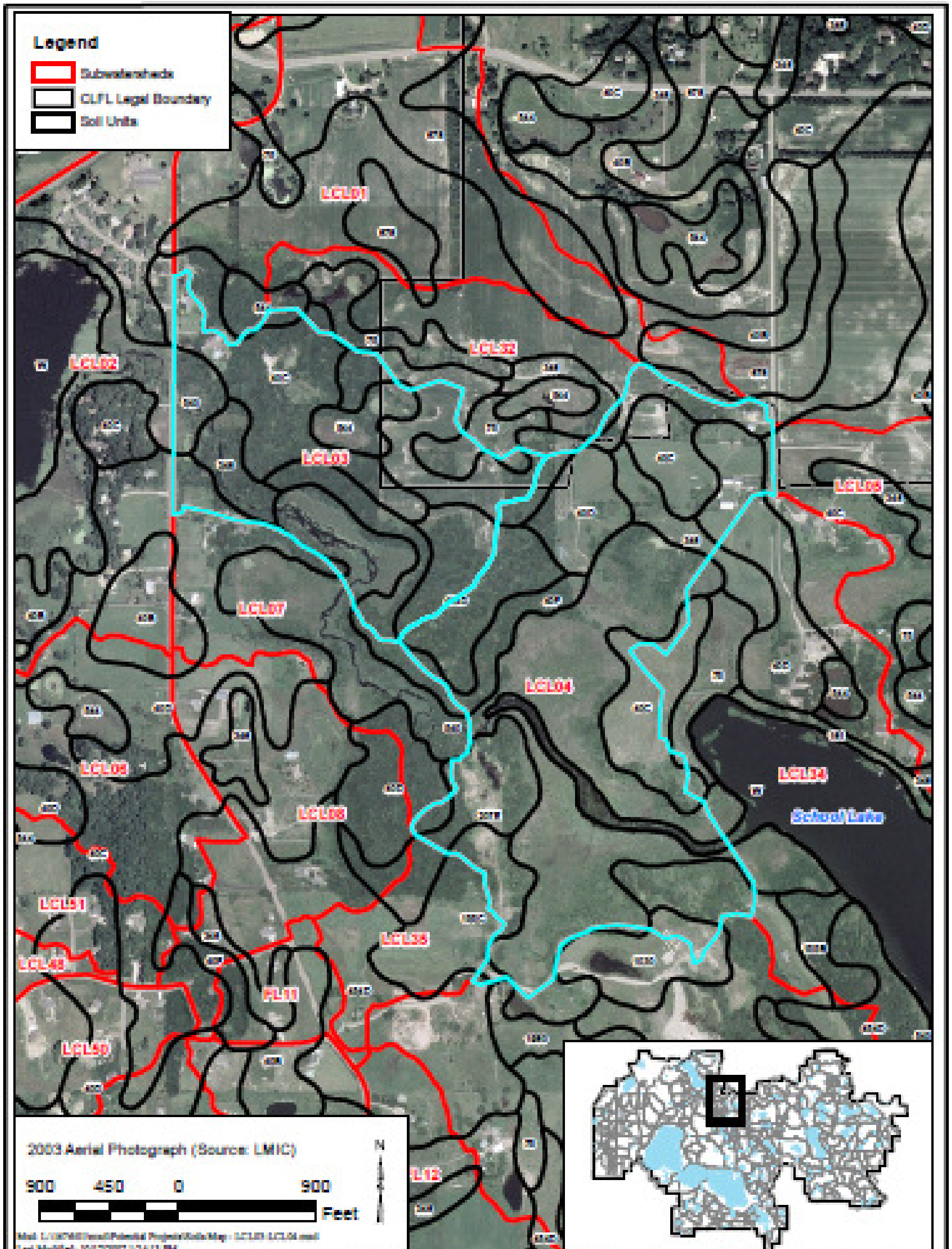
Public Waters Inventory - LCL03-LCL04

Wenck

Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359-0429

OCT 2007

Figure 1



Comfort Lake Forest Lake Watershed District

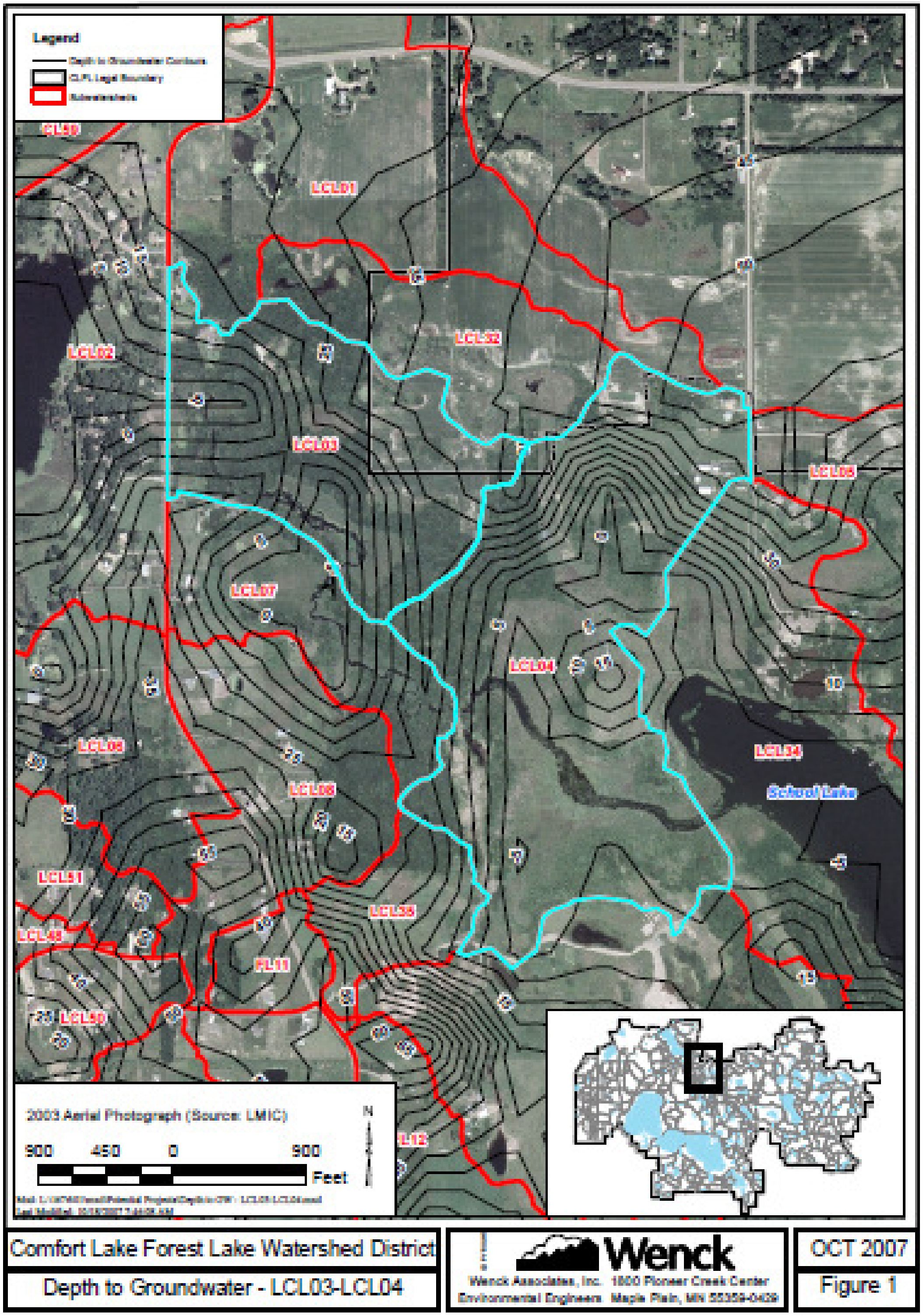
SSURGO Soils Map - LCL03-LCL04

Wenck

Wenck Associates, Inc. 1800 Pioneer Creek Center
Environmental Engineers Maple Plain, MN 55359-0429

OCT 2007

Figure 1


Legend
LCL01
LCL32
LCL02
LCL03
LCL05
LCL07
LCL04
LCL34
School Lake
LCL06
LCL08
LCL51
LCL35
FL11
LCL50
2003 Aerial Photograph (Source: LMIC)
900 450 0 900
Feet
Comfort Lake Forest Lake Watershed District
Depth to Groundwater - LCL03-LCL04
Wenck
Wenck Associates, Inc. Environmental Engineers
1800 Pioneer Creek Center Maple Plain, MN 55359-0429
OCT 2007
Figure 1

Alternative:	School Lake Outlet Structure and Wetland Restoration	LCL04		
Item	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Investment Cost Estimate				
Sheet Pile Weir (30' x 170')	5100	sq. feet	$ 15	$ 76,500
Beaver Dam Removal	1	Lump Sum	$ 2,000	$ 2,000
Site Restoration	4	acre	$ 5,500	$ 22,000
				$ -
				$ -
				$ -
				$ -
Mobilization/Demobilization	1	Lump Sum	$ 20,000	$ 20,000
Contingencies	1	ea.	20%	$ 24,100
Subtotal, Construction	--	--	--	$ 144,600
Engineering, Legal, Admin.	1	ea.	35%	$ 50,610
Land, Easements	4	acre	$ 20,000	$ 80,000
Total Investment Cost				$ 280,000
Annual Operating Cost				
Staff operational time	16	person hours	$ 50	$ 800
				$ -
				$ -
Annual operation costs				$ 800
Overhaul Cost at 20 years				
				$ -
				$ -
				$ -
Total replacement costs				$ -
Project Present Value				
Investment Cost				$ 280,000
Economic life	20	yr.		
Replacement occurs at	20	yr.		
Discount rate	5.0%			
Present Value of Annual Costs				$ 9,970
Present Value of Maintenance & Replacement				$ -
Total Present Value				$ 290,000
Project Annual Cost				
Annual cost (annuity)				$ 23,000

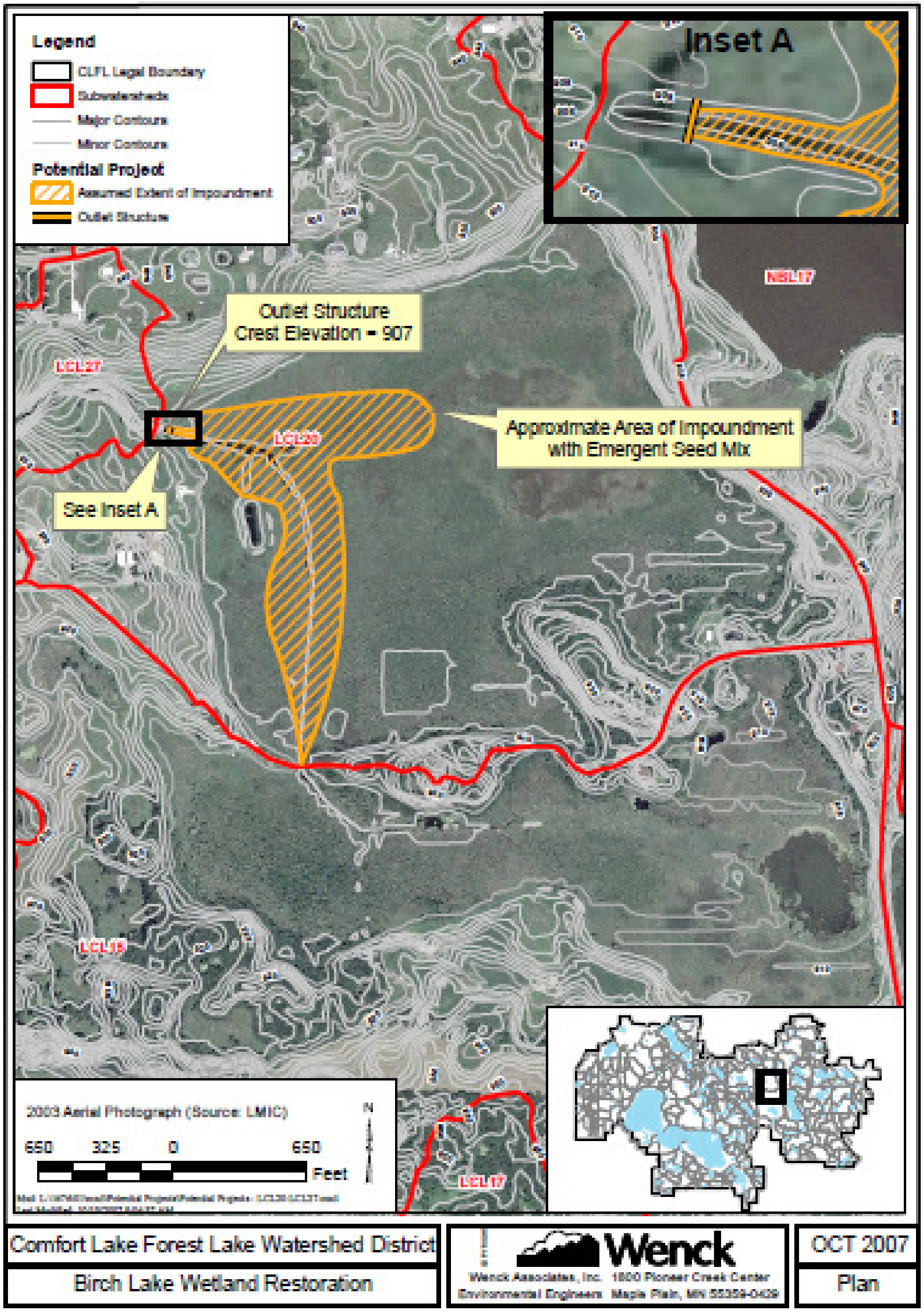
Birch Lake Wetland Restoration

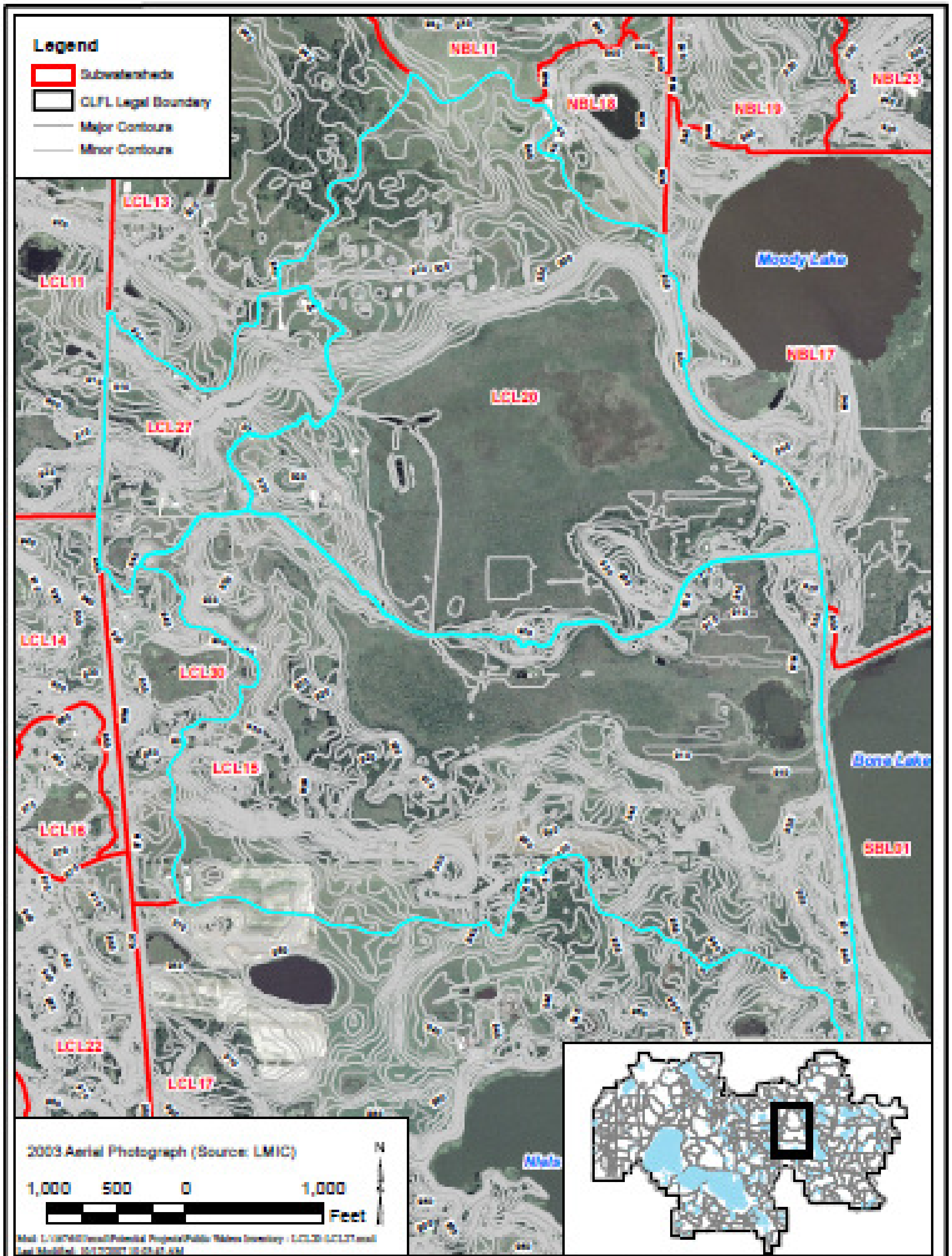
The watershed and lake response model indicates that the 60% of the load to Birch Lake is from Bone Lake (254 pounds) and 40% is from the intervening watersheds (150 pounds). The concentrations are around 60 to 80 ug/L, too low to expect common treatment options to be effective. However, the phosphorus concentration in Birch Lake is about twice that in Bone Lake, substantially higher than anticipated based on the external load. Therefore, the model was used to estimate that there is an excess load of about 250 pounds from the contributing watershed between Bone and Birch or from within Birch Lake itself. The Birch Lake internal load, as described in the District's watershed wide-load allocation modeling effort included in Appendix A; but because the flow is almost entirely within channelized wetlands, the wetlands are suspected of causing the increased loading and a wetland restoration was recommended. The excess load must be confirmed through special studies of this stream reach before a project can be planned. These investigations should be designed to identify sources, and if possible, identify causes of the increased loading. The study should also verify that internal loading in Birch Lake is not the source.

For the preliminary design and cost estimate, it has been assumed that the source of the excess phosphorus loading is the large wetland (125 acres at El. 908) in Subwatershed LCL20. One hypothetical cause of loading may be the alternating flooding, draining and drying of the wetland sediments. Under dry conditions, oxidation can lead to release of phosphorus bound in organic wetland soils, then flooding bring the water in contact with the released phosphorus, and subsequent natural draining of the wetland would transport the phosphorus downstream. Based on the available information, the preliminary project design (to be used as a placeholder until the problem can be further diagnosed) includes the following:

- Construction of a sheet pile weir at El. 907 to maintain wetted soils in the wetland for a longer period of the year, limiting water exchange with the wetland as well as the associated phosphorus transport.
- Such a project is often referred to as restoring the hydroperiod of the wetland. On the basis of the existing topography, the weir is not expected to cause increased open water or impounding, but merely increase the depth in the ditches cut through the channels.

The benefit of the project would be reduction of the 130-pound phosphorus load to Birch Lake and reduction of downstream loading to School Lake. The estimated outflow load from Bone Lake is 254 pounds. The outflow load from Subwatershed LCL20 is 385 pounds which is 130 pounds greater than the Bone Lake outflow. The goal of the wetland restoration is to restore a net zero (i.e., inflow equals outflow) discharge of phosphorus, which would result in a reduction of 130 pounds of phosphorus. The estimated present-value cost for this project (including engineering, property easements, construction and operation and maintenance costs) is $650,000. The estimated annual load reduction is expected to be 130 pounds per year; with an annualized cost of $52,000 per year, the cost-effectiveness over twenty years is $400 per pound. Details of the design and cost estimate are included in the following pages. Feasibility and design investigations specific to the wetland restoration would include the above-mentioned diagnostic investigations. The cost estimate includes a large contingency for the case that the diagnostic investigations lead to a different project type.


