

# SPIRIT LAKES WATER QUALITY ASSESSMENT

## NORTH SPIRIT (WBIC 1515200) AND SPIRIT LAKE (WBIC 1513000) (PRICE/TAYLOR CO.)

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### Introduction

Total phosphorus (TP) and chlorophyll *a* (CHL) impairment thresholds for recreational use, and fish and aquatic life use are exceeded by North Spirit and Spirit Lakes. These impairment thresholds are used for identifying waters to be placed on the 303d list. Watershed tributary and groundwater monitoring and a review of existing in-lake data were done in 2010 to document conditions and to determine if it is possible to reduce in-lake TP concentrations below impairment thresholds. Lake sediment cores were also collected and analyzed to compare lake conditions before and after watershed development. The watershed was suspected of having high naturally occurring groundwater phosphorus concentrations, and higher than average background stream phosphorus concentrations.

North Spirit and Spirit Lakes are located in southeastern Price County, with the southern end of each lake extending into Taylor County. The lakes are connected by a boatable channel. North Spirit Lake is larger and deeper at 213 acres, with a maximum depth of 22 feet. Spirit Lake has an area of 126 acres with a maximum depth of 9 feet. The total watershed area for the two lakes is 16 mi<sup>2</sup> (10,240 acres)(figure 1). The “immediate” watershed for North Spirit Lake is 1.83 mi<sup>2</sup> (1,171 acres)(figure 2). The main tributary to the two lakes is an unnamed stream (locally called Stone Creek) that flows into the channel between the two lakes (figure 2). Observations indicate most of the inflow enters Spirit Lake, with a small percentage backflowing into North Spirit Lake at times. Both lakes are drained by a dammed outlet on the northeast end of Spirit Lake. The dam has raised the lake levels by 1 ½ feet.

Both lakes are fertile and hypereutrophic. Trophic state and color data for the lakes are summarized below:

Parameter	Spirit Lake	North Spirit Lake
Mean Total Phosphorus (ug/l) (June-Aug.)	115	77
Mean Chlorophyll a (ug/l)(Jul.15-Sept.15)	68	59
Mean Secchi depth (ft) (June-Aug.)	2.6	5.0
True Color (Pt-Co units)(spring and fall, 2004)	60 - 110	20 - 25

Spirit Lake has higher total phosphorus and chlorophyll *a* concentrations, and correspondingly lower Secchi depths. True color, which is due primarily to dissolved organic materials in wetland drainage, is high in Spirit Lake and low in North Spirit Lake. The high color in Spirit Lake contributes to the lower Secchi depths.