Inset A
Legend
CLFL Legal Boundary
Subwatersheds
Major Contours
Minor Contours
Potential Project
Assumed Extent of Impoundment
Outlet Structure
Outlet Structure
Crest Elevation = 907
LCL27
LCL20
NBL17
Approximate Area of Impoundment
with Emergent Seed Mix
See Inset A
LCL18
LCL17
2003 Aerial Photograph (Source: LMIC)
660 325 0 660
Feet
N
Comfort Lake Forest Lake Watershed District
Birch Lake Wetland Restoration
Wenck
Wenck Associates, Inc. 1800 Pioneer Creek Center
Environmental Engineers Maple Plain, MN 55359-0429
OCT 2007
Plan



Comfort Lake Forest Lake Watershed District

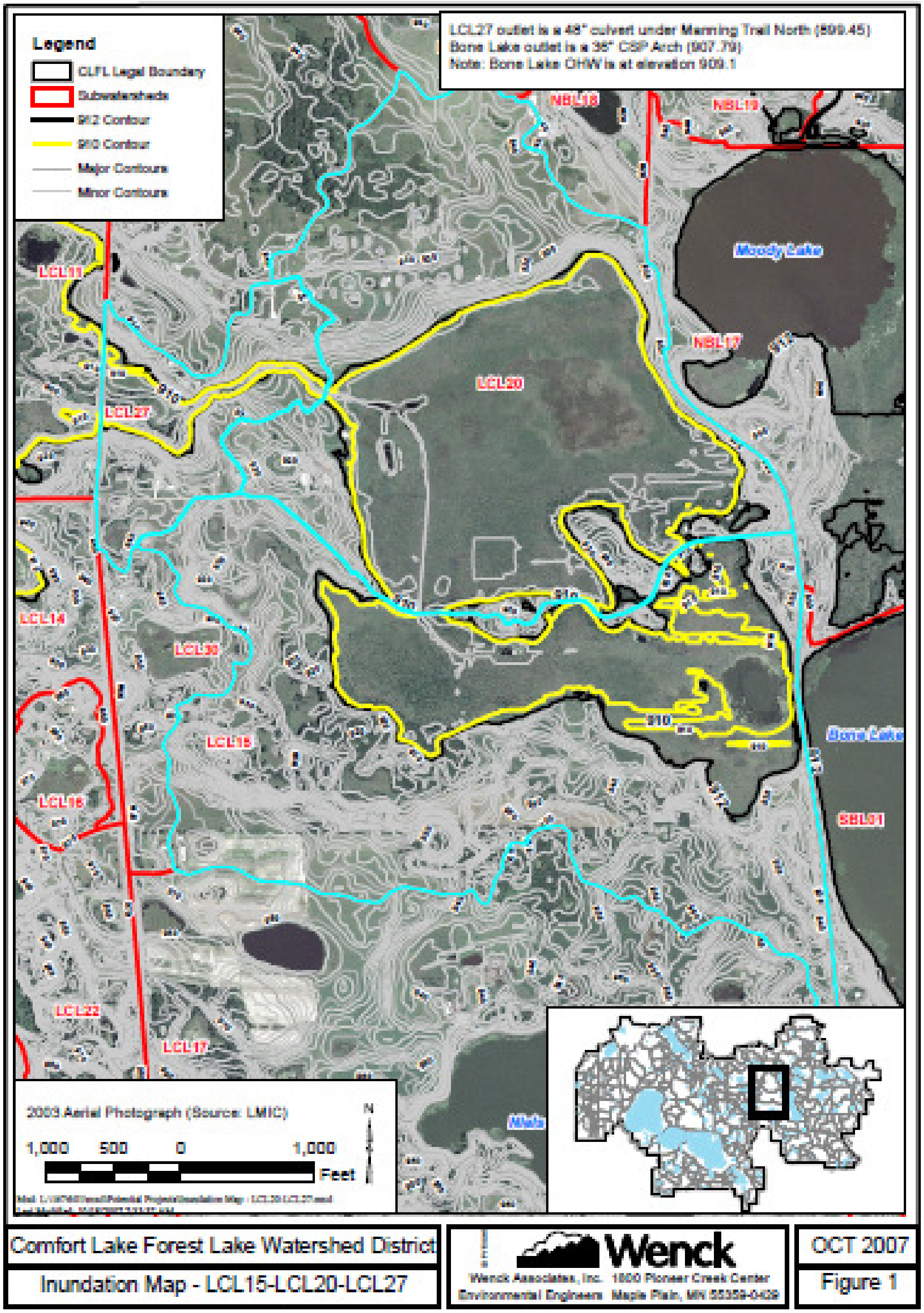
Topographic Map - LCL15-LCL20-LCL27

Wenck

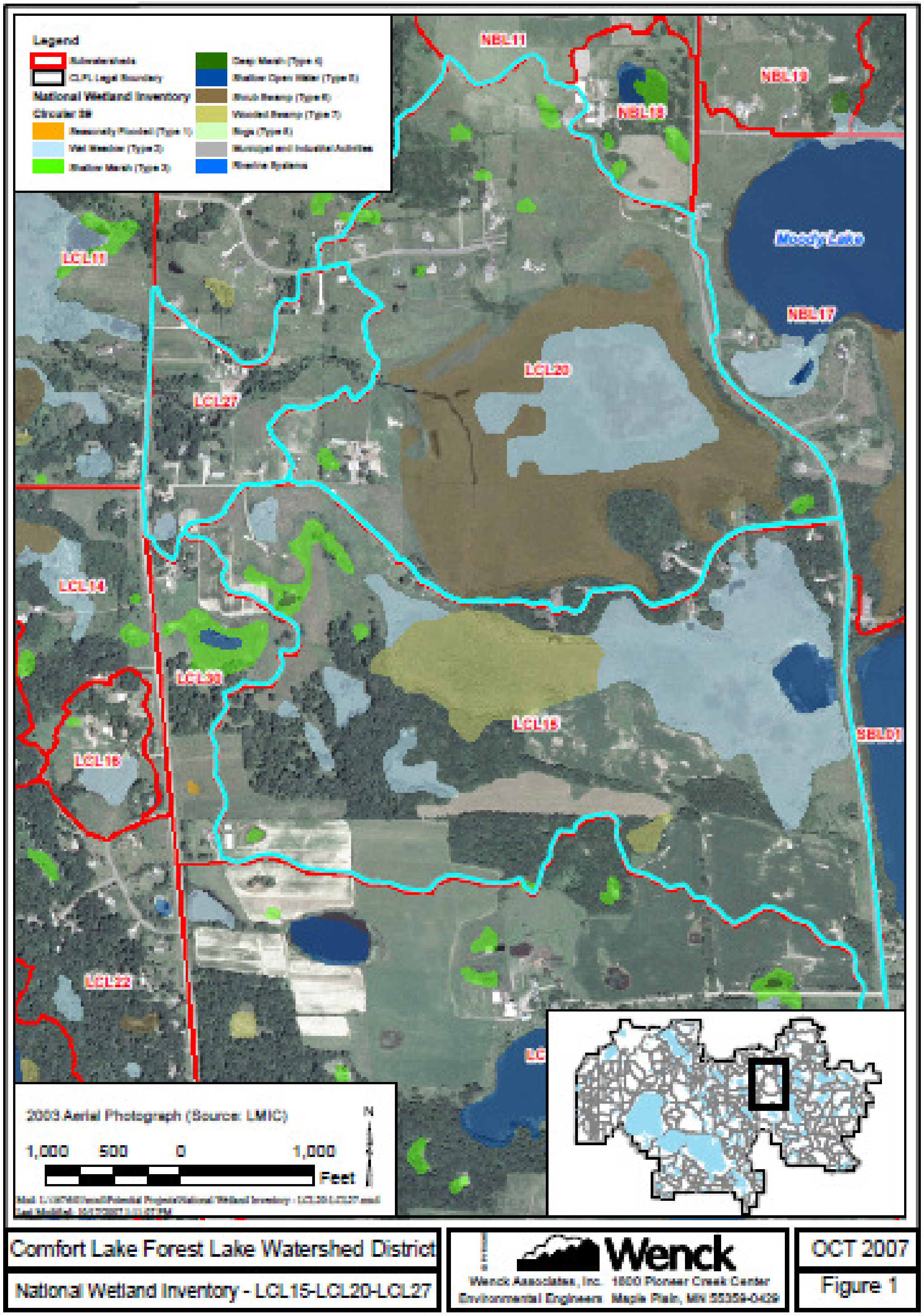
Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359-0429

OCT 2007

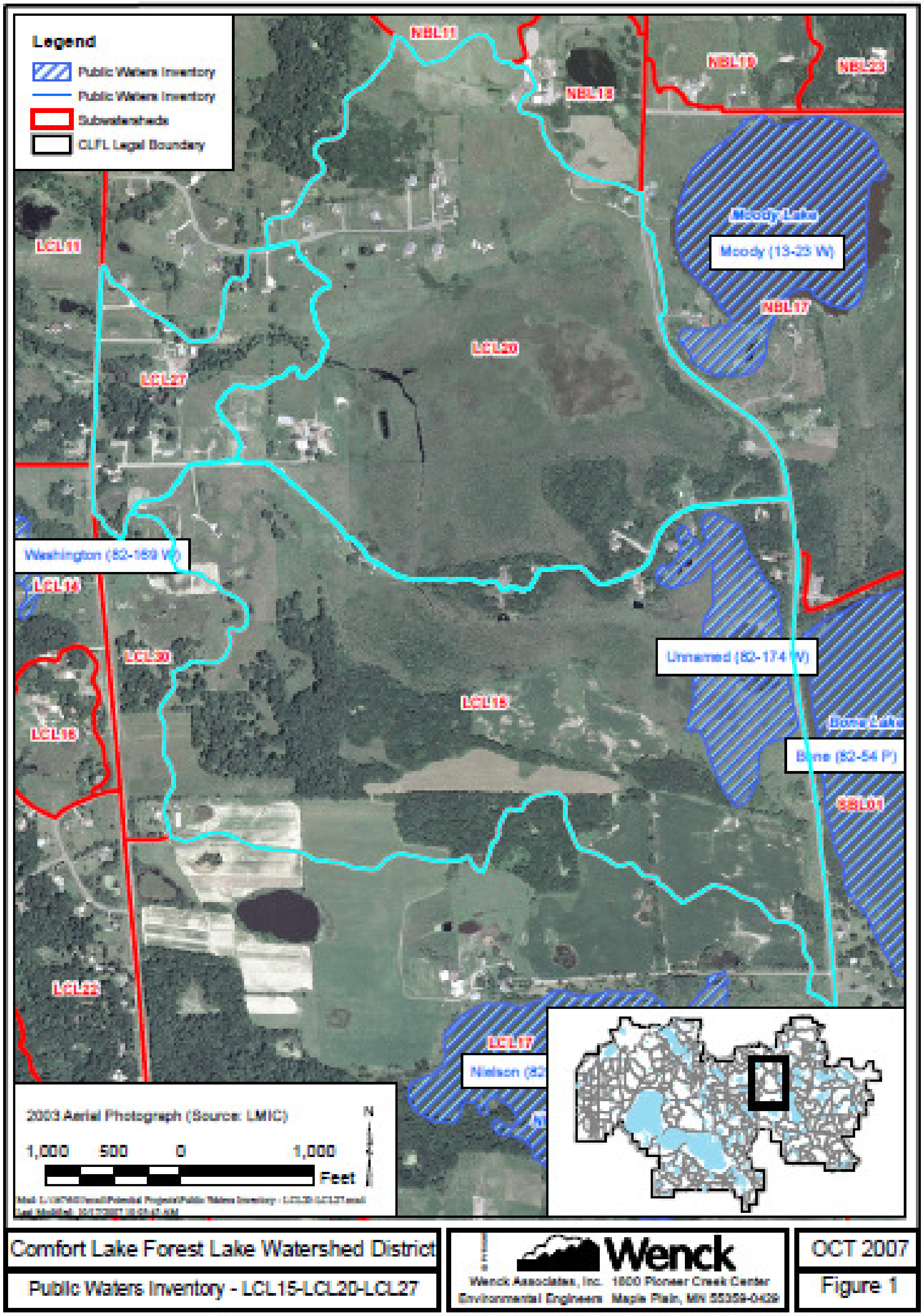
Figure 1



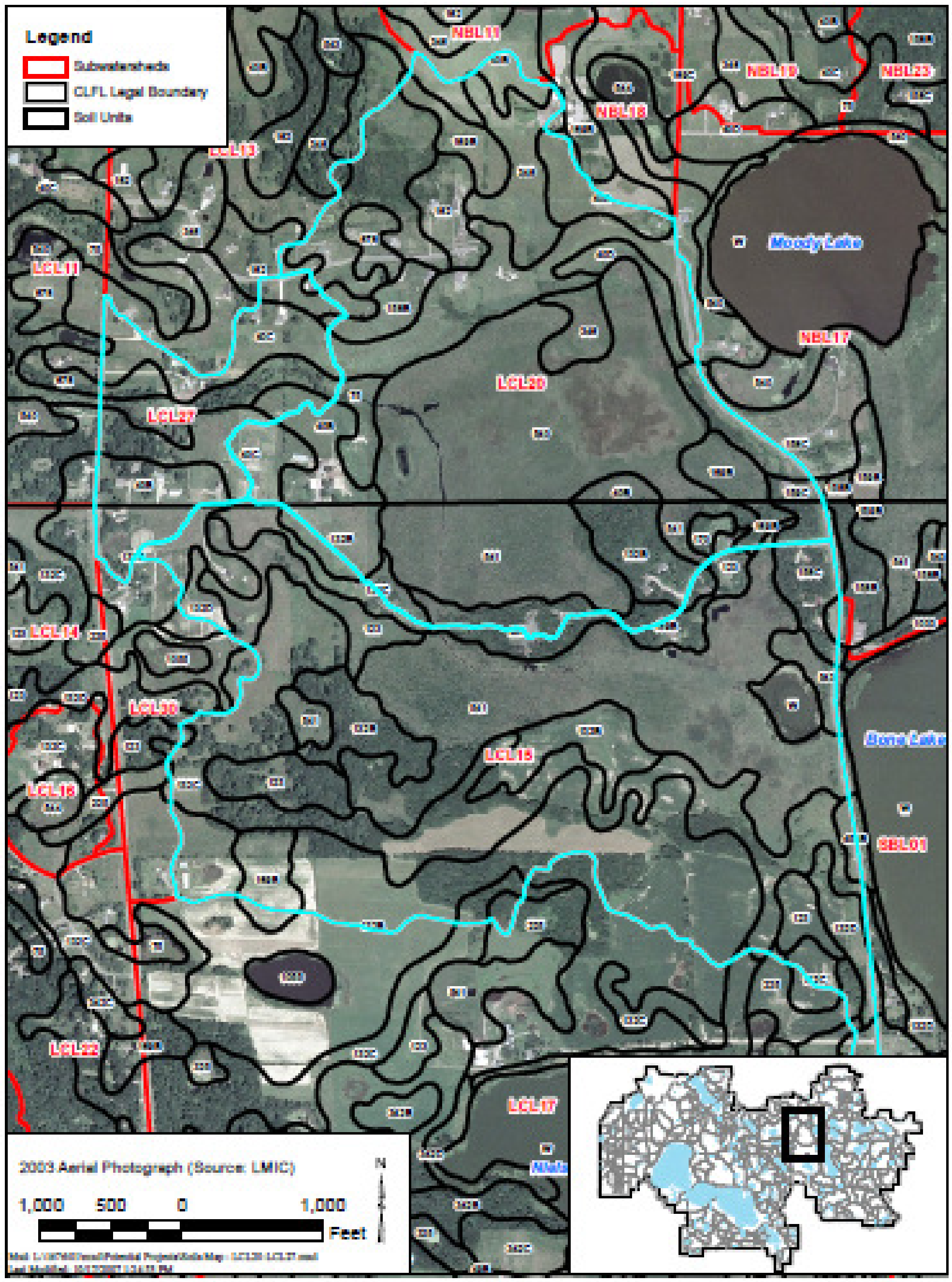
LCL27 outlet is a 48" culvert under Manning Trail North (899.45)
Bone Lake outlet is a 36" CSP Arch (907.79)
Note: Bone Lake OHW is at elevation 909.1
Legend
CLFL Legal Boundary
Subwatersheds
912 Contour
910 Contour
Major Contours
Minor Contours
NBL18
NBL19
Moody Lake
NBL17
LCL11
LCL27
LCL20
LCL14
LCL30
LCL15
LCL16
Bone Lake
SBL01
LCL22
LCL17
2003 Aerial Photograph (Source: LMIC)
1,000 500 0 1,000
Feet
N
Comfort Lake Forest Lake Watershed District
Inundation Map - LCL15-LCL20-LCL27
Wenck
Wenck Associates, Inc. 1800 Pioneer Creek Center
Environmental Engineers Maple Plain, MN 55359-0429
OCT 2007
Figure 1



Legend
National Wetland Inventory
NBL11
NBL18
NBL19
Moody Lake
NBL17
LCL11
LCL20
LCL27
LCL14
LCL30
LCL15
LCL16
SBL01
LCL22
2003 Aerial Photograph (Source: LMIC)
N
1,000 500 0 1,000
Feet
Comfort Lake Forest Lake Watershed District
National Wetland Inventory - LCL15-LCL20-LCL27
Wenck
Wenck Associates, Inc. 1800 Pioneer Creek Center
Environmental Engineers Maple Plain, MN 55359-0429
OCT 2007
Figure 1



Legend
Public Waters Inventory
Public Waters Inventory
Subwatersheds
CLFL Legal Boundary
NBL11
NBL19
NBL23
NBL18
Moody Lake
Moody (13-23 W)
NBL17
LCL11
LCL20
LCL27
Washington (82-169 W)
LCL14
LCL30
Unnamed (82-174 W)
LCL15
LCL16
Bone Lake
Bone (82-54 P)
SBL01
LCL22
LCL17
2003 Aerial Photograph (Source: LMIC)
1,000 500 0 1,000
Feet
N
Comfort Lake Forest Lake Watershed District
Public Waters Inventory - LCL15-LCL20-LCL27
Wenck
Wenck Associates, Inc. 1800 Pioneer Creek Center
Environmental Engineers Maple Plain, MN 55359-0429
OCT 2007
Figure 1



Comfort Lake Forest Lake Watershed District

SSURGO Soils Map - LCL15-LCL20-LCL27

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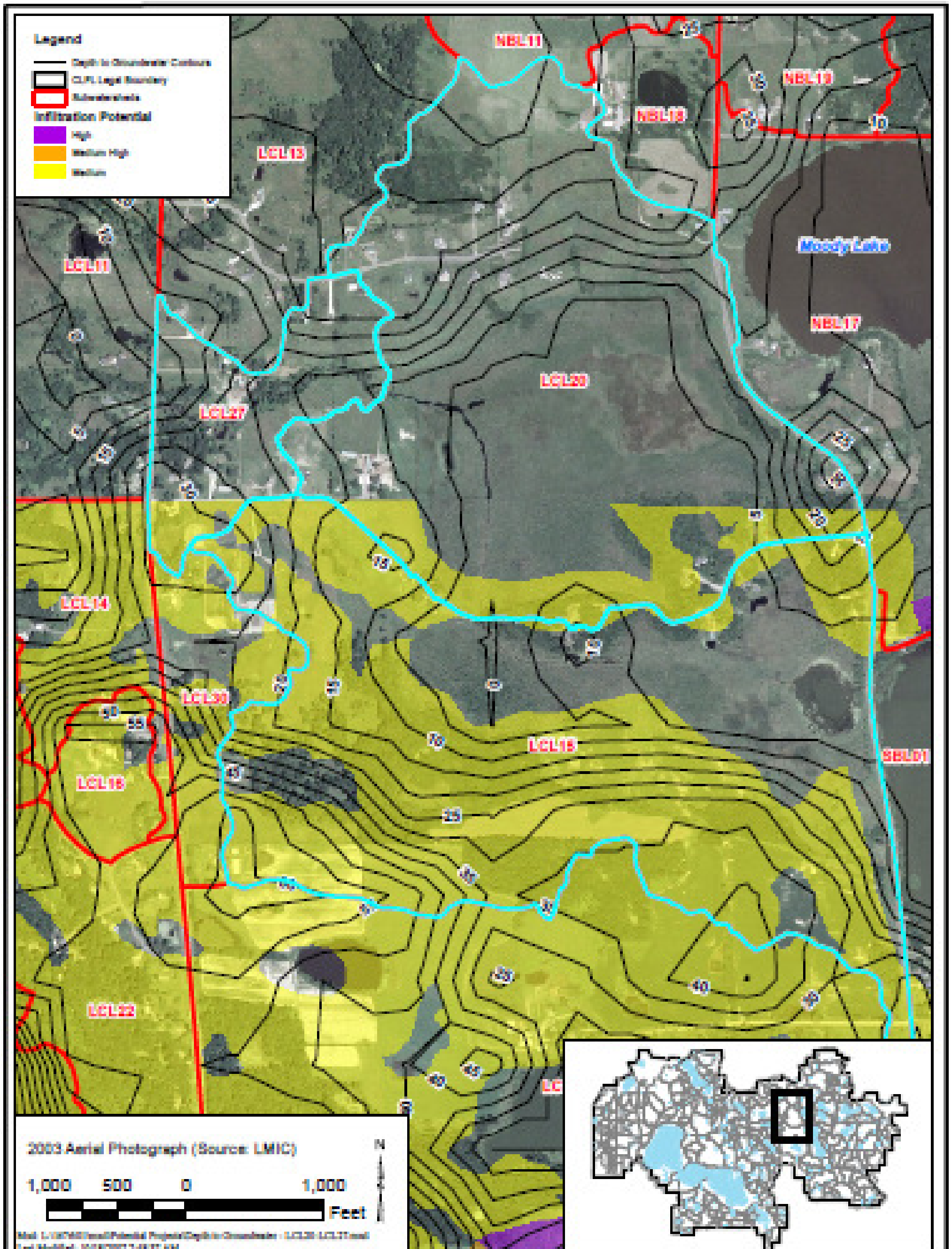
Environmental Engineers Maple Plain, MN 55359-0429

OCT 2007

Figure 1



Comfort Lake Forest Lake Watershed District

Depth to Groundwater - LCL15-LCL20-LCL27

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OCT 2007

Figure 1

Best Management Projects
In addition to the above referenced projects, landowner education encouraging appreciation and stewardship of the referenced wetlands and the installation of localized best management practices (BMPs) is recommended to supplement the load reduction efforts planned through the School Lake outlet structure and wetland restoration and Birch Lake wetland restoration projects. The education efforts could focus on the benefits and functions of area wetlands, their unique characteristics, and could be completed through targeted education sessions, neighborhood meetings, door to door discussions with landowners or other methods.