**Figure 1. Spirit Lakes Watershed with 2010 Surface Water Monitoring Sites**

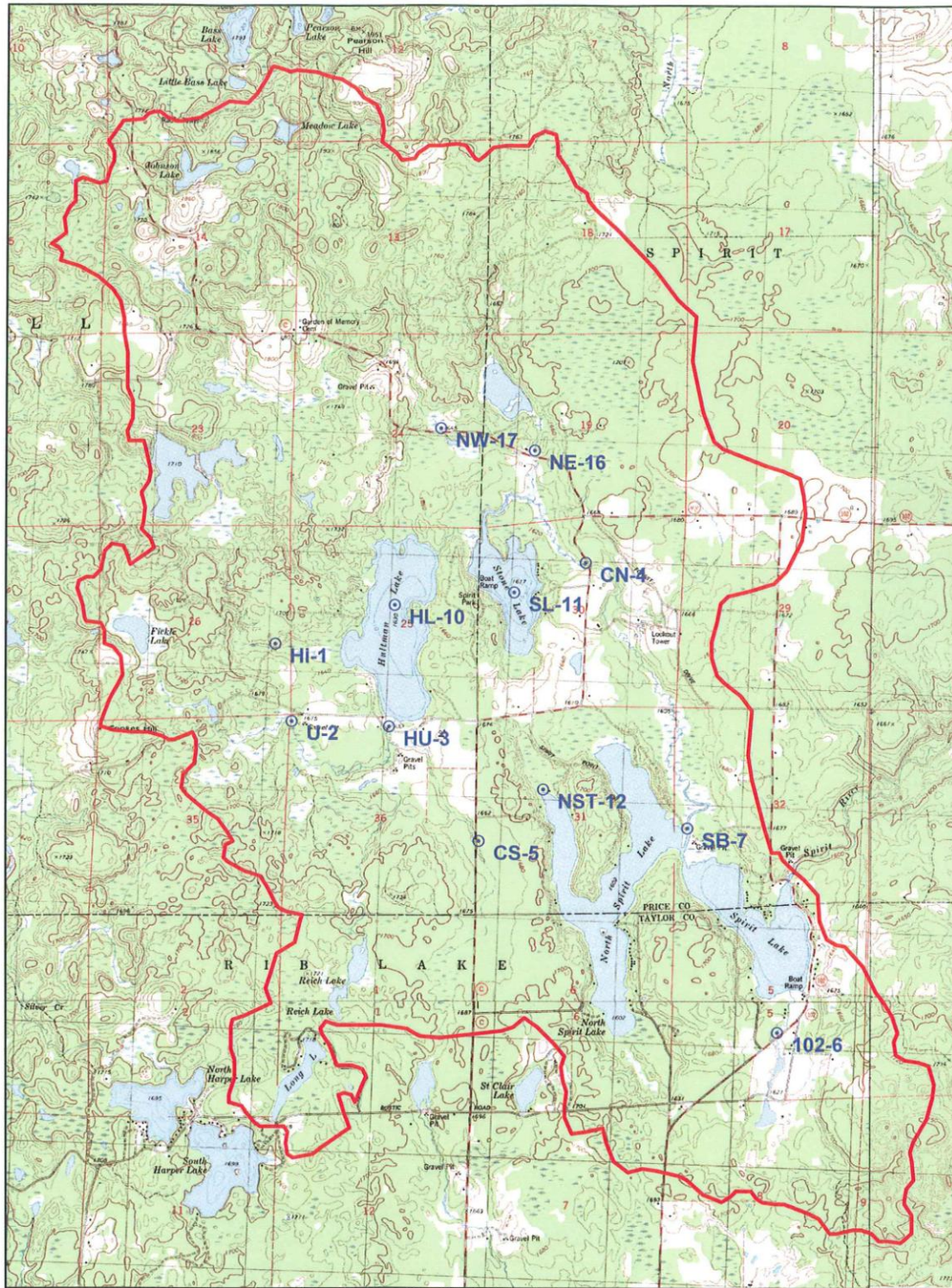


Figure 2. North Spirit Lake Immediate Watershed



### Watershed Tributary Monitoring

Four sites with undeveloped (wooded and wetland) watersheds were monitored for TP and flow on 3-6 dates (appendix 1 and figure 1). TP concentrations ranged from 26 to 214 ug/l, with a median of 52 ug/l. Highest TP concentrations were found in July.

A total of 22 paired measurements (TP and flow) were obtained. A flow-weighted TP concentration was calculated for each site. This concentration was then coupled with the long-term average runoff value for the area (11.8 inches; USGS) and an areal total phosphorus export rate was calculated. For the four undeveloped watershed sites, TP export rates ranged from 0.108 to 0.200 kg/ha/yr, with an average value of 0.151 kg/ha/yr.

Developed areas (agricultural and residential) in the Spirit Lakes watershed comprise only 10% of the total area. Five sites with development in their watersheds were also monitored for phosphorus and flow on 3-6 dates (appendix 1 and figure 1). TP concentrations ranged from 47 to 240 ug/l, with a median of 72 ug/l. Highest TP concentrations were also found in July.

A total of 27 paired measurements were obtained. Areal total phosphorus export rates were calculated as described above. For the five developed watershed sites, TP export rates ranged from 0.236 to 0.327 kg/ha/yr, with an average value of 0.288 kg/ha/yr.

Undeveloped Watershed TP Export		Lightly Developed Watershed TP Export	
Site	kg/ha/yr	Site	kg/ha/yr
HI-1	0.127	HU-3	0.303
U-2	0.108	CN-4	0.298
CS-5	0.200	102-6	0.327
NE-16	0.168	SB-7	0.278
		NW-17	0.236
Mean =	0.151	Mean =	0.288

The undeveloped watershed sites may underestimate background TP export. They are small headwater areas that probably receive less groundwater discharge than sites at lower elevations. Frequent heavy rains in the summer and fall of 2010 may also have diluted any high phosphorus groundwater discharge they receive with low phosphorus runoff.

Also, all of these sites, except CS-5, have small waterbodies within their watersheds that may be capturing some phosphorus. Site CS-5 had a TP export rate (0.20 kg/ha/yr) that is very similar to rates found for other nearby undeveloped watersheds with high groundwater phosphorus concentrations (Roesler 2007).

Higher TP concentrations in July are probably due to wetland drainage. Drainage from soft water wetlands often contains higher TP concentrations in summer. This results

from release of iron bound and organic bound phosphorus when bacterially induced decomposition of organic matter accelerates and causes dissolved oxygen depletion.

Wetland influence on the streams and lakes in the watershed is substantial. Iron precipitates were observed at stream site HI-1 in July when the TP concentration was highest. This indicates iron compounds were dissolving upstream and releasing phosphorus. Low dissolved oxygen concentrations were also found at most stream sites in July (appendix 1). A mid-afternoon dissolved oxygen concentration of 0.3 mg/l was measured at stream site CN-4 on the July sampling date. The high color in Spirit Lake (60-110 Pt-Co units) also results from extensive wetland drainage.