Recommended BMPs for residential properties include raingardens, vegetated swales, and biofiltration/bioretention areas as well as practices such as rain barrels and the redirection of roof downspouts to vegetated areas. These practices are recommended for residential sites because they are aesthetically pleasing additions to a residential yard or are simple modifications to the management of roof runoff.

The BMPs recommended for roadways include porous pavement, vegetated swales, raingardens, biofiltration/bioretention areas, and filtration. These practices are recommended for roadway sites because they can be adapted to a linear arrangement within the road right-of-way.

The installation of local best management practices to protect the quality of could include the targeted implementation of projects by CLFLWD, through the existing cost-share program where feasible, such as:

- biofiltration or other suitable feature (s) to capture runoff from area roads (i.e. July Avenue and Manning Trail) treat it prior to discharge to the wetlands and Birch and School lakes
- best management projects in cooperation with road authorities where roads currently drain untreated to the wetland
- working with specific landowners to increase buffer areas where there are currently smaller buffers
- working with specific landowners who have structures or compost in the wetland to relocate those features

In addition to the residential and roadway BMPs discussed above, lakeshore and agricultural BMPs are also important;

The BMPs recommended for agricultural areas include:

- conservation tillage to reduce soil and nutrient runoff to water resources
- buffers, vegetated swales , and rock inlets to protect streams and lakes from sediment and nutrients contained in agricultural runoff
- livestock and manure management to reduce animal impacts to streams and nutrient loading to lakes

The BMPs recommended for lakeshore properties include:

- lakeshore septic improvements to reduce the number of failing septic systems and reduce nutrient loads
- shoreline restoration to improve shoreline habitat and reduce erosion
- the establishment and preservation of native vegetative buffers to promote filtration and shoreline stabilization

Recommendations
Based on the findings of this study it is recommended that the CLFLWD:

Continue District's baseline monitoring program ongoing monitoring of the Little Comfort Lake Watershed water quality and outflow in order to:

- Review and calibrate the District's water quality model for the watershed
- Evaluate the impact of the project(s) undertaken in an adaptive management approach in order to determine effectiveness of project(s) and to determine additional needs to meet downstream goals.

Complete in the Little Comfort Lake Watershed:
Continuously promote localized BMPs by leveraging and targeting the CLFLWD cost-share program toward projects or by designing and installing projects that will:

- Increase the width and quality of wetland buffers
- Look for opportunities for partnerships to construct water quality treatment BMPs for roadways and developed areas that discharge to the Birch Lake and School Lake wetland with no current treatment
- Undertake the School Lake Outlet Structure and Wetland Restoration Project (prior to Birch Lake Wetland Restoration project)
- If it is determined that further phosphorus reduction is needed after the evaluation of the completed School Lake Outlet and Wetland Restoration Project, undertake the Birch Lake Wetland Restoration project.

REFERENCES

Comfort Lake - Forest Lake Watershed District. 2005. Hydraulic Capacity and Model Calibration Report. Prepared by SRF Consulting Group, Inc.

Comfort Lake - Forest Lake Watershed District. 2007. Watershed and Lake Water Quality Modeling Investigation for the Development of a Watershed Capital Improvement Plan. Prepared by Wenck Associates, Inc.

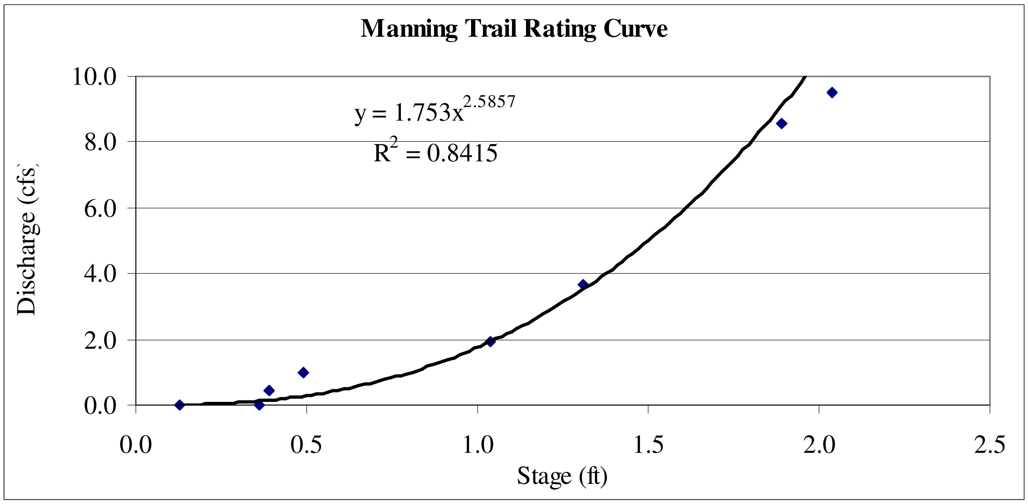
Washington Conservation District. 2009. Comfort Lake – Forest Lake Watershed District Water Monitorint Report. Prepared for the Comfort Lake – Forest Lake Watershed District.

APPENDIX

APPENDIX A
Tributary Rating Curves

Manning Trail

Stage	Discharge (cfs)
2.04	9.517
1.89	8.548
1.31	3.673
1.04	1.924
0.36	0.013
0.39	0.455
0.49	0.966
0.13	0.010

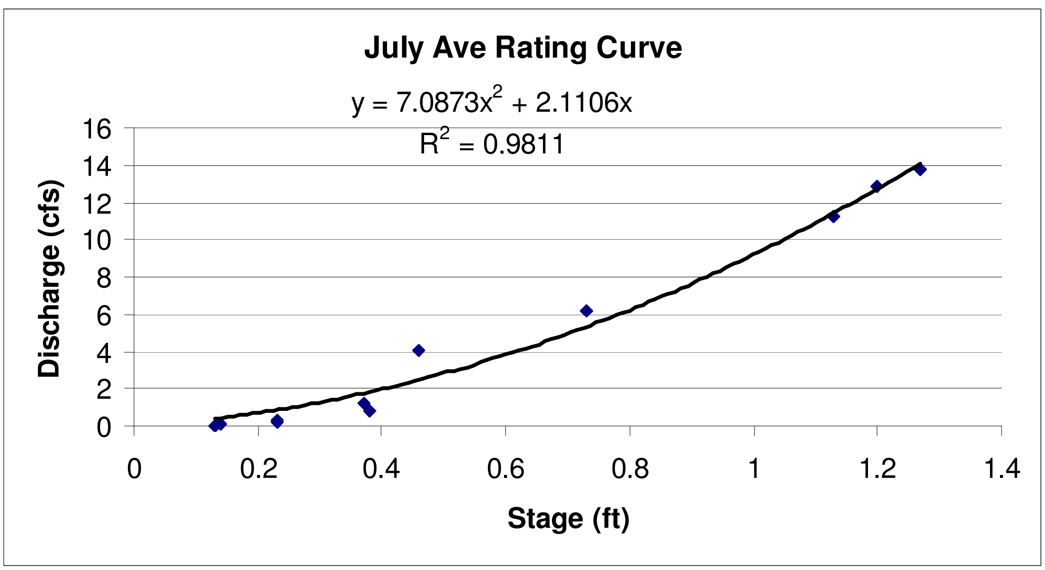


Manning Trail Rating Curve

Equation used to determine wetted area of the pipe when an area-velocity relationship was used to calculate discharge (5/19/09 – 7/10/09, x=stage): A=0.0075*(x^4)-0.2867*(x^3)+1.5206*(x^2)+1.1906*x

July Avenue

Stage	Discharge (cfs)
1.2	12.888
1.27	13.791
1.13	11.283
0.73	6.171
0.46	4.07
0.23	0.27
0.23	0.23
0.13	0.03
0.38	0.786
0.37	1.24
0.14	0.11



July Avenue Rating Curve

Little Comfort Rating Curve

An area-velocity relationship was used at this site to calculate discharge (4/9/09 – 11/2/09, x=stage): $A=0.3462*(x^5)-2.4773*(x^4)+7.1474*(x^3)-9.5605*(x^2)+18.65207*x$

APPENDIX B

Little Comfort Lake Watershed Modeling Results from District's 2007 Load Allocation Modeling Study (CLFLWD 2007)

INTRODUCTION

Comfort Lake – Forest Lake Watershed District

The Comfort Lake – Forest Lake Watershed District (CLFLWD, the District) covers approximately 48 square miles in Washington and Chisago Counties. The outlet from Forest Lake forms the headwaters of the Sunrise River, which in turn flows through Comfort Lake, the outlet for the District. From there, the Sunrise River flows north and joins the St. Croix River.

The District was formed in 1999, taking the place of the Forest Lake Watershed Management Organization (FLWMO) and expanding in area to include all tributaries to Comfort Lake, as well as the landlocked basins of First and Second Lake. The District completed its first Watershed Management Plan in 2001. The plan included the following mission statement:

> *"The mission of the Comfort Lake – Forest Lake Watershed District is to protect and conserve it water resources. The District will use sound scientific water management approaches, technologies and methods. The District will develop a uniform, integrated approach to water management within a rapidly changing and urbanizing area."*

In the plan, the CLFLWD designated its 49 lakes as either recreational or non-recreational lakes; the six recreational lakes, which have become the focus of water quality management, include:

- Bone Lake;
- Little Comfort Lake;
- Sylvan Lake;
- Shields Lake;
- Forest Lake; and
- Comfort Lake

Need for Study

Interest in improvement of the lakes has been evident for a number of years. The first studies of phosphorus loading in the District date back to the 1970s. MPCA's draft 2008 303d list of impaired waters includes Moody, Bone, School, Shields, and Comfort Lakes as being impaired for excess nutrients and Forest Lake as being impaired for PCBs in fish tissue. Even though Birch Lake's water quality does not meet the State water quality standard criteria, Birch Lake was not listed because (based on factors MPCA uses to determine if a waterbody is a lake or wetland) the MPCA classifies Birch Lake as a wetland as opposed to a lake.

The 2001 Watershed Management Plan identified a need for projects and programs to protect and improve the District's recreational lakes. The District's growing season average total phosphorus goal is 30 ug/L for its designated recreational lakes. The Plan also identified data and studies that would be needed for comprehensive and uniform approach to management. Since then, the District has undertaken the following activities aimed at development of a comprehensive capital improvement plan:

- The District initiated a long-term hydrologic and water quality monitoring plan in 2003 which continues through the present.
- The District completed topographic mapping of the watershed with 2-foot contours.
- The District completed XP-SWMM modeling of the entire watershed to delineate the watershed and determine flood elevations and discharges within the District (SRF, 2005).
- The District is currently in the process of developing rules to regulate the impacts of development on water quality and quantity.
- The District initiated this study in April 2006 with the goal of determining a set of BMPs and capital projects which the District can implement in order to meet water quality goals for its recreational lakes.

Scope of Study

In April 2006, the CLFLWD Board of Managers approved initiation of the study of water quality in the watershed and six key lakes that is documented in this report. A flow chart of the study process is shown in Diagram 1.1. The objective of the District is to improve water quality in the recreational lakes. Therefore, the study objectives are as follows:

- Develop understanding of water quality in District lakes;
- Identify opportunities for improvement;
- Identify projects that impact water quality; and
- Prioritize the projects in terms of results and cost effectiveness

The key elements of the study include:

- Review monitoring data and recommend additional studies for the 2006 monitoring season;
- Develop water budgets for the lakes using existing data and an existing XP-SWMM model for the watershed;

- Quantify external phosphorus loads to each lake based on a Unit-Area-Load watershed model and stream monitoring data;
- Quantify internal phosphorus loads to the lakes from in-situ phosphorus measurements and laboratory experiments;
- Model lake responses to existing hydraulic and nutrient loading;
- Determine the phosphorus load reductions needed to meet water quality goals;
- Review of ecological data to improve understanding of the lakes and inform the proper selection of management activities;
- Identify practices, programs, projects and management activities that can be implemented to achieve the target water quality goals;
- Seek input from study Stakeholders and work with the Board of Managers to determine the final capital improvement plan;
- Prepare preliminary designs and cost estimates for the selected projects, and;
- Prioritize the selected projects on the basis of scientific and practical reasoning.

Although the study focused on managing water quality in the six key recreational lakes, three additional lakes – Moody, Birch and School Lakes – were identified as being key to managing water quality in Bone and Little Comfort Lakes, so they were also studied in detail. Twelve peripheral lakes – Lendt, Third, Sea, Neilson, Clear, Twin, Cranberry, Elwell, Heims, First, Second, and Shallow Pond – were included in the water balance and nutrient loading components of the study, because they drain to (and therefore influence) the other lakes being studied. Figure 1 shows the locations of the six recreational lakes, the three secondary lakes and the 12 peripheral lakes.

The study elements above were completed during 2006 and 2007 and are documented in this report. The report will provide the basis for the 2008 revision of the CLFLWD Watershed Management Plan. It also will serve as the basis for Total Maximum Daily Load studies to be completed during 2008.

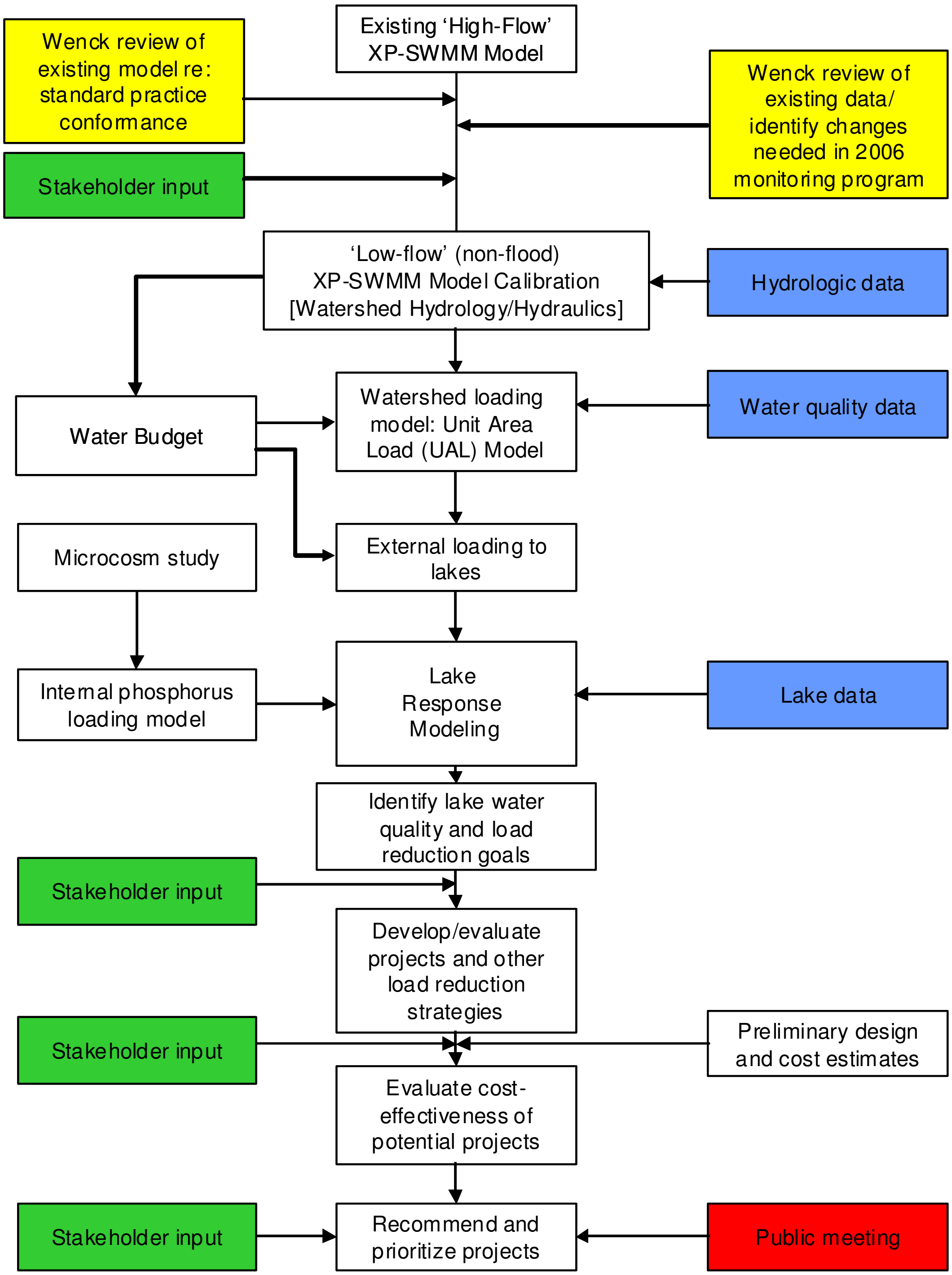
Data Sources

The primary data sources for this study include:

- SRF (2005) produced an XP-SWMM model of the entire Comfort Lake – Forest Lake Watershed District (hydrologic boundary). SRF delineated approximately 300 subwatersheds for the model based on two-foot contour topography. The delineation served as the basis for the modeling contained in the present study (see subwatersheds shown in Figure 2). In addition, approximately 70 key culverts and weirs were surveyed for the model.
- Much of the GIS data needed for this study was available from the SRF model data. Additional public sources were used.
- Historic lake water quality data from the STORET database.
- Historic fisheries data from DNR.
- Lake bathymetry was taken from DNR lake depth maps and from soundings of Birch and School Lakes by Washington Conservation District (WCD).

- Watershed hydrologic and water quality monitoring performed by WCD under contract to the District from 2003 through 2006. Wenck recommended changes and additions to the program before the 2006 season. Aquatic plant surveys were also added to the monitoring program in 2006. Modeling work for the study began after data became available in early 2007.
- Sediment cores collected by Wenck were analyzed in microcosm experiments assessing internal loading rates.
- Animal unit survey by CLFLWD Manager Moe and administrator Anhorn, supplemented by County sources.
- Several lake and watershed studies carried out in the past were reviewed. Their key findings or recommendations are summarized in Sections 3 through 11.

Diagram 1.1 Study Process Flow Chart



Organization of Report

This report summarizes the study methodologies, decision-making process and the resulting watershed management and capital improvement plan for the watershed, generally organized as follows:

- Section 2 describes the development of the watershed hydrologic and water quality models used as the technical basis for the investigations. These include the development of model inputs, use of monitoring data, water and phosphorus budgets, model construction, and calibration. This modeling was used for simulation of lake response to load reductions, described in the subsequent sections.
- Sections 3 through 11 describe the detailed assessment of the nine lakes that are the focus of this study. Each section describes the background information for the subject lake: watershed, lake size, water quality history, and ecological character. Then the water and phosphorus budgets, lake response model results, water quality goals and targeted load reductions are summarized. The sections are organized in upstream to downstream order, starting with Moody Lake across the northern part of the watershed to Little Comfort, and then from Shields and Sylvan Lakes, through Forest Lake and finally to Comfort Lake. (This order is maintained through all listings.) Section 11 includes a detailed analysis of growing season loading and phosphorus response for Comfort Lake.
- Section 12 details the process of screening potential capital improvement projects and management activities for all the lakes, and the rationale for selecting projects for implementation. It also includes descriptions of the final preliminary project designs, cost estimates, prioritization and capital improvement plan.

A compact disc (CD) containing data, models and other information used in the study process that is too extensive to include in this report document was provided to the District by Wenck Associates. This information can be used as a resource by the District in future watershed management.

WATERSHED AND LAKE INVESTIGATION METHODOLOGIES

Detailed water and nutrient budgets combined with lake response models provide a useful tool for identifying watershed management options and their potential effects on lake water quality. This information is then used by watershed managers to make informed decisions about how to allocate restoration dollars or fund capital improvement projects and efforts.

Modeling analyses for this study were completed using the following models, tools and data: monitoring data, scientific literature, watershed inventories, the XP-SWMM (v9.1) dynamic watershed hydrologic and hydraulic model, water budget, geographical information systems (GIS) analysis and synthesis, a unit area loading model for estimating watershed loads, and a lake response model to assess effects of load changes. Diagram 1.1 shows the sequence used in developing the modeling for this study. The major components of the watershed and lake investigations were:

- Watershed hydrology
- Phosphorus loading (external and internal)
- Lake response modeling

The methodologies used to analyze these three components are discussed in Sections 2.1, 2.2 and 2.3 below. The results for each of the nine lakes studied are described in Sections 3 through 11.

Hydrologic Investigations and Lake Water Budgets

Hydrologic investigations were aimed at developing detailed annual water budgets for the nine study lakes as well as for the twelve peripheral lakes (Section 1.3). The water budgets were developed first on the basis of the discharge monitoring conducted by the Washington Conservation District (WCD) under contract to CLFLWD. Not all sites could be monitored, however, and monitoring was only available during ice-free conditions. Therefore, the XP-SWMM model was used to augment the monitoring data and "fill in" the water budgets for unmonitored sites and unmonitored time frames. The calibration and use of the XP-SWMM model is detailed in Appendix B and water budget development is described in Appendix C.

Water budgets were developed for a "modified water year" for the one-year (365 day) time period ending with the end of the monitoring season. Three sets of water budgets were developed for average, wet, and dry conditions. The study focuses on the "benchmark year" condition which is selected as the 2004 water year because it most-closely represents the average condition in terms of total runoff from the watershed (use of the term "normal year" is avoided). In order to assess and select the benchmark, wet and dry year monitoring data, the WCD monitoring data for the watershed (from 2003-2006) was compared to 36 years of USGS stream flow data for the Sunrise River available for 1950 and 1985. In 2004, 5.21-inches of annual runoff was measured at the watershed outlet from Comfort Lake. This is the closest (of years monitored) to the average annual runoff (5.57-inches) from the USGS historical data (see table below). Therefore, 2004 data was used to represent 'benchmark' conditions. Water budgets were then developed for three years – 2004, 2003, and 2006 – representing benchmark, wet and dry conditions, respectively.

WCD Monitoring	Annual Adjusted Runoff (in)	
2003	7.56	Wet
2004	5.21	Benchmark
2005	2.02	Dry
2006	2.48	Dry

USGS Monitoring (1950-85)	Annual Runoff (in)
Minimum	2.32
Maximum	9.50
Average	5.57

Watershed runoff was estimated based on the hydrologic and hydraulic model (XP-SWMM v9.1). The XP-SWMM model was calibrated to cumulative discharge volume for benchmark conditions using the 2004 monitoring season data. Appendix B provides more detail on the XP-SWMM modeling methodology.

The water budgets for 2004, 2003 and 2006 (benchmark, wet and dry conditions, respectively) were based on the WCD monitoring data and the XP-SWMM results. Additional details on the water budget analysis methodology are included in Appendix C. The results of the water budget analyses for each of the nine lakes studied are included in Sections 3 through 11 of this report.

Phosphorus Loading

Understanding the phosphorus sources to the CLFLWD lakes is a major focus of this study. This section provides a brief description of the potential sources of phosphorus in CLFLWD lakes and the methods used to quantify phosphorus loading for the study. Detailed nutrient budgets were ultimately developed for each of the nine lakes studied, based on the nutrient loading assumptions described in this section. (Budgets for the peripheral lakes were determined within the loading and response model.)

Individual phosphorus sources were identified, quantified and summed to determine the lake phosphorus budget. Phosphorus sources assessed in the phosphorus budgets included:

<u>External phosphorus loading</u> from:

- Non-point source loads exported from the landscape as affected by land use (Sections 2.2.1 through 2.2.4)
- Point-source discharges as in septic system releases (Sections 2.2.5 through 2.2.7)
- Atmospheric deposition (Section 2.2.8)
- Groundwater exchange (Section 2.2.9)

Internal phosphorus loading from:

- Lake sediment release (Section 2.2.10)

Phosphorus losses addressed in the lake model (Section 2.3)

- Lake discharge (surface water and ground water)
- Sedimentation

Non-Point Source Load Export Coefficients

The CLFLWD watershed phosphorus loads were determined using unit area loading rates (UALs) in terms of pounds of phosphorus per year (lb/ac/yr). UALs were selected based on literature values that best represented land use (direct runoff) conditions in the CLFLWD watershed (see Appendix E and Table 2.1). The recommended values are largely based on the Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (MPCA, 2004).

Table 2.1 – Total phosphorus (TP) values for land uses used in CLFLWD unit area loading (UAL) model

Land Use	Phosphorus UAL	
	kg/ha/yr	lb/ac/yr
Cropland	0.38	0.34
Forest	0.075	0.67
Grassland	0.169	0.15
Developed – High	1.5	1.34
Developed – Med	1.15	1.02
Developed – Low	0.91	0.81
Golf Course	0.91	0.81
Sand & Gravel Mining	0.0	0.0
Wetlands	-0.02	-0.02

A geographic information system (GIS) analysis of land use and land cover data was used to determine areas for each land use/land cover in each subwatershed. These areas were used within the watershed loading and lake response model to calculate non-point source loads for each of the 286 subwatersheds modeled in XP-SWMM (see figure in Appendix F). Phosphorus loads calculated by UALs were input to the lake loading model by lakeshed.

Urban/Development Runoff

Phosphorus transported by storm water represents one of the largest contributors of phosphorus to lakes in Minnesota. Transport of urban runoff to local water bodies is quite efficient as a result of local storm sewer systems. As a result of this efficiency, other materials are transported to the water bodies including eroded soil, grass clippings, fertilizers, leaves, car wash wastewater, and animal waste. All of these materials contain phosphorus which can impair local water quality. Some of the material may add to increased internal loading through the breakdown of organics and subsequent release from lake sediments. Additionally, the input of organic material can increase the sediment oxygen demand further exacerbating the duration and intensity of phosphorus release from lake sediments.

Excess chemical or organic fertilizer applied to lawns and golf courses can be readily transported to local streams and lakes during runoff events and is immediately available for algal growth. Consequently, excess fertilizer can represent a significant threat to lake water quality in urban watersheds. The metro-area phosphorus fertilizer ban and golf course management plans can substantially reduce these potential loads. Therefore, storm water is an important water quality source in urban and urbanizing watersheds. Because the CLFLWD's watershed is expected to develop further in the next 20 years, storm water will be an important source of phosphorus to control. Approximately 19% of the CLFLWD is currently developed. UALs for developed areas varied depending on the density of development, usually interpreted as percent impervious surfaces in the watershed (e.g., pavement, roofs); this is detailed in Appendix D.

Agricultural Runoff

Agricultural runoff can supply significant phosphorus loads to surface waters by transporting eroded soil particles and associated nutrients, as well as dissolved phosphorus from excess fertilizers. Approximately 18% of the CLFLWD is tilled agriculture (cropland) with significant amounts of subsurface drainage and ditching. Runoff and erosion from these fields is estimated to be a significant contributor to watershed loads to CLFLWD's lakes. Table 2.1 shows the phosphorus UAL rate for cropland areas in the watershed loading model.

Wetlands

The traditional paradigm for wetlands and water quality is that wetlands act as a sink for nutrients such as nitrogen and phosphorus. It is becoming more common in the State of Minnesota, especially in urban areas, for detailed investigations to find that wetlands (highly modified with channelized flow paths) are acting as sources of phosphorus to surface waters. The phosphorus loading model included most wetlands acting as slight sinks, because there are not detailed studies identifying particular wetlands as nutrient sources. Some wetlands have been identified through the modeling as potential sources in need of additional study and restoration; these are identified in Section 12. Approximately 19% of the CLFLWD area is wetland. Table 2.1 shows the phosphorus UAL rate for wetland areas that were assumed in the watershed loading model (-0.02 pounds TP/acre).

Point Source Discharges

There are no point sources, in the classic sense, within the CLFLWD watershed. There are two NPDES Phase II permits for small municipal separate storm sewer systems (MS4) in the CLFLWD: Washington County and the City of Forest Lake. The NPDES permit number for Washington County is MS400160. Forest Lake is a designated MS4 that was required to obtain permit coverage by February 15, 2007. Loading from the municipal storm sewers is estimated in the non-point source model using UALs and not as point sources. The Forest Lake wastewater treatment plant effluent (MNG640118-SD-1) discharges outside the watershed.

Shoreline Septic Systems

Failing or nonconforming individual septic treatment systems (ISTS) can be an important source of phosphorus to surface waters. Appendix H of the "2004 Legislative Report: Detailed Assessment of Phosphorus Sources to Minnesota Watersheds" indicates that there is an average 11.4% failure rate of ISTS for the St. Croix River Basin and that 22% of phosphorus loads to ISTSs eventually makes its way to lakes or streams. While the average failure rate is relatively low, the number of ISTS may represent a significant source of phosphorus to District lakes.

Septic system loads for the watershed were estimated based on the following: number of septic systems in the watershed and results from Appendix H of the 2004 Legislative Report, including 2.68 capita per residence, 1.83 pounds of phosphorus production per capita per year, and an average of 78% phosphorus retention by the system and soils.

Digital aerial photography, parcel maps and land use coverages were reviewed to determine the number of residences around eight of the studied lakes. Then, the estimated ISTS phosphorus discharge rate of 1.08 pounds per ISTS per year was multiplied by the number of ISTSs to determine the ISTS load for each un-sewered lake in the watershed loading model.[1] The following table summarizes the ISTS loading assumed in the modeling.

Lake	Estimated # of ISTSs	Lakeshore Septic Phosphorus Load (lbs P/year)
Third Lake	15	16.2
Moody Lake	8	8.6
Bone Lake	78	84.1
Birch Lake	4	4.3
School Lake	7	7.5
Little Comfort Lake	15	16.2
Shallow Pond	91	98.1
Sylvan Lake	67	72.3
Forest Lake (East Basin)	-n/a-	-
Shields Lake	-n/a-	-
Forest Lake (Center Basin)	-n/a-	-
Forest Lake (West Basin)	-n/a-	-

[1] Phil Gravel, City Engineer for Forest Lake, provided the sanitary sewershed map for the City of Forest Lake. Residences around Forest Lake (West, Center and East basins) and Shields Lake are sewered, thus the ISTS load for these lakes is zero.

Livestock
Animal agriculture can have a substantial effect on water quality. Animal waste, which contains both phosphorus and nitrogen, is often applied to agricultural fields as fertilizer. A regional Minnesota study suggests that manure is applied at a rate 74% greater than the University of Minnesota-recommended amount of phosphorus (Mulla et al. 2001). This can result in an extra 35 pounds per acre of phosphorus, which could ultimately be transported by runoff or enter the ground water. Additionally, runoff from feedlots can transport animal waste containing phosphorus directly to surface waters. Animal waste is a contributor to watershed loads, but is spatially variable and subwatershed-specific.

An informal livestock inventory by one of the District managers and the District Administrator was used along with county animal unit data to estimate the total domestic animal population in each subwatershed (Appendix F). The population estimates were used in conjunction with the following animal-specific phosphorus production rates to estimate phosphorus loading for the individual subwatersheds.

Animal Unit [AU]	Production Rate of P in Manure as P[lb/AU/d]	Citation
Beef Cattle	0.097	[c]ASAE D384.2
Beef Calves	0.055	ASAE D384.2
Dairy Cattle	0.17	ASAE D384.2
Dairy Calves	0.055	Assumed AUF = 1.0[a] Beef Calf
Horses	0.029 (sedentary)	ASAE D384.2
Chickens	0.011	ASAE D384.2
Sheep	0.0087[b]	MWPS
Goats	0.0097	Assumed AUF = 0.1 Mature Beef Cow
European Red Deer	0.0055	Assumed AUF = 0.1 Beef Calf
Llamas	0.0055	Assumed AUF = 0.1 Beef Calf
Dogs	0.0000275	Assumed AUF = 0.0005 Beef Calf

a) Use MPCA Feedlot Inventory Animal Unit Factor (AUF) to relate published value for Mature Beef Cattle Production Rate of P in Manure.
b) Converted from 0.02 lbs P2O5/day using P2O5=2.29*P (MWPS, 2004)
c) American Society of Agricultural Engineers

Not all phosphorus that is generated by livestock manure is transported by subwatershed runoff to a tributary stream or downstream wetland or lake. A reduced percentage of the phosphorus generated by livestock is accounted for in the modeled lake nutrient budgets. While research finds that livestock waste can contribute from 7 to 65% (Mulla, et.al., 1999) of the total phosphorus load in surface waters, this is dependent on many factors. The watershed loading models for the nine study lakes assume 4% delivery of phosphorus loading estimated from domestic animal sources in each lake's watershed (via runoff).

Atmospheric Deposition
Precipitation and dust containing phosphorus fall directly on lake and land surfaces and must be quantified as a direct input to the lake phosphorus budgets. Although

atmospheric inputs (precipitation and dryfall) must be accounted for in development of a nutrient budget, these inputs are impossible to control. Approximately 18% of the CLFLWD surface area is open water.

Atmospheric loading rates for the benchmark, wet and dry years (2004, 2003 and 2006) were set at 0.13 lb P/ac/yr, 0.16 lb P/ac/yr, and 0.11 lb P/ac/yr, based on data available for the St. Croix River Basin in the 2004 Legislative Report (see table below).

Atmospheric P Deposition for St. Croix River Basin

Deposition Component	Atmospheric P Deposition [kg/ha/yr]	Atmospheric P Deposition [lb/ac/yr]
Low-precipitation P deposition	0.0938	0.0837
Average-precipitation P deposition	0.1211	0.1081
High-precipitation P deposition	0.1488	0.1328
Dry P deposition	0.0280	0.0250
Dry-year total P deposition	0.1218	**0.1087**
Average-year total P deposition	0.1491	**0.1331**
Wet-year total P deposition	0.1768	**0.1578**

Source: Barr Engineering (2004)

Groundwater Exchange

Exchange between the lakes and ground water was included in the watershed loading and lake response models to:

1) Balance water budgets regionally (i.e., across the whole watershed) between recharge areas in the eastern portion of the watershed and discharge areas in the west. The **regional** exchanges of groundwater have both recharge and discharge zones that have a net zero effect in the CLFLWD.

2) Represent losses to groundwater in landlocked basins (which have no natural or active surface overflow). This **local** interaction is how landlocked subwatersheds contribute to downstream receiving waters.

The regional groundwater recharge is water **leaving** a waterbody **to** groundwater. This removes water volumes and phosphorus loads from their respective budgets. The total load is calculated using the volume defined in the water budget and phosphorus concentrations predicted in the lake response model.

In contrast, regional groundwater discharge is water **entering** a waterbody **from** groundwater. This adds water volumes and phosphorus loads to their respective budgets. The total load is calculated using the volume defined in the water budget and the MPCA's median phosphorus concentration of 56 ug/L for surficial quaternary aquifers.

The groundwater attributed to landlocked "upstream lakes" represents water leaving a landlocked lake (e.g. Sea Lake, Nielson Lake, Elwell Lake, Sylvan Lake, and Clear Lake) by way of groundwater and entering the next down-gradient lake via regional groundwater flows. This total load is calculated using the groundwater volume defined in the water budget and the MPCA's median phosphorus concentration of 56 ug/L for surficial quaternary aquifers. More detail on estimating these volumes are presented in the water budget, Appendix C.

The northeast portion of the CLFLWD drains to First and Second Lakes, which are landlocked, having no surface overflow to downstream resources. Runoff volumes and phosphorus loads are calculated for their subwatersheds; but no lake response models were developed because First and Second Lakes are not part of the study and no lake water quality data have been collected for them. (Lake models can be added later with relatively little effort). Excess water from these lakes is assumed to be lost to groundwater discharge out of the District. The First and Second Lake watersheds do not affect the water quality in the District's six recreational lakes.

Internal Phosphorus Release

An important part of the nutrient budget in many Minnesota lakes, internal loading is the recycling of phosphorus contained in lake-bottom sediments back into the water column, where it can be utilized by phytoplankton. Internal loading is most commonly associated with anoxic conditions in the hypolimnion during summer and winter stratified periods. When oxygen is depleted near the sediment surface (water concentration less than 2.0 mg/L), phosphorus-iron bonds and other weak bonds are broken, releasing dissolved phosphorus for transport into the water column.

Two measures were available to estimate the internal load to the study lakes. Wenck collected sediment cores that were tested in the U.S. Army Corps of Engineers environmental lab at the Eau Galle reservoir in Wisconsin. Cores from six lakes were subjected to anoxic conditions in the lab to measure their phosphorus release rates. Hypolimnetic phosphorus accumulation was also calculated using growing season phosphorus measured by the WCD.

The results of these studies and calculation of internal loads are documented in Appendix G. The lake internal loads used in the lake response model are listed below.

Lake	Internal Phosphorus Load (pounds/year)
Bone Lake	165
Moody Lake	490
Little Comfort Lake	56
School Lake	46
Birch Lake	18
Forest Lake (East Basin)	251
Forest Lake (Center Basin)	97
Forest Lake (West Basin)	73
Sylvan Lake	17
Shields Lake	76
Comfort Lake	223

Internal loading can also result from sediment resuspension that may result from rough fish activity, wind mixing or prop wash from boat activity. Additionally, curly leaf pondweed can increase internal loading in littoral areas when it senesces and releases phosphorus during the summer growing season (late June to early July). These factors are not part of the internal load estimates, but must be controlled in some lakes to achieve improvement.

Lake Exchange

Connected lakes or bays can exchange nutrients through advective exchange, where currents convey water between them, or diffusive exchange, where turbulent exchange of smaller volumes back and forth cause a net transport from high concentration toward low concentration. Because most of the CLFLWD lakes are not directly connected, diffusive exchange was assumed to be negligible. Forest Lake's three basins were modeled as separate lakes, so that exchange of phosphorus occurred through advection. Furthermore, no backwater or return flows were assumed in the exchange process.

Watershed Loading and Lake Response Model

Sections 2.1 and 2.2, along with Appendices C though H, describe the inputs to the CLFLWD Watershed Loading and Lake Response Model (WLLRM). The WLLRM is a spreadsheet model built in Microsoft Excel for CLFLWD. It includes all of the modeling data and equations for watershed phosphorus loading and lake water quality response. The model calculates lake response based on the Canfield-Bachmann (1981) natural lakes phosphorus sedimentation model. The components of the model include:

Model Water Budget Inputs

- Lake area and volume.
- Flow sequence.
- Inflow water budgets.
- Groundwater input and output volumes.
- Lake surface precipitation and evaporation.
- Landlocked watersheds and water bodies.

Model Phosphorus Loading Inputs

- GIS inputs of land use and land cover determined in ArcGIS for each of the 286 subwatersheds previously delineated for the existing XP-SWMM model.
- Non-point source annual phosphorus load estimates based on the UAL method for the 286 subwatersheds.
- Shoreline septic loads are estimated for lakeshore properties in non-sewered areas.
- Phosphorus loads due to livestock are calculated for each of the subwatersheds with identified populations of domestic animals.
- Atmospheric loading to the lake surface.
- Internal phosphorus load estimates.

Lake Response to Phosphorus Loads

- Each lake response is modeled using the Canfield-Bachmann (1981) natural lakes phosphorus sedimentation model. It balances the effects of hydraulic loading and discharge through the outlet with phosphorus sedimentation to estimate the growing season in-lake phosphorus concentration.
- Phosphorus – Chlorophyll-*a*, and Chlorophyll-*a* – Secchi depth relationships were compared to the ecoregion relationships from MNLEAP and either confirmed to fit, or adjusted to fit historic data for each lake.
- Lake response to load reductions was determined for the benchmark year, and corresponding changes in total phosphorus, Chlorophyll-*a*, and Secchi depth were plotted against load reduction for each of the study lakes.
- The lake export load was determined from the predicted in-lake phosphorus concentration and water volume. Adjustments to this load were made due to the differences between the growing season average in-lake concentration and the actual discharge concentration that would apply to the annual discharge load.

Watershed Routing of Water and Phosphorus

- The spreadsheet model includes routing through the study lakes as well as other minor lakes and ponds in the watershed to estimate fate and transport of phosphorus upstream of the monitoring locations and study lakes. Routing through minor lakes followed the Canfield-Bachmann model equation directly in the spreadsheet model. Phosphorus retention in lakes must be simulated in order to predict loads downstream of lakes.