### Groundwater Monitoring

Twelve residential wells, three springs, and one free-flowing artesian well were sampled to evaluate groundwater TP concentrations (figure 3 and appendix 1). Lake resident volunteers assisted with the effort. Tom Raschke identified the locations of springs entering North Spirit Lake. Tom Wendt collected the residential well samples.

The twelve residential wells had a median TP concentration of 254 ug/l (range = 62-1,120 ug/l)(figure 4). Wells ranged in depth from 35 to 199 feet. A review of well construction reports for the area showed that most wells less than 150 feet deep are in sand and gravel aquifers. Only one of the sampled wells was greater than 150 feet deep (199 ft). Local wells greater than 150 feet deep are usually in bedrock (granite). Well depth was moderately correlated with TP concentration ( $R^2 = 0.56$ )

The three springs and the artesian well, all of which flow directly into North Spirit Lake, had a median TP concentration of 188 ug/l (range = 177-245 ug/l)(figure 4). Wisconsin groundwater TP concentrations typically average about 25 ug/l, so it is apparent that local groundwater TP concentrations are unusually high. The reason for this is uncertain, but it is probably a naturally occurring geological condition and is little influenced by watershed development.

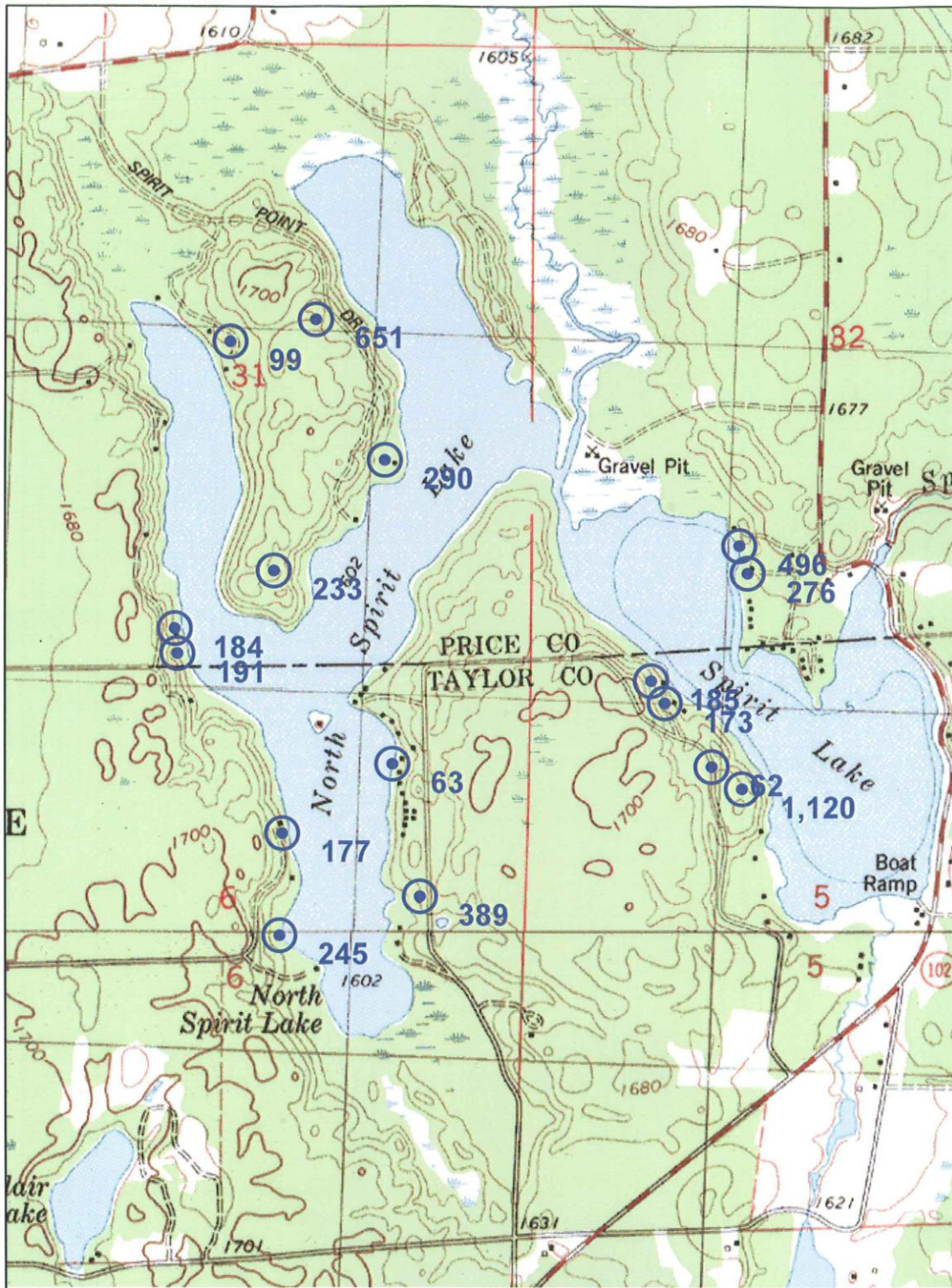
### Existing Lake Data Review

A considerable set of lake data exists for Spirit and North Spirit Lakes due primarily to the efforts of volunteer lake monitors (Tom and Nancy Wendt, Joseph Burger, David Clark, Clyde Schultz, Neal Olkives, and Bernard Strobach). TP and chlorophyll samples, temperature profiles, and Secchi depths (SD's) were collected 3-5 times per growing season (May-Oct) from 2001-2010 for Spirit Lake, and from 2003-2010 for North Spirit Lake. SD data was collected for several additional years. A 1994 lake management planning grant study was also done that includes top and bottom total phosphorus samples for five dates.

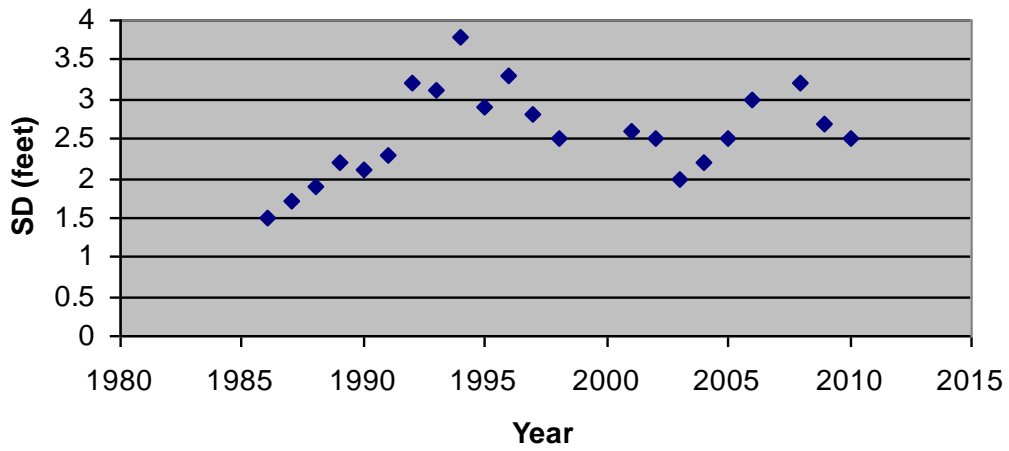
Mean trophic state data for the lakes is presented in the table in the introduction section above (p. 1). Detailed trophic state and other past monitoring data is contained in tables 1



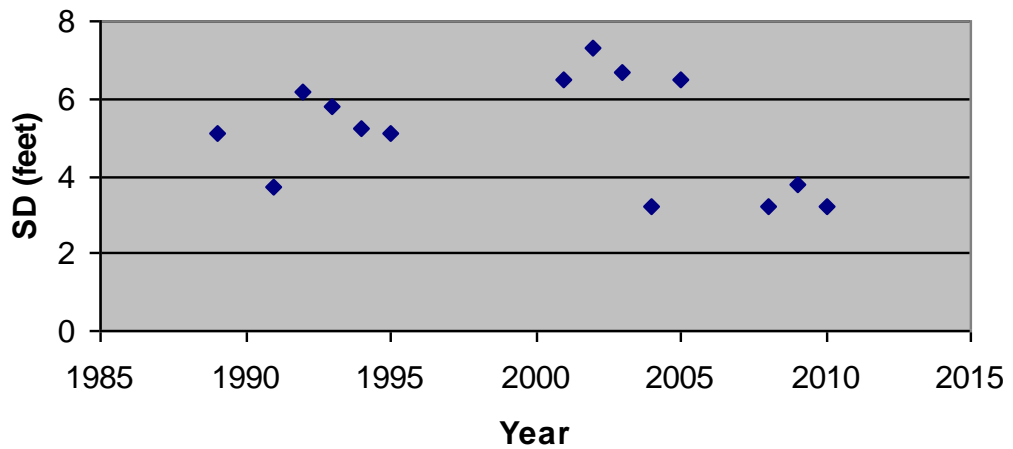
**Figure 4. Spirit Lakes Groundwater Total Phosphorus Concentrations (ug/l)**



**Spirit Lake June-Aug. Secchi Depth Means,  
1986-2010**



**North Spirit Lake June-Aug. Secchi Depth  
Means 1989-2010**



Mean summer Secchi depths in Spirit Lake are mostly in the 2 to 3.3 feet range. The lowest Secchi