- The routing within the model allows the simulation of load reductions and can simulate the "cascading" effect of improvements in upstream lakes benefiting downstream lakes.

Model Calibration

- Calibration of the model was made by several steps including:
  - Global adjustments to the UALs to improve fit to monitored annual loads;
  - Global adjustments to the percent yield to water bodies from animal unit loads;
  - Identification of loading increments – such as differences between the modeled load increases and the increase in load between a lake outlet and the downstream monitored load – that would indicate unusual conditions such as phosphorus export from an impacted wetland;
  - Adjustment of internal loads to match in-lake concentrations where estimates suggested a range of possible loads;
  - Finally, the Canfield-Bachmann settling rate was adjusted by a calibration factor in order to improve the fit to the benchmark, wet and dry year conditions.

Model Simulations to Evaluate Lake Water Quality and Load Reduction Goals

- Besides the load reduction curves presented within the model, standard simulations included the evaluation of load reductions necessary to meet water quality goals. The model was used to evaluate necessary load reductions for the study lakes to meet short-term goals, with the lakes meeting the default MPCA total phosphorus goals of 40 ug/L and 60 ug/L growing season average surface concentration, for deep and shallow lakes, respectively. Then, the load reduction necessary to meet the goals could be reduced by the amount provided by upstream lakes meeting their goals.
- The process was repeated with the 30 ug/L goal for the District's recreational lakes.
- Then load reduction goals could be established for each of the study lakes.

Model results are described for each of the study lakes in Sections 3 through 11 which follow. Section 12 screens and identifies capital projects to bring about lake water quality improvements in the District.

MOODY LAKE

Physical Setting

Moody Lake Watershed

Moody Lake's watershed encompasses 2,435 acres (8% of CLFLWD) and four lakes. Land use in the watershed includes cropland (31%), wetlands (25%), grassland (17%) and forest (14%). Some of the farm land in the Moody Lake watershed is being developed to medium-density residential land uses. The main tributaries drain the northeast and northwest portions of the watershed through two culverts on the north edge of Moody Lake.

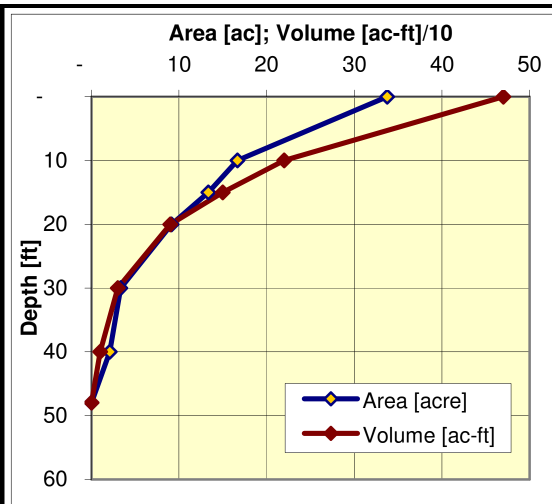
The northeast tributary originates at Pine Lake and flows through a series of several wetland complexes, grassland with livestock access to Fourth Lake to Moody Lake. Overflow from Lendt Lake combines with discharge from Fourth Lake in subwatershed NBL23.

The main land use in the northwest portion of the watershed is cropland (47%), much of which may be drained pre-settlement wetlands (only 12%). It drains from the southeast edge of Wyoming through natural channels past livestock operations (with direct channel access), and through culverts under road crossings to Moody Lake.

Moody Lake

Moody Lake (MN DNR Lake # 13-0023-00) is considered a deep lake, although it shares some character of a shallow lake due to its significant littoral area of 61%. Its maximum depth ensures that it remains thermally stratified through the growing season. A bathymetric map of Moody Lake is presented in Appendix H; its depth and volume are summarized below:

Depth [ft]	Area [acre]	Volume [ac-ft]
-	34	470
10	17	220
15	13	150
20	9	90
30	3	30
40	2	10
48	-	-
14	Average Depth	
48	Maximun Depth	
61%	Littoral	



Moody Lake Water Quality History

Present Conditions, Trends

Summaries of historic water quality are presented in tabular and graphic form for Moody Lake in Appendix I (original data and sources are included on the report CD). The data are presented as growing season (June 1 to September 30) averages of surface total phosphorus, chlorophyll-*a*, and Secchi depth for each year data was available. Data were available for Moody Lake from 2005 and 2006; the two-year average of growing season, surface total phosphorus average is 167 ug/L. This is far above typical values for North Central Hardwood Forest ecoregion (23-50 ug/L), and is indicative of hypereutrophic conditions. The two-year average chlorophyll-*a* average is 52 ug/L (ppb). With just two years of water quality monitoring, no trends in water quality can be identified for Moody Lake.

Past Studies

No studies have previously been made directly investigating the water quality of Moody Lake. Investigations of Bone Lake (see below) have identified the discharge from the Moody Lake subwatershed as an important source of phosphorus to Bone Lake. Limited inflow monitoring was done downstream of the wetland separating Moody from Bone Lake. Therefore the concentrations and loads reflected not just the discharge from Moody Lake, but the effect of that wetland. The 2001 Comfort Lake-Forest Lake Watershed District Watershed Management Plan did not identify Moody as one of the six key recreational lakes to be protected.

Moody Lake Ecological Analysis

Analysis of recent ecological data for the study lakes are included in Appendix J. Key findings relative to Moody Lake are presented below:

- Panfish population declined dramatically from 1989 to 1998 survey.
- Very high numbers of black bullheads were collected in most recent survey; winter kill may have occurred.
- Macrophyte community diversity is very low, few desirable submergent species are present.
- Curly leaf pond weed is abundant in the lake, found in both spring and fall surveys in 2006.

Moody Lake Water Budget

The watershed runoff volume is the largest component of Moody Lake’s water budget tabulated below. Note that benchmark conditions refer to the 2004 Water Year, the year studied that most closely represents “normal conditions.” Wet and dry conditions were represented by 2003 and 2006 Water Years respectively, as reflected in the total Comfort Lake watershed runoff. (Due to the size of the entire watershed, annual differences at Comfort Lake may not be reflected at each lake). The benchmark year was used for the load reduction calculation and project sizing. The wet and dry years were used for verifications of the watershed and lake models. Appendix C describes the development of the lake water budgets and presents a bar plot of the benchmark conditions for this lake.

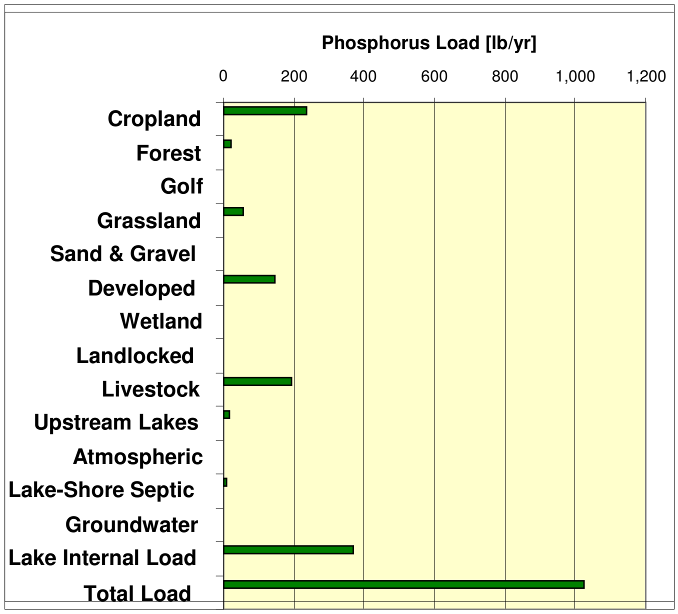
Moody Lake Water Budget Outflow and Inflow Volumes		Benchmark Conditions (2004)	Wet Conditions (2003)	Dry Conditions (2006)
Inflow Volumes [ac-ft]	Watershed Runoff	498	1,288	160
	Precipitation (direct)	61	66	64
	Flow from Upstream Lakes via Surface	38	110	7
	Flow from Upstream Lakes via Groundwater	16	41	2
	Regional Groundwater Inflow	-	-	-
	Net Inflow (Change in Storage)	-	-	-
TOTAL INFLOW [ac-ft]		**614**	**1,505**	**233**
Outflow Volumes [ac-ft]	Evaporation from Lake	(81)	(87)	(87)
	Discharge through Outlet	(470)	(1,355)	(82)
	Discharge via Groundwater	-	-	-
	Regional Groundwater Outflow	(64)	(64)	(64)
TOTAL OUTFLOW [ac-ft]		**(614)**	**(1,505)**	**(233)**
Moody Lake Residence Time [year]		0.8	0.3	2.0

Under benchmark conditions, the lake receives 1.3 times its volume in water inputs for a residence time of just 0.8 years. Under wet conditions flushing doubles and under dry conditions it would take two years to flush once. The lake response model balances the effects of phosphorus loading, discharge from the lake (through its outlet), and calculates settling of phosphorus on an annual timestep in order to estimate the growing season, surface total phosphorus.

Moody Lake Phosphorus Budget

External Loading

Direct cropland watershed runoff loads and livestock loads are the primary external components of the Moody Lake's phosphorus budget. Detailed phosphorus budgets tabulated in Appendix K; and graphically summarized below:



Internal Loading

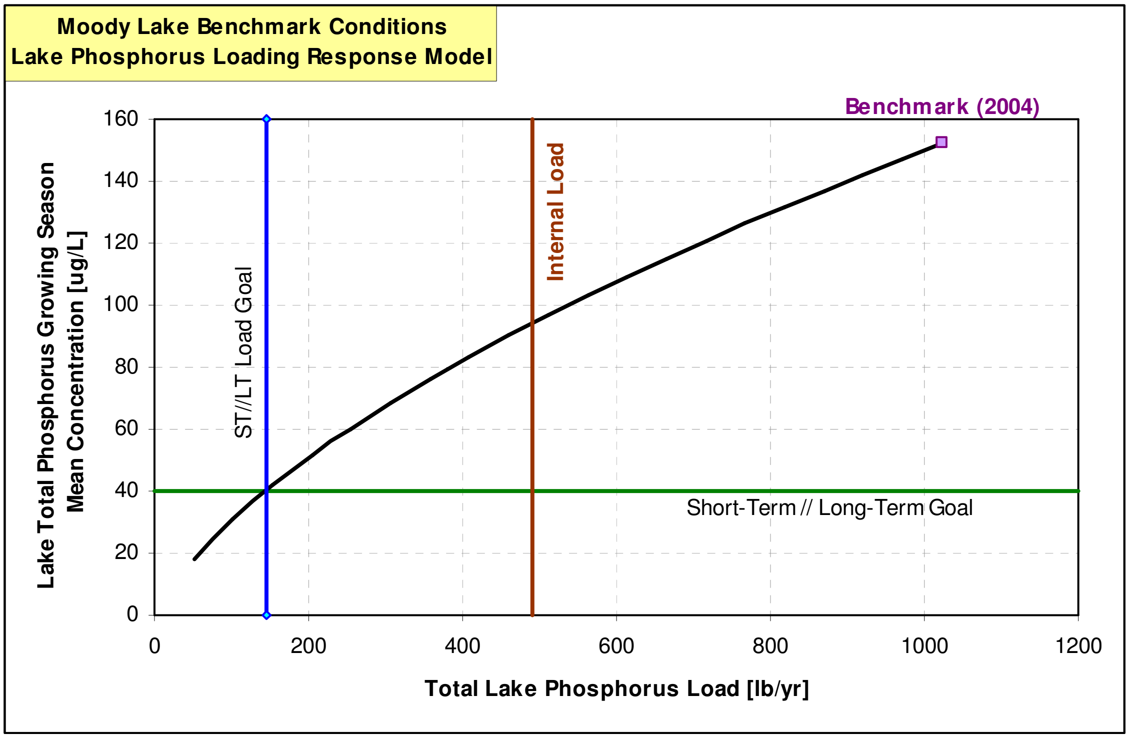
The Moody Lake internal load of 490 pounds was estimated from the accumulation of ortho-phosphorus mass in the hypolimnion during the 2006 summer stratified period. The release rate experiments showed a much smaller load of 80 pounds. This may be in part due to the fact that the sediment sample floated in the microcosm and had to be held in place with a mesh fabric during the experiment (see Appendix G). The internal load was adjusted to 368 pounds in the calibration.

Moody Lake Model and Load Response

Empirical models are frequently used in the evaluation of lake response to phosphorus loading; phosphorus is the limiting nutrient for most Minnesota lakes. Lake models, such as the Canfield-Bachmann (1981) equation, are used to evaluate the phosphorus sedimentation and predict average in-lake phosphorus concentration as a result of external and internal loads, and water outflow rates. A second empirical relationship is then used to predict the in-lake algal concentration – measured by the concentration of the photosynthetic pigment chlorophyll-*a* - from the in-lake phosphorus. Finally a third empirical relationship is used to predict water clarity, or Secchi depth, from the chlorophyll-*a* concentrations. These second and third empirical relations are usually ecoregion, or even lake-specific. Development of the phosphorus – chlorophyll-*a* – Secchi depth correlations is summarized in Appendix I.

Once the empirical models are selected and calibrated (if necessary), generation of lake-specific load response curves can be computed by step-wise reducing the total phosphorus load and calculating the lake response variables for each step using the empirical models.

The Moody Lake response models and load response curves are presented in Appendix K. The Moody Lake load response curve for growing season, surface total phosphorus is shown below:



LEGEND
COLOR **DESCRIPTION**
Black – Modeled Lake Response to Load Reductions
Brown – Internal Load
Green – Lake Total Phosphorus Goal (MPCA Standard)
Purple – Non-Degradation Goal
Blue – Load Required to Meet Goals

Moody Lake Goals and Load Reductions

In-Lake Phosphorus Goal

The Moody Lake growing season, surface total phosphorus goal is 40 ug/L, the MPCA standard for "deep" lakes. Moody is not designated as a District recreation lake, so no additional standard applies, and 40 ug/L is the short-term and long-term goal for Moody Lake.

Load Reduction Goals

The watershed loading and lake response spreadsheet model (Appendix K) predicts that a total phosphorus load of 144 pounds would allow Moody Lake to meet its in-lake total phosphorus goal. Under benchmark conditions, the total phosphorus load to Moody Lake is currently 1,023 pounds. The difference in these endpoints is the load reduction goal of 879-pounds of external and internal loading, this is a 86% reduction from existing benchmark conditions.

Source		Existing	Short-term Goals	Long-term Goals
Lake Total Phosphorus	[ug/L]	152	40	40
Total Load	[lb]	1,023	144	144
Load Reduction Goals	[lb]		(879)	(879)
	[%]		86%	86%

Load Reduction due to Upstream Lakes

The watershed loading and lake response model was used to determine load reductions caused by *upstream lakes meeting their goals*. Because Moody Lake is the most-upstream lake considered in this study, there are no load reductions to Moody Lake caused by improvements in upstream lakes.

Best Management Practices and Load Reduction Projects

Section 12 describes the process of BMP and project selection for all of the studied lakes.

BONE LAKE

Physical Setting

Bone Lake Watershed

Bone Lake's watershed is the second largest management area of the District with 5,760 acres (18% of CLFLWD) and seven lakes (including Moody Lake's watershed to the north). Moody Lake's watershed is the largest of Bone Lake's tributary areas, and enters Bone Lake at the north end of Bone Lake (and is described in the Moody Lake section).

The remaining tributary areas of the Bone Lake watershed encompass 3,325 acres. Bone Lake's shoreline is mostly developed with residences, although to the northeast, it is bounded by roads. Besides Moody Lake, there are three main inlets to Bone Lake, referred to as: northeast (drainage from Third Lake enters through subwatershed NBL10), southeast (the inlet through SBL08 receives drainage from Sea Lake via SBL05 and from the large watershed to the southeast via SBL07), and southwest (via SBL38). Land use in the direct watershed is cropland (39%), wetlands (15%), grassland (13%), forest (10%), and lake open water (10%).

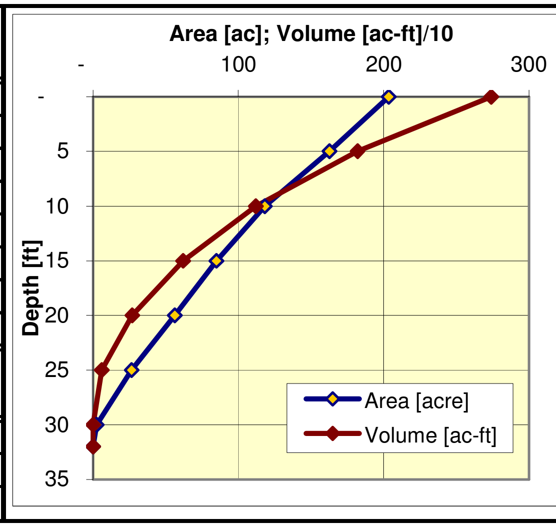
Livestock historically have had access to the drainage channels and rich fen in the wetland in the southwest portion of the watershed where the runoff drains through wetlands to Bone Lake. The rich fens are noted for preservation.

There are relatively few wetlands south of Bone Lake. Channels draining mostly through cropland do not generally have buffers. Residences in the area are mostly farmsteads though development is expected to increase in the future.

Bone Lake

Bone Lake (MN DNR Lake # 82-0054-00) is considered a deep lake, although it shares some character of a shallow lake due to its significant littoral area of 58%. Its 32-foot maximum depth ensures that it remains thermally stratified through the growing season. A bathymetric map of Bone Lake is presented in Appendix H; its depth and volume are summarized below:

Depth [ft]	Area [acre]	Volume [ac-ft]
-	204	2,740
5	163	1,820
10	118	1,120
15	85	620
20	56	270
25	27	60
30	2	-
32	-	
13	Average Depth	
32	Maximun Depth	
58%	Littoral	



Bone Lake Water Quality History

Present Conditions, Trends

Summaries of historic water quality are presented in tabular and graphic form for Bone Lake in Appendix I (original data and sources are included on the report CD). The data are presented as growing season (June 1 to September 30) averages of surface total phosphorus, chlorophyll-*a*, and Secchi depth for each year data was available. Data were available for Bone Lake from 1975 to 2006; the average (since 1990, not continuous) total phosphorus is 56 ug/L. This is above typical values for North Central Hardwood Forest (NCHF) ecoregion (23-50 ug/L), and is indicative of eutrophic conditions.

There is not a significant trend (improving or deteriorating) for surface total phosphorus between 1975 to 2006. However, phosphorus has ranged from a low of 34 ug/L in 1998 to a high of 103 ug/L in 1991.

Chlorophyll-*a* data collected shows an improving trend, over the past four years, with growing season averages decreasing each year. The 2006 observation of 21 ug/L (the lowest measured) is at the upper range of values typical for NCHF ecoregion (5-22 ug/L), but it has ranged from 21 to 52 ug/L.

Secchi depth also shows no significant trend, although it has fluctuated from 0.9 to 1.7 meters, with a growing season average around 1.3 meters. Data collected indicates that Bone Lake isn't as clear as typical lakes found in the NCHF ecoregion (1.5 to 3.2 meters).

Past Studies

Key findings and recommendation of past studies of Bone Lake are summarized below:

- National Biocentric (1976) found that Bone Lake was in a pronounced state of eutrophy, and that nitrogen was the limiting nutrient during mid-summer (phosphorus limited at other times). They developed a phosphorus budget of 1,800 lb/yr for Bone

Lake with the main loads coming from Moody Lake (40 to 60%) and the southeast tributary (20 to 40%). The study recommended reducing the total phosphorus load by 50%, focusing on these subwatersheds. Recommended actions included manipulation of wetland water levels; diversion of flows from Moody Lake; treatment of lake sediments to reduce recycling of phosphorus; and fertilizer and manure management.

- Wenck (1987) studied Bone Lake and estimated a normal runoff phosphorus load of 2,900 lb/yr and suggested a load of 5,300 lb/yr for fully urbanized conditions (without controls). The study recommended measures to prevent these increases (BMPs for new development) as well as farm conservation plans; further projects could not be recommended due to the unfortunate timing of runoff monitoring.

- Wilson (1990) reviewed existing water quality data and applied MNLEAP to review goals for Bone and other lakes in the watershed. He recommended a phosphorus goal for Bone Lake near 45 ug/L. He also made general recommendations for the whole watershed including BMPs to minimize the effects of increased urbanization, including sedimentation ponds, maintenance of wetlands, construction site BMPs, fertilizer management programs and wetland treatment areas.

- The 1990 FLWMO Watershed Management Plan recommended rough fish management for Bone Lake along with reducing phosphorus inputs to the lake and the general management activities of the WMO.

- The 2001 Comfort Lake-Forest Lake Watershed District Watershed Management Plan identified a study process that included the present study to determine the projects and programs to protect lake water quality, particularly in six key recreational lakes Comfort, Little Comfort, Bone, Forest, Shields and Sylvan Lakes.

- North American Wetland Engineering (2005) prepared a Bone Lake Management Plan which screened several projects and management activities, leading to the recommendation of: Rough fish harvesting; watershed controls (i.e., rules); shoreline BMPs; a settling basin with chemical addition for the Moody Lake subwatershed; sediment phosphorus inactivation; and barley straw treatments of the lake.

Bone Lake Ecological Analysis

Detailed analysis of recent ecological data for the study lakes are included in Appendix J. Key findings relative to Bone Lake are presented below:

- Biomass was evenly distributed among panfish, top predator and rough fish groups in last survey.
- Carp present in the lake are large, averaging approximately 8 pounds in last survey
- Exotic species curly leaf pondweed and Eurasian water milfoil are present in lake.
- Some desirable submergent species exist but they are not abundant.

Bone Lake Water Budget

The Bone Lake water budget is tabulated below for benchmark conditions (which refers to the 2004 Water Year, the year studied that most closely represents "normal conditions") and for wet and dry conditions (represented by 2003 and 2006 Water Years respectively, as reflected in the total watershed runoff at the Comfort Lake outlet).[2] The benchmark year was used for the load reduction calculation and project sizing. The wet and dry years were used for verifications of the watershed and lake models. Appendix C describes the development of the lake water budgets and presents a plot of the benchmark conditions for this lake.

Bone Lake Water Budget Outflow and Inflow Volumes		**Benchmark Conditions (2004)**	**Wet Conditions (2003)**	**Dry Conditions (2006)**
Inflow Volumes [ac-ft]	Watershed Runoff	1,431	996	630
	Precipitation (direct)	369	391	357
	Flow from Upstream Lakes via Surface	499	1,439	90
	Flow from Upstream Lakes via Groundwater	162	218	163
	Regional Groundwater Inflow	-	-	-
	Net Inflow (Change in Storage)	-	-	(62)
TOTAL INFLOW [ac-ft]		**2,461**	**3,044**	**1,177**
Outflow Volumes [ac-ft]	Evaporation from Lake	(486)	(523)	(523)
	Discharge through Outlet	(1,591)	(2,137)	(394)
	Discharge via Groundwater		-	-
	Regional Groundwater Outflow	(383)	(383)	(383)
TOTAL OUTFLOW [ac-ft]		**(2,461)**	**(3,044)**	**(1,301)**
Bone Lake Residence Time [year]		1.1	0.9	2.2

Bone Lake receives a relatively large runoff volume annually, as reflected in the short residence times. This has an important effect on the in-lake phosphorus, which is also controlled by phosphorus loading. The lake response model (see below) is used to balance these effects and calculate settling of phosphorus on an annual timestep in order to estimate the growing season, surface total phosphorus.

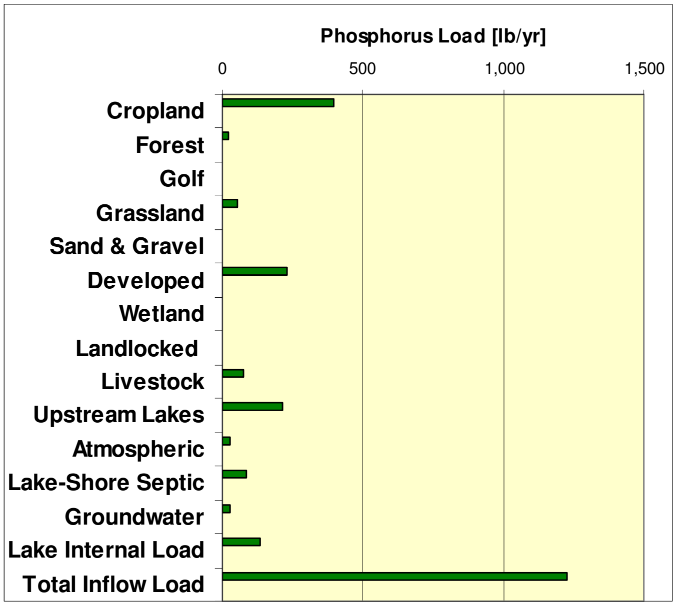
Bone Lake Phosphorus Budget

External Loading

Cropland and developed watershed runoff loads are the primary external components of the Bone Lake phosphorus budget. Upstream lakes, especially Moody, contribute another significant load that must be controlled to improve Bone Lake. Livestock and septic

[2] Due to the size of the entire watershed annual differences at Comfort Lake may not be reflected at each lake.

loads are also significant, controllable sources of phosphorus to Bone Lake. The total load to Bone Lake is 1,229 pounds per year under the benchmark condition. Detailed phosphorus budgets are tabulated in Appendix K; and summarized graphically below:



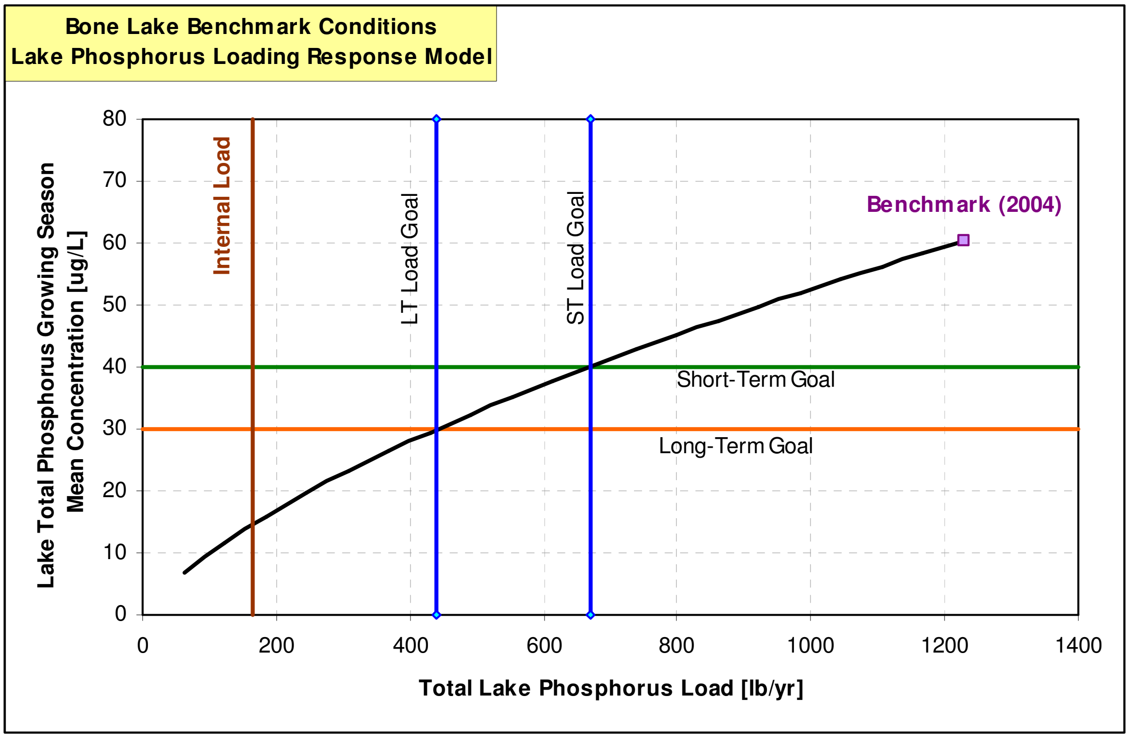
Internal Loading

The Bone Lake internal load of 188 pounds was determined from the microcosm release rate experiments and the average anoxic factor for 2003 to 2006 (see Appendix G). The internal load was adjusted to 132 pounds in the calibration.

Bone Lake Model and Load Response

Empirical models are frequently used in the evaluation of lake response to phosphorus loading; phosphorus is the limiting nutrient for most Minnesota lakes. Lake models, such as the Canfield-Bachmann (1981) equation, are used to evaluate the phosphorus sedimentation and predict average in-lake phosphorus concentration as a result of external and internal loads, and water outflow rates. A second empirical relationship is then used to predict the in-lake algal concentration – measured by the concentration of the photosynthetic pigment chlorophyll-*a* - from the in-lake phosphorus. Finally a third empirical relationship is used to predict water clarity, or Secchi depth, from the chlorophyll-*a* concentrations. These second and third empirical relations are usually ecoregion, or even lake-specific. The phosphorus – chlorophyll-*a* – Secchi depth correlations (summarized in Appendix I) were selected from the MNLEAP model (Heiskary, 1987).

Load response curves were computed for Bone Lake by step-wise reducing the total phosphorus load and calculating the lake response variables for each step using the empirical models. The Bone Lake response models and load response curves are presented in Appendix K; the Bone Lake load response curve for phosphorus is shown below.



LEGEND

COLOR	DESCRIPTION
Black	– Modeled Lake Response to Load Reductions
Brown	– Internal Load
Green	– Lake Total Phosphorus Goal (MPCA Standard)
Purple	– Non-Degradation Goal
Blue	– Load Required to Meet Goals

Bone Lake Goals and Load Reductions

In-Lake Phosphorus Goal

The Bone Lake growing season, surface total phosphorus goal is 40 ug/L, the MPCA standard for "deep" lakes; it represents a short-term goal for the lake.

Bone Lake has a more stringent long-term goal of 30 ug/L, which is the standard suggested by the District in the 2001 Watershed Management Plan.

Load Reduction Goals

The watershed loading and lake response spreadsheet model (Appendix K) predicts that a total phosphorus load of 669 pounds would allow Bone Lake to meet its in-lake total phosphorus short-term goal of 40 ug/L. Under benchmark conditions, the total phosphorus load to Bone Lake is currently 1,229 pounds. The difference in these endpoints is the load reduction goal of 560 pounds, or a 46% reduction of the benchmark load.

An additional 226 pound load reduction, lowering the total phosphorus load to 443 pounds and would allow Bone Lake to meet its in-lake total phosphorus long-term goal of 30 ug/L. The relationship between loading and the in-lake phosphorus goals is illustrated in the lake response curve in Section 4.6 and summarized in the table below:

Source		Existing	Short-term Goals	Long-term Goals
Lake Total Phosphorus	[ug/L]	60	40	30
Total Load	[lb]	1,229	669	443
Load Reduction Goals	[lb]		(560)	(786)
	[%]		46%	64%

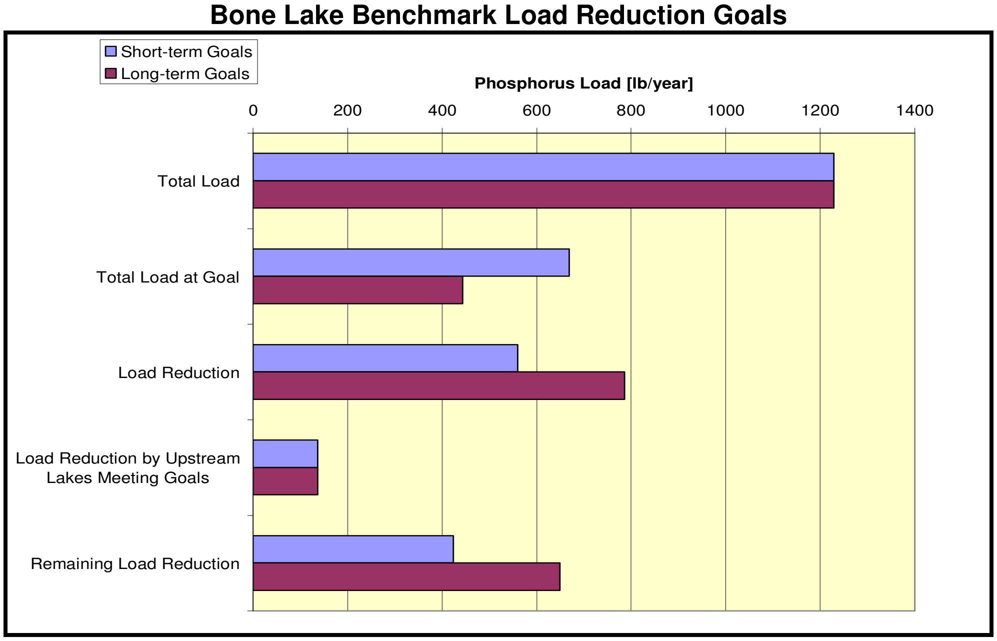
Load Reduction due to Upstream Lakes

The watershed loading and lake response model was used to determine load reductions to Bone Lake caused by *upstream lakes meeting their goals*. Moody Lake is upstream of Bone Lake, and improvements at Moody Lake would reduce the magnitude of load reductions required for Bone Lake to meet goals.

If Moody Lake's outlet discharged at its short-term goal of 40 ug/L, Bone Lake's load reduction goal, to meet the short-term goal of 40 ug/L, is 423 pounds (a reduction of 137 pounds).

If Moody Lake's outlet discharged at its long-term goal of 40 ug/L, Bone Lake's load reduction goal, to meet the long-term goal of 30 ug/L, is 649 pounds (a reduction of 137 pounds).

Bone Lake Benchmark Load Reduction Goals



Best Management Practices and Load Reduction Projects

Section 12 describes the process of BMP and project selection for all of the studied lakes.

BIRCH LAKE

Physical Setting

Birch Lake Watershed

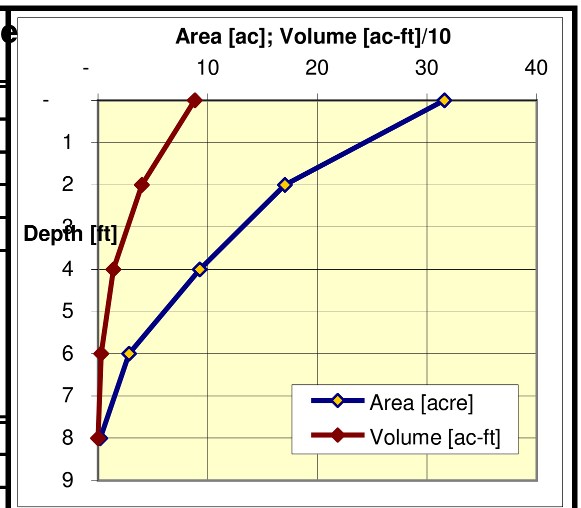
Birch Lake is a flow-through lake situated roughly two miles downstream of Bone Lake. Its intervening watershed encompasses 1,890 acres (6% of CLFLWD) and two lakes (Nielsen Lake and Birch Lake). The land use in Birch Lake's watershed is wetlands (25%), forest (24%), cropland (23%), and grassland (13%). Nielsen Lake is landlocked; its groundwater outflow apparently drains toward Birch Lake. The land use in Nielsen Lake's watershed is cropland with scattered small wetlands. There is a small pocket of rich fens noted in LCL22.

The two-mile flow path from Bone to Birch Lake starts at the Bone Lake outlet, a culvert under County Road 1. There are backwater effects from a 0.5 acre open water area just downstream from the culvert. From there, the channel is apparently ditched through wetlands in LCL15 and LCL20 subwatersheds. From there, the channel is not straightened in LCL27 and LCL11 to Birch Lake, but flows through a narrower wetland corridor with some recent development occurring on the surrounding upland areas.

Birch Lake

Birch Lake is considered a shallow lake, with a littoral area of 100%. MPCA defines a shallow lake as lakes with a maximum depth of 15 feet or less, or with a littoral area of 80% or more (shallow enough to support emergent and submerged rooted aquatic plants). Birch Lake does not stratify throughout the summer growing season. A bathymetric map of Birch Lake is presented in Appendix H; its depth and volume are summarized below:

Depth [ft]	Area [acre]	Volume [ac-ft]
-	32	88
2	17	40
4	9	14
6	3	3
8	0	-
2.8	Average Depth	
8.0	Maximun Depth	
100%	Littoral	



Birch Lake Water Quality History

Present Conditions, Trends

Summaries of historic water quality are presented in tabular and graphic form for Birch Lake in Appendix I (original data and sources are included on the report CD). The data are presented as growing season (June 1 to September 30) averages of surface total phosphorus, chlorophyll-*a*, and Secchi depth for each year data was available. Data were available for Birch Lake from 2005 and 2006; the two-year average total phosphorus average is 127 ug/L. The two-year average chlorophyll-*a* average is 42 ug/L (ppb). With just two years of water quality monitoring, no trends in water quality can be identified for Birch Lake.

Past Studies

There are no past studies of Birch Lake water quality other than the recent monitoring. The 2001 Comfort Lake-Forest Lake Watershed District Watershed Management Plan did not identify Birch Lake as one of the six key recreational lakes to be protected.

Birch Lake Ecological Analysis

Ecological data (fish and macrophyte data) were not collected for Birch Lake as part of this study. Without ecological data it is not possible to describe the current state of competing equilibria for this shallow lake (Turbid and Clearwater State).

Birch Lake Water Budget

Bone Lake's discharge is the largest component of Birch Lake's water budget tabulated below.[3] The benchmark year was used for the load reduction calculation and project sizing. The wet and dry years were used for verifications of the watershed and lake models. Appendix C describes the development of the lake water budgets and presents a bar plot of the benchmark conditions for Birch Lake.

[3] Note that benchmark conditions refer to the 2004 Water Year, the year studied that most closely represents "normal conditions." Wet and dry conditions were represented by 2003 and 2006 Water Years respectively, as reflected in the total Comfort Lake watershed runoff. Due to the size of the entire watershed annual differences at Comfort Lake may not be reflected at each lake.

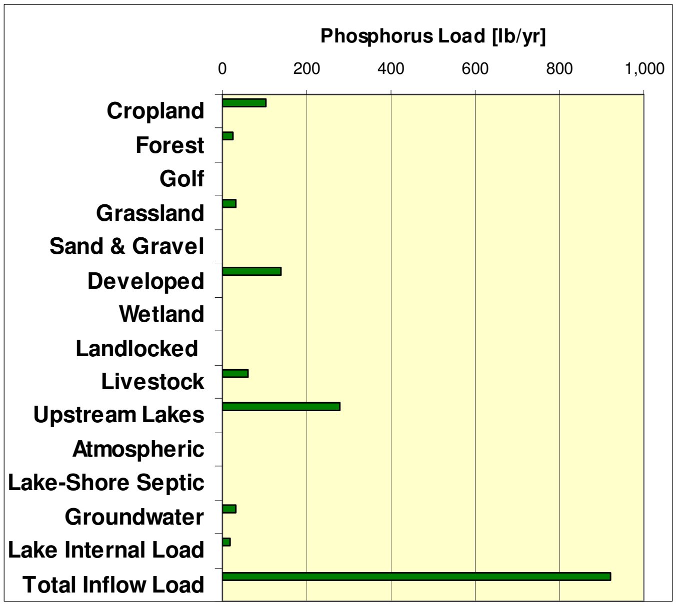
Birch Lake Water Budget Outflow and Inflow Volumes		Benchmark Conditions (2004)	Wet Conditions (2003)	Dry Conditions (2006)
Inflow Volumes [ac-ft]	Watershed Runoff	555	1,042	825
	Precipitation (direct)	57	60	54
	Flow from Upstream Lakes via Surface	1,591	2,137	394
	Flow from Upstream Lakes via Groundwater	195	224	204
	Regional Groundwater Inflow	12	12	12
	Net Inflow (Change in Storage)	-	-	-
TOTAL INFLOW [ac-ft]		**2,411**	**3,476**	**1,489**
Outflow Volumes [ac-ft]	Evaporation from Lake	(75)	(81)	(81)
	Discharge through Outlet	(2,335)	(3,395)	(1,446)
	Discharge via Groundwater		-	-
	Regional Groundwater Outflow	-	-	-
TOTAL OUTFLOW [ac-ft]		**(2,411)**	**(3,476)**	**(1,527)**
Birch Lake Residence Time [year]		**0.0**	**0.0**	**0.1**

Under benchmark conditions, the lake flushes 27 times per year. Under wet conditions flushing increases to 40 times, and under dry conditions this lake still flushes 17 times. Birch Lake's short residence times reduce its ability to process and remove phosphorus biologically, so that sedimentation of phosphorus is relatively small. Much of its load will be discharged from the lake through its outlet.

Birch Lake Phosphorus Budget

External Loading

The detailed phosphorus budget for Birch Lake is tabulated in Appendix K and graphically summarized below. The total load to Birch Lake is 919 pounds, with upstream lakes as the largest source. Loading from developed and agricultural land uses combined were similar in magnitude to the upstream lake loading.



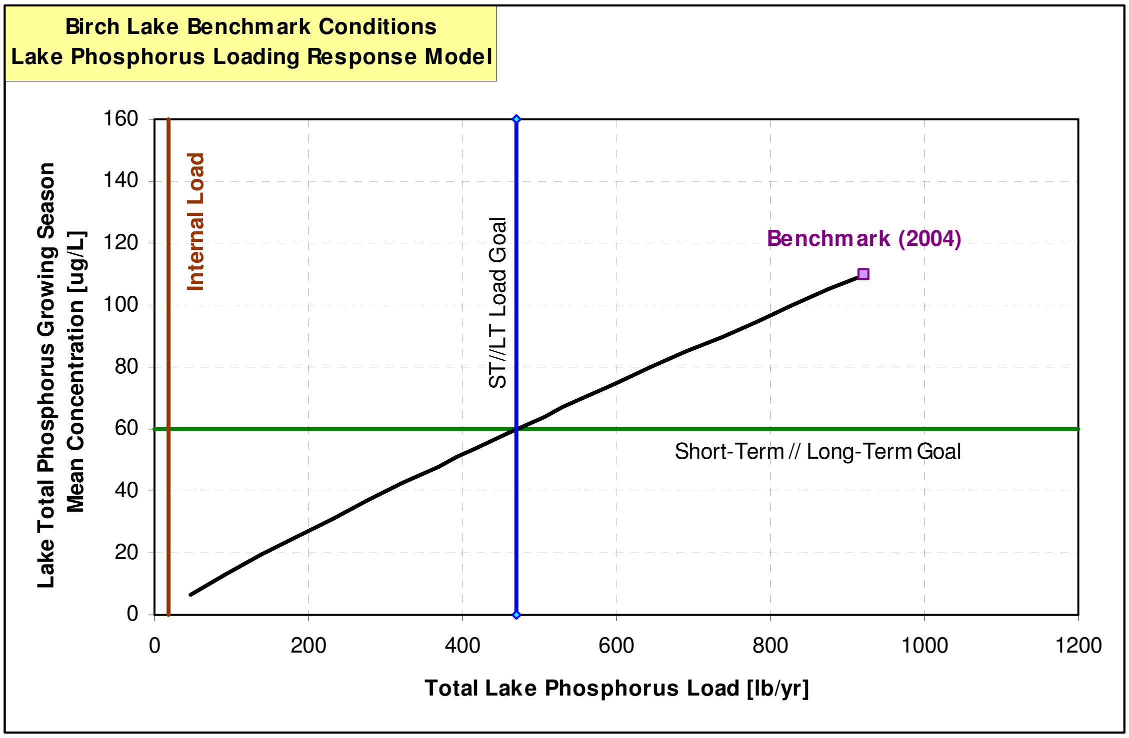
Internal Loading

The Birch Lake internal load of 18 pounds was estimated using an assumed sediment release rate and the average anoxic factor for 2005 and 2006 (see Appendix G).

Birch Lake Model and Load Response

Empirical models are frequently used in the evaluation of lake response to phosphorus loading; phosphorus is the limiting nutrient for most Minnesota lakes. Lake models, such as the Canfield-Bachmann (1981) equation, are used to evaluate the phosphorus sedimentation and predict average in-lake phosphorus concentration as a result of external and internal loads, and water outflow rates. A second empirical relationship is then used to predict the in-lake algal concentration – measured by the concentration of the photosynthetic pigment chlorophyll-*a* - from the in-lake phosphorus. Finally a third empirical relationship is used to predict water clarity, or Secchi depth, from the chlorophyll-*a* concentrations. These second and third empirical relations are usually ecoregion, or even lake-specific. Selection of the phosphorus – chlorophyll-*a* – Secchi depth correlations for Birch Lake is summarized in Appendix I.

Load response curves were computed for Birch Lake by step-wise reducing the total phosphorus load and calculating the lake response variables for each step using the empirical models. The Birch Lake response models and load response curves are presented in Appendix K; the load response curve for phosphorus is shown below:



LEGEND

COLOR	**DESCRIPTION**
Black	**– Modeled Lake Response to Load Reductions**
Brown	**– Internal Load**
Green	**– Lake Total Phosphorus Goal (MPCA Standard)**
Purple	**– Non-Degradation Goal**
Blue	**– Load Required to Meet Goals**

Birch Lake Goals and Load Reductions

In-Lake Phosphorus Goal

The Birch Lake growing season, surface total phosphorus goal is 60 ug/L, the MPCA standard for "shallow" lakes; this applies both in the short-term and long-term.

Load Reduction Goals

The watershed loading and lake response spreadsheet model (Appendix K) predicts that a total phosphorus load of 471 pounds would allow Birch Lake to meet its in-lake total phosphorus goal. Under benchmark conditions, the total phosphorus load to Birch Lake is currently 922 pounds. The difference in these endpoints is the load reduction goal of 451 pounds of external and internal loading, this is a 49% reduction from existing benchmark conditions.

Source		Existing	Short-term Goals	Long-term Goals
Lake Total Phosphorus	[ug/L]	110	60	60
Total Load	[lb]	922	471	471
Load Reduction Goals	[lb]		(451)	(451)
	[%]		49%	49%

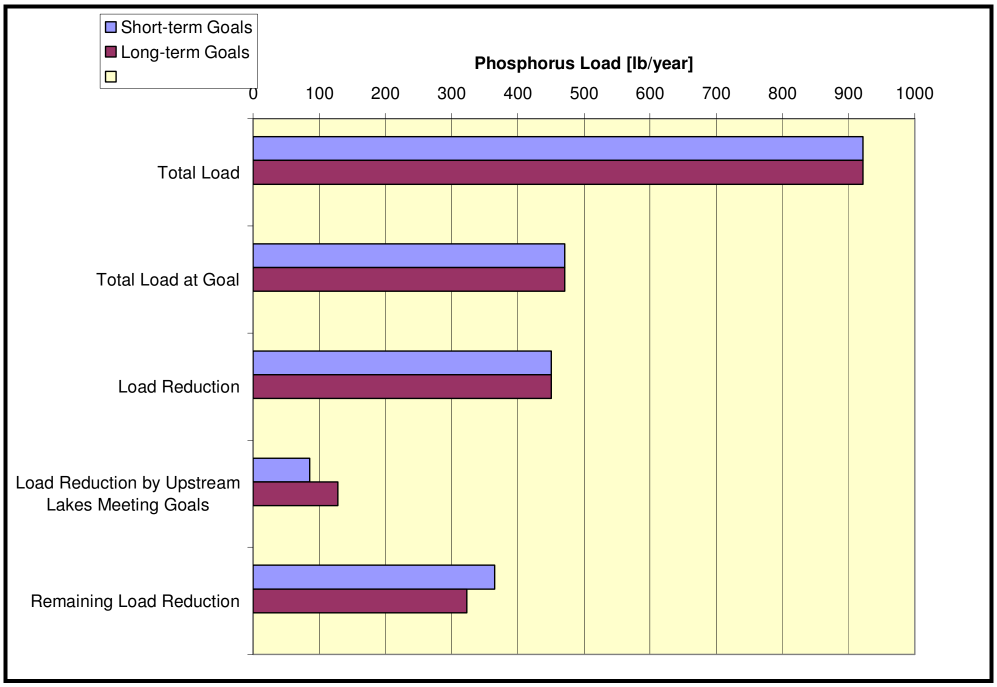
Load Reduction due to Upstream Lakes

The watershed loading and lake response model was used to determine load reductions to Birch Lake caused by *upstream lakes meeting their goals*. Bone Lake is upstream of Birch Lake, and improvements at Bone Lake would reduce the magnitude of load reductions required for Birch Lake to meet goals.

If Bone Lake's outlet discharged at its short-term goal of 40 ug/L, Birch Lake's load reduction goal, to meet the short-term goal of 60 ug/L, is 365 pounds (a reduction of 86 pounds).

If Bone Lake were meeting the long-term goal of 30 ug/L, Birch Lake's load reduction goal, to meet the long-term goal of 60 ug/L, is 323 pounds (a reduction of 128 pounds).

Birch Lake Benchmark Load Reduction Goals



Best Management Practices and Load Reduction Projects

Section 12 describes the process of BMP and project selection for all of the studied lakes.

SCHOOL LAKE

Physical Setting

School Lake Watershed

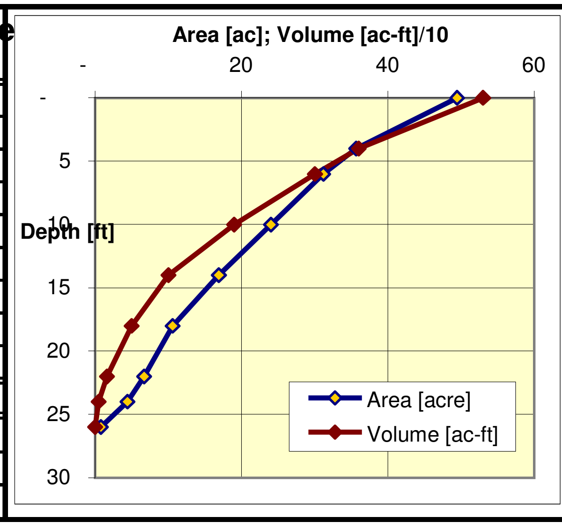
The intervening watershed between School Lake and Birch Lake is just 780 acres (2% of CLFLWD). The land use and land cover are cropland (33%), grassland (19%), wetlands (14%), and forest (12%). The watershed is mostly situated northeast of School Lake.

The northeast portion of the watershed is cropland with livestock grazing areas that drain to a wetland; from there a channel flows through grasslands to School Lake. Discharge from Birch Lake flows to School Lake by way of a defined channel within wetland complexes. Wetlands buffer School Lake from development encroaching from the south.

School Lake

School Lake is considered a deep lake; 66% of the area is littoral. Its maximum depth ensures that it remains thermally stratified through the growing season. A bathymetric map of School Lake is presented in Appendix H; its depth and volume are summarized below:

Depth [ft]	Area [acre]	Volume [ac-ft]
-	49	530
4	36	360
6	31	300
10	24	190
14	17	100
18	11	50
22	7	16
24	4	5
26	1	-
11	Average Depth	
26	Maximun Depth	
66%	Littoral	



School Lake Water Quality History

Present Conditions, Trends

Summaries of historic water quality are presented in tabular and graphic form for School Lake in Appendix I (original data and sources are included on the report CD). The data are presented as growing season (June 1 to September 30) averages of surface total phosphorus, chlorophyll-*a*, and Secchi depth for 2005 and 2006. With a two-year average total phosphorus average of 73 ug/L it is significantly better than Birch Lake. This is above typical values for North Central Hardwood Forest Ecoregion (23-50 ug/L), and is indicative of eutrophic conditions. The two-year average chlorophyll-*a* average is

39 ug/L (ppb). With just two years of water quality monitoring, no trends in water quality can be identified for School Lake.

Past Studies

There are no past studies of School Lake water quality other than the recent monitoring. The 2001 Comfort Lake-Forest Lake Watershed District Watershed Management Plan did not identify School Lake as one of the six key recreational lakes to be protected.

School Lake Ecological Analysis

Ecological data (fish and macrophyte data) were not collected for School Lake as part of this study.

School Lake Water Budget

Birch Lake's discharge is the dominant component of School Lake's water budget tabulated below.[4] The benchmark year was used for the load reduction calculation and project sizing. The wet and dry years were used for verifications of the watershed and lake models. Appendix C describes the development of the lake water budgets and presents a bar plot of the benchmark conditions for School Lake.

School Lake Water Budget Outflow and Inflow Volumes		**Benchmark Conditions (2004)**	**Wet Conditions (2003)**	**Dry Conditions (2006)**
Inflow Volumes [ac-ft]	Watershed Runoff	478	727	491
	Precipitation (direct)	109	94	101
	Flow from Upstream Lakes via Surface	2,335	3,395	1,446
	Flow from Upstream Lakes via Groundwater	15	17	17
	Regional Groundwater Inflow	19	19	19
	Net Inflow (Change in Storage)	-	-	-
TOTAL INFLOW [ac-ft]		**2,956**	**4,252**	**2,075**
Outflow Volumes [ac-ft]	Evaporation from Lake	(118)	(127)	(127)
	Discharge through Outlet	(2,838)	(4,125)	(1,947)
	Discharge via Groundwater		-	-
	Regional Groundwater Outflow	-	-	-
TOTAL OUTFLOW [ac-ft]		**(2,956)**	**(4,252)**	**(2,075)**
School Lake Residence Time [year]		**0.2**	**0.1**	**0.3**

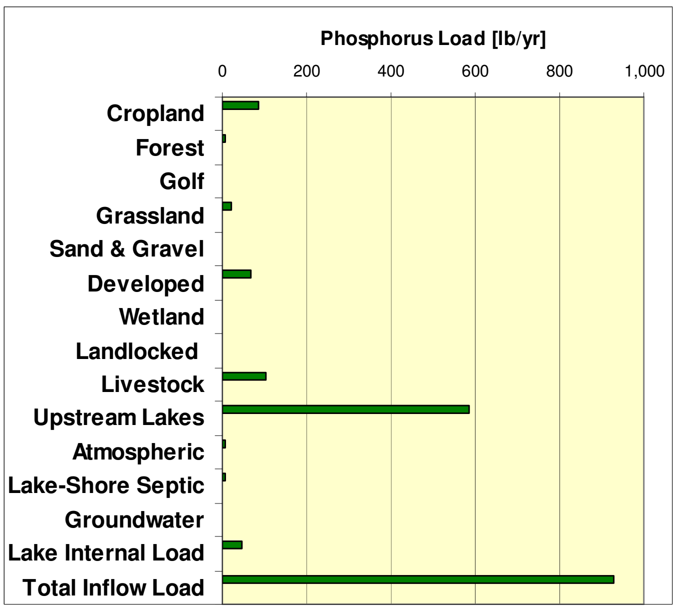
[4] Note that benchmark conditions refer to the 2004 Water Year, the year studied that most closely represents "normal conditions." Wet and dry conditions were represented by 2003 and 2006 Water Years respectively, as reflected in the total Comfort Lake watershed runoff. Due to the size of the entire watershed annual differences at Comfort Lake may not be reflected at each lake.

Due to its large watershed area, its residence time is less than three months, even under dry conditions. The high flow-through rate (flushing more then four times per year) tends to reduce its ability to retain phosphorus. The lake response model balances the effects of phosphorus loading, discharge from the lake (through its outlet), and calculates settling of phosphorus on an annual timestep in order to estimate the growing season, surface total phosphorus.

School Lake Phosphorus Budget

External Loading

Most of the School Lake load is from Birch Lake. The intervening watershed load is comprised of loads from cropland, developed areas, and livestock. The School Lake phosphorus budget is tabulated in Appendix K; and summarized graphically below:



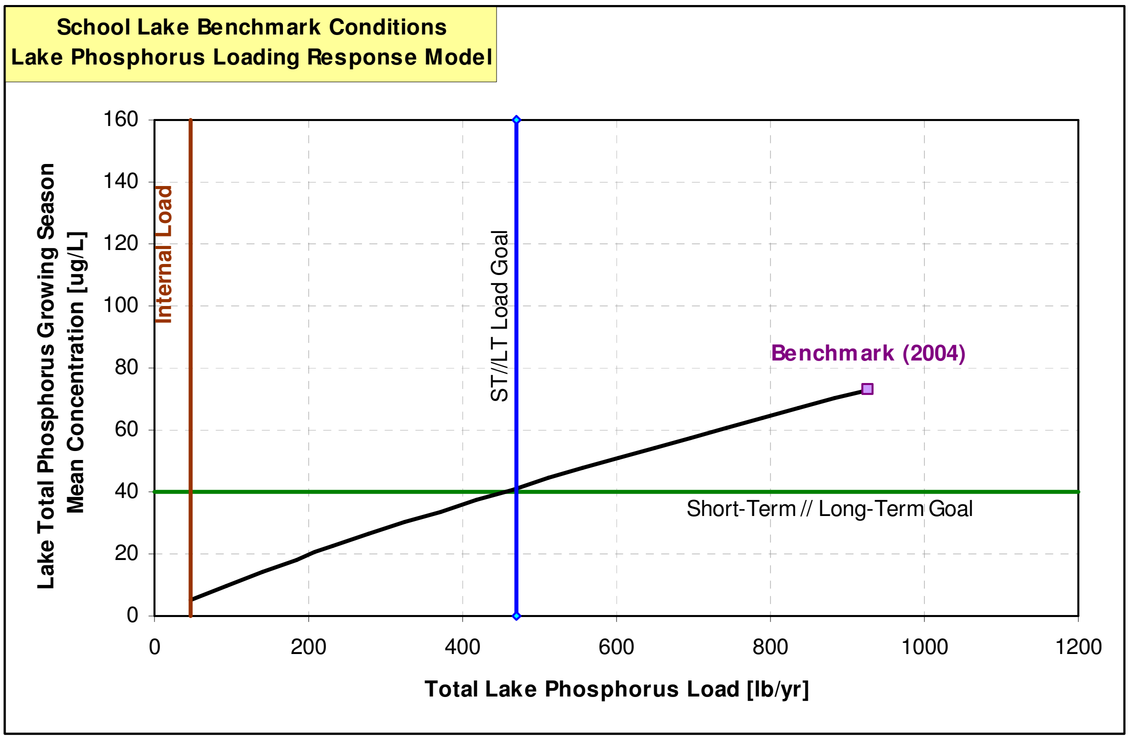
Internal Loading

The School Lake internal load of 45 pounds was determined with an estimated sediment anoxic release rate and the average anoxic factor for 2005 and 2006 (see Appendix G).

School Lake Model and Load Response

Empirical models are frequently used in the evaluation of lake response to phosphorus loading; phosphorus is the limiting nutrient for most Minnesota lakes. Lake models, such as the Canfield-Bachmann (1981) equation, are used to evaluate the phosphorus sedimentation and predict average in-lake phosphorus concentration as a result of external and internal loads, and water outflow rates. A second empirical relationship is then used to predict the in-lake algal concentration – measured by the concentration of the photosynthetic pigment chlorophyll-*a* - from the in-lake phosphorus. Finally a third empirical relationship is used to predict water clarity, or Secchi depth, from the chlorophyll-*a* concentrations. These second and third empirical relations are usually ecoregion, or even lake-specific. Selection of the phosphorus – chlorophyll-*a* – Secchi depth correlations is summarized in Appendix I.

Load response curves were computed for School Lake by step-wise reducing the total phosphorus load and calculating the lake response variables for each step using the empirical models. The School Lake response models and load response curves are presented in Appendix K; the School Lake load response curve for phosphorus is shown below:



LEGEND

COLOR	**DESCRIPTION**
Black	**– Modeled Lake Response to Load Reductions**
Brown	**– Internal Load**
Green	**– Lake Total Phosphorus Goal (MPCA Standard)**
Purple	**– Non-Degradation Goal**
Blue	**– Load Required to Meet Goals**

School Lake Goals and Load Reductions

In-Lake Phosphorus Goal

The School Lake growing season, surface total phosphorus goal is 40 ug/L, the MPCA standard for "deep" lakes; this applies to both the short-term and long-term goals.

Load Reduction Goals

The watershed loading and lake response spreadsheet model (see response curve in Section 6.6) predicts that a total phosphorus load of 452 pounds would allow School Lake to meet its in-lake total phosphorus goal. Under benchmark conditions, the total phosphorus load to School Lake is currently 928 pounds. The difference in these endpoints is the load reduction goal of 476 pounds of external and internal loading, this is a 51% reduction from existing benchmark conditions.

Source		Existing	Short-term Goals	Long-term Goals
Lake Total Phosphorus	[ug/L]	73	40	40
Total Load	[lb]	928	452	452
Load Reduction Goals	[lb]		(476)	(476)
	[%]		51%	51%

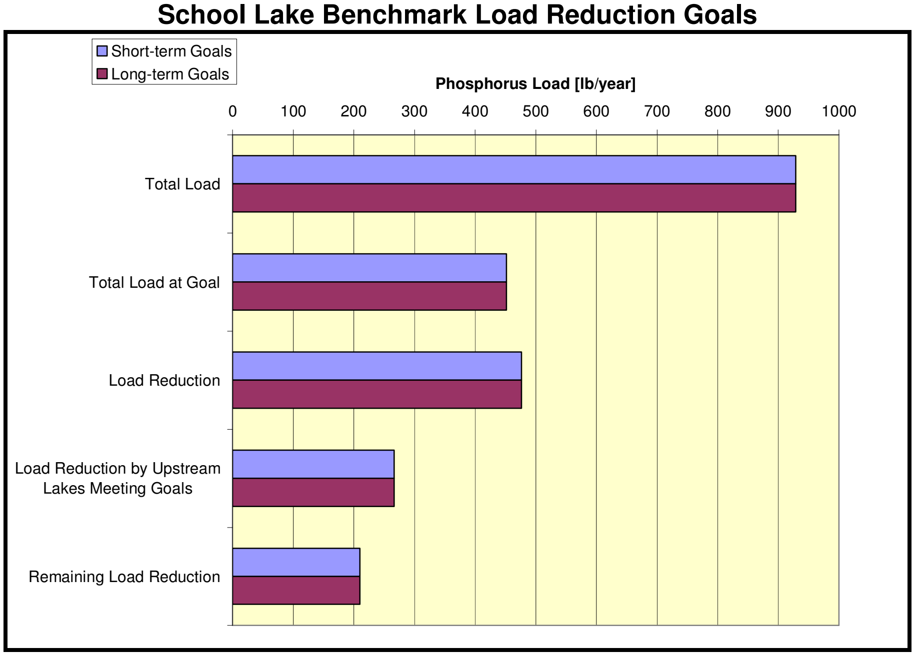
Load Reduction due to Upstream Lakes

The watershed loading and lake response model was used to determine load reductions to School Lake caused by *upstream lakes meeting their goals*. Birch Lake is upstream of School Lake, and improvements at Birch Lake would reduce the magnitude of load reductions required for School Lake to meet goals.

If Birch Lake's outlet discharged at its short-term goal of 60 ug/L, School Lake's load reduction goal, to meet the short-term goal of 40 ug/L, is 210 pounds (a reduction of 267 pounds).

If Birch Lake's outlet discharged at its long-term goal of 60 ug/L, School Lake's load reduction goal, to meet the long-term goal of 40 ug/L, is 210 pounds (a reduction of 267 pounds).

School Lake Benchmark Load Reduction Goals



Best Management Practices and Load Reduction Projects

Section 12 describes the process of BMP and project selection for all of the studied lakes.

LITTLE COMFORT LAKE

Physical Setting

Little Comfort Lake Watershed

The Little Comfort Lake watershed comprises 4,410 acres (14% of CLFLWD) starting at the Bone Lake Outlet. This area includes three named lakes and their watersheds: Nielson Lake, School Lake and Birch Lake (described in previous sections).

The portion of Little Comfort Lake watershed downstream of School Lake encompasses 1,740 acres (6% of CLFLWD). The tributary land use is wetlands (25%), cropland (21%), grassland (21%) and forest (17%). There are two main inlets to Little Comfort Lake; one that receives flows from School Lake, and another one entering Little Comfort Lake along the southern shore (LCL48).

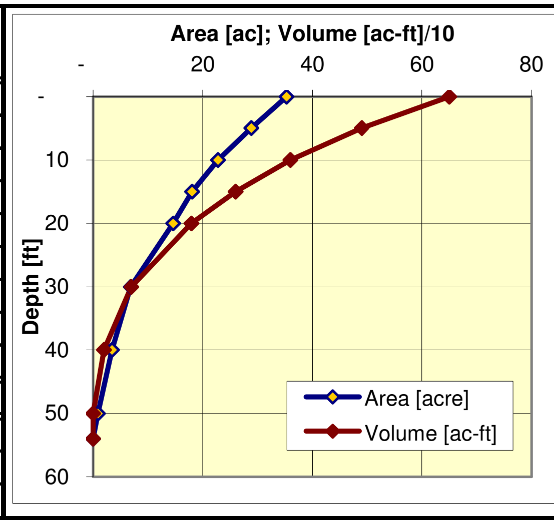
The watershed drains by way of naturally meandering channels (through LCL04, LCL07 and LCL03) from School Lake (over a beaver dam north of a sand and gravel operation) through forest buffered wetlands and through a couple of culverts under road crossings into Little Comfort Lake. The watershed, upland of wetlands and woods, is mostly grassland and cropland with very few residences.

Drainage that collects along the southern shore (LCL48) of Little Comfort Lake is from two drainages. The south drainage originates in a wetland complex at the watershed divide with Forest Lake (LCL47) and drains north to Little Comfort Lake. East of this drainage route is developing residential, while to the west of this drainage route remains cropland. The southwest drainage also originates in a wetland at the watershed divide with Forest Lake (LCL44) and watershed divide with Sunrise River. It drains toward Little Comfort Lake through cropland, by way of the watershed's remaining wetlands.

Little Comfort Lake

Little Comfort Lake (MN DNR Lake # 13-0054-00) is considered a deep lake with 49% of the area being littoral. Its maximum depth ensures that it remains thermally stratified through the growing season. A bathymetric map of Little Comfort Lake is presented in Appendix H; its depth and volume are summarized below:

Depth [ft]	Area [acre]	Volume [ac-ft]
-	35	650
5	29	490
10	23	360
15	18	260
20	15	180
30	7	70
40	3	20
50	1	-
54	-	-
18	Average Depth	
54	Maximun Depth	
49%	Littoral	



Little Comfort Lake Water Quality History

Present Conditions, Trends

Summaries of historic water quality are presented in tabular and graphic form for Little Comfort Lake in Appendix I (original data and sources are included on the report CD). The data are presented as growing season (June 1 to September 30) averages of surface total phosphorus, chlorophyll-*a*, and Secchi depth for each year data was available. Data were available for Little Comfort Lake in 1994 and 2006; the two-year average (not continuous) total phosphorus average is 105 ug/L. This is above typical values for North Central Hardwood Forest Ecoregion (23-50 ug/L), and is indicative of hypereutrophic conditions. Considering just 2006, the surface total phosphorus average of 76 ug/L is indicative of eutrophic conditions. The two-year average chlorophyll-*a* average is 29 ug/L (ppb). With just two years of water quality monitoring, no trends in water quality can be identified for Little Comfort Lake.

Past Studies

Key findings and recommendation of past studies of Little Comfort Lake are summarized below:

- MPCA (et al., 1995) completed a Lake Assessment Program study of Comfort and Little Comfort Lakes based on monitoring completed in 1994. (Appendix L includes a quantitative review of the 1995 study). The study suggested a total phosphorus goal of 40 ug/L for Little Comfort Lake and noted that the lakes would be sensitive to change in trophic status with relatively minor increases in the nutrient loading rates from watershed and in-lake sources. Recommendations included: Evaluation of on-site septic systems around the lake; development should occur in a manner to minimize water quality impacts; a study to identify nutrient sources to determine sites for BMPs and projects. The study also concluded that the water quality of the lakes in 1994 was good compared to other lakes in the eco-region. The report also suggested restoration of wetlands might reduce nutrient loads.

- Blue Water Science (et al., 2002) completed a Clean Water Partnership - Phase 1 Resource Investigation of Comfort and Little Comfort Lakes. (Appendix L includes a quantitative review of the 2002 study). The study was probably the most extensive investigation of Comfort and Little Comfort lakes to date. The study recommended several items which would apply to Little Comfort:
  - Promote small-scale infiltration projects in all subwatersheds;
  - Promote shoreline restoration and maintenance of shoreline septic systems;
  - Remove rough fish and install carp barriers;
  - Plan for milfoil invasion;
  - Increase native aquatic plants;
  - Maintenance around culverts; and
  - Whole-lake alum treatment (considered a reserve project).

  In 1998, monitoring of the main inflow to Little Comfort Lake showed concentrations ranging from 25 to over 600 ug/L. Concentrations above 100 ug/L occurred mostly in May through August. However, the loading calculated for Little Comfort is equivalent to about 90 ug/L. The reported flow-weighted mean for April to September 1998 was 123 ug/L. This suggests that high summer flows could increase loading and average inflow concentrations to Little Comfort Lake.

  The 1994 and 1998 bottom phosphorus data suggested internal loading of phosphorus with bottom values roughly seven times surface values. The internal load estimate was 260 pounds for Little Comfort. The study also recommended a spring plant survey to quantify the presence of curly leaf pondweed.

- The 2001 Comfort Lake-Forest Lake Watershed District Watershed Management Plan identified a study process that included the present study to determine the projects and programs to protect lake water quality, particularly six key recreational lakes Comfort, Little Comfort, Bone, Forest, Shields and Sylvan Lakes.

Little Comfort Lake Ecological Analysis

Analysis of recent ecological data for the study lakes are included in Appendix J. Key findings relative to Little Comfort Lake are presented below:

- Panfish and top predators comprise the majority of biomass.
- Rough fish population has remained stable across surveys.
- Overall plant community diversity is low.
- Lake is dominated by dense stands of curly leaf pondweed and coontail.

Little Comfort Lake Water Budget

School Lake's discharge is the largest component of Little Comfort's water budget tabulated below. Appendix C describes the development of the lake water budgets and presents a bar plot of the benchmark conditions for this lake.[5]

Little Comfort Lake Water Budget Outflow and Inflow Volumes		Benchmark Conditions (2004)	Wet Conditions (2003)	Dry Conditions (2006)
Inflow Volumes [ac-ft]	Watershed Runoff	967	1,391	1,098
	Precipitation (direct)	78	71	72
	Flow from Upstream Lakes via Surface	2,838	4,125	1,947
	Flow from Upstream Lakes via Groundwater	2	3	34
	Regional Groundwater Inflow	14	14	14
	Net Inflow (Change in Storage)	4	(26)	-
TOTAL INFLOW [ac-ft]		**3,902**	**5,578**	**3,165**
Outflow Volumes [ac-ft]	Evaporation from Lake	(84)	(91)	(91)
	Discharge through Outlet	(3,810)	(5,539)	(3,074)
	Discharge via Groundwater		-	-
	Regional Groundwater Outflow	-	-	-
TOTAL OUTFLOW [ac-ft]		**(3,895)**	**(5,630)**	**(3,165)**
Little Comfort Lake Residence Time [year]		**0.2**	**0.1**	**0.2**

School Lake Discharge dominates. Under benchmark conditions, the lake flushes 6.0 times. Under wet conditions flushing increases to 8.6 times, and under dry conditions it flushes 4.9 times. The lake response model balances the effects of phosphorus loading, discharge from the lake (through its outlet), and calculates settling of phosphorus on an annual timestep in order to estimate the growing season, surface total phosphorus.

Little Comfort Lake Phosphorus Budget

External Loading

Loads from upstream lakes are the largest portion of the Little Comfort Lake phosphorus budget. Detailed phosphorus budgets tabulated in Appendix K; and graphically summarized below:

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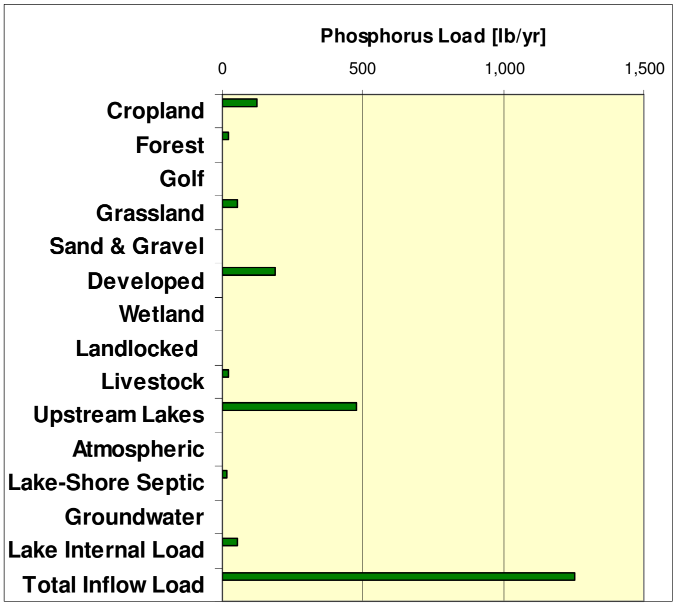
[5] Note that benchmark conditions refer to the 2004 Water Year, the year studied that most closely represents "normal conditions." Wet and dry conditions were represented by 2003 and 2006 Water Years respectively, as reflected in the total Comfort Lake watershed runoff. Due to the size of the entire watershed annual differences at Comfort Lake may not be reflected at each lake. The benchmark year was used for the load reduction calculation and project sizing. The wet and dry years were used for verifications of the watershed and lake models.



Internal Loading

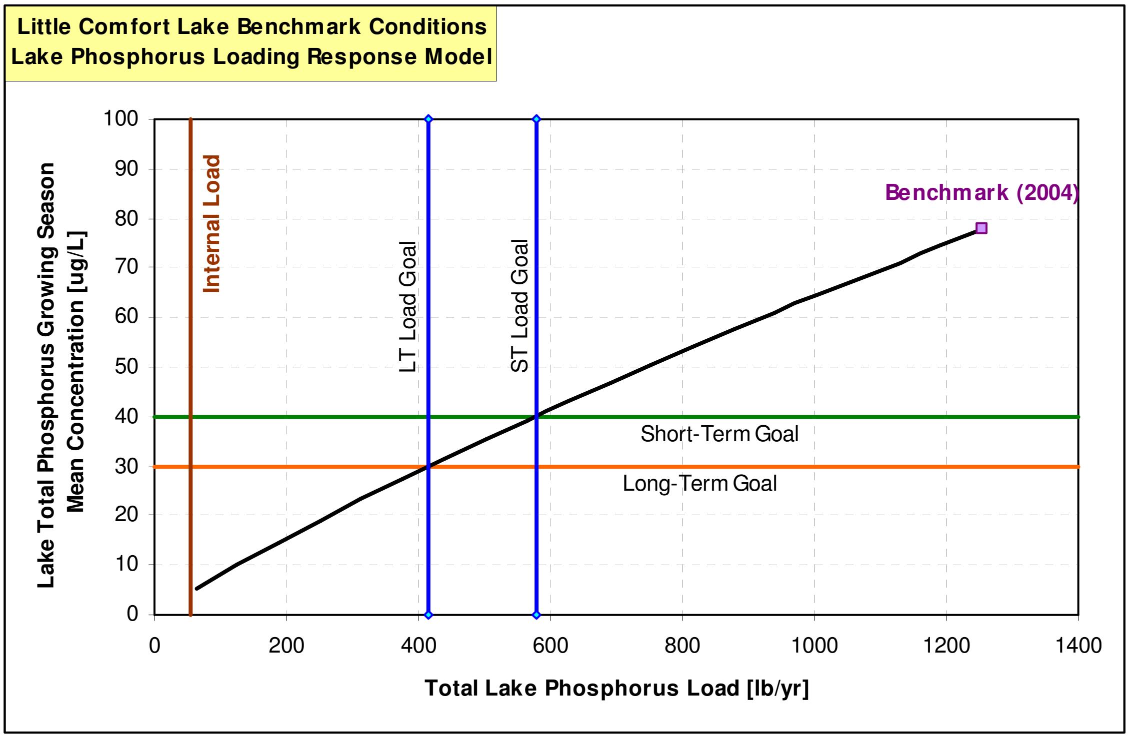
The Little Comfort Lake internal load of 59 pounds was determined from the microcosm release rate experiments and the anoxic factor for 2006 (see Appendix G). The internal load was adjusted to 56 pounds in the calibration.

Little Comfort Lake Model and Load Response

Empirical models are frequently used in the evaluation of lake response to phosphorus loading; phosphorus is the limiting nutrient for most Minnesota lakes. Lake models, such as the Canfield-Bachmann (1981) equation, are used to evaluate the phosphorus sedimentation and predict average in-lake phosphorus concentration as a result of external and internal loads, and water outflow rates. A second empirical relationship is then used to predict the in-lake algal concentration – measured by the concentration of the photosynthetic pigment chlorophyll-*a* - from the in-lake phosphorus. Finally a third empirical relationship is used to predict water clarity, or Secchi depth, from the chlorophyll-*a* concentrations. These second and third empirical relations are usually ecoregion, or even lake-specific. Selection of the phosphorus – chlorophyll-*a* – Secchi depth correlations is summarized in Appendix I.

Once the empirical models are selected and calibrated (if necessary), generation of lake-specific load response curves were computed for Little Comfort Lake by step-wise reducing the total phosphorus load and calculating the lake response variables for each step using the empirical models.

The Little Comfort Lake response models and load response curves are presented in Appendix K; the Little Comfort Lake load response curve for phosphorus is shown below:



LEGEND

COLOR	**DESCRIPTION**
Black	**– Modeled Lake Response to Load Reductions**
Brown	**– Internal Load**
Green	**– Lake Total Phosphorus Goal (MPCA Standard)**
Purple	**– Non-Degradation Goal**
Blue	**– Load Required to Meet Goals**

Little Comfort Lake Goals and Load Reductions

In-Lake Phosphorus Goal

The Little Comfort Lake growing season, surface total phosphorus goal is 40 ug/L, the MPCA standard for "deep" lakes; it represents a short-term goal for the lake.

Little Comfort Lake has a more stringent long-term goal of 30 ug/L, which is the standard suggested by the District in the 2001 Watershed Management Plan for recreational lakes.

Load Reduction Goals

The watershed loading and lake response spreadsheet model (Appendix K) predicts that a total phosphorus load of 577 pounds would allow Little Comfort Lake to meet its in-lake total phosphorus short-term goal of 40 ug/L. Under benchmark conditions, the total phosphorus load to Little Comfort Lake is currently 1,255 pounds. The difference in these endpoints is the load reduction goal of 678 pounds of external and internal loading, this is a 54% reduction from existing benchmark conditions.

An additional 161-pound load reduction lowers the total phosphorus load to 416-pounds and would allow Little Comfort Lake to meet its in-lake total phosphorus long-term goal of 30 ug/L.

Source		Existing	Short-term Goals	Long-term Goals
Lake Total Phosphorus	[ug/L]	78	40	30
Total Load	[lb]	1,255	577	416
Load Reduction Goals	[lb]		(678)	(839)
	[%]		54%	67%

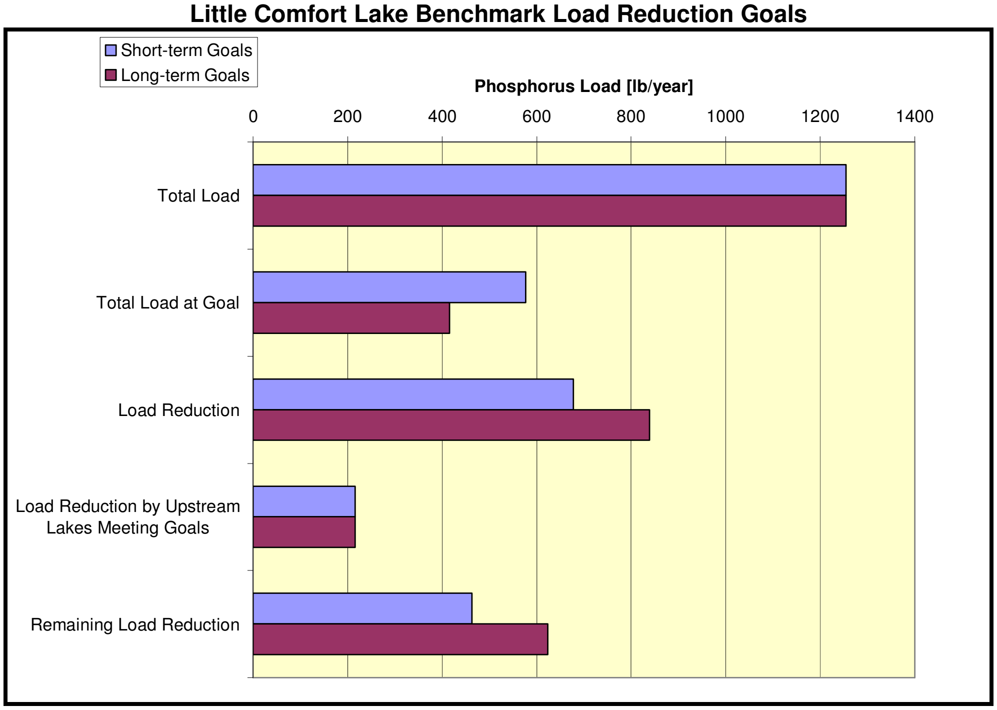
Load Reduction due to Upstream Lakes

The watershed loading and lake response model was used to determine load reductions caused by *upstream lakes meeting their goals*. School Lake is upstream of Little Comfort Lake, and improvements at School Lake would reduce the magnitude of load reductions required for Little Comfort Lake to meet goals.

If School Lake's outlet discharged at its short-term goal of 40 ug/L, Little Comfort Lake's load reduction goal, to meet the short-term goal of 40 ug/L, is 463 pounds (a reduction of 215 pounds).

If School Lake's outlet discharged at its long-term goal of 40 ug/L, Little Comfort Lake's load reduction goal, to meet the long-term goal of 30 ug/L, is 624 pounds (a reduction of 215 pounds).

Little Comfort Lake Benchmark Load Reduction Goals



Best Management Practices and Load Reduction Projects

Section 12 describes the process of BMP and project selection for all of the studied lakes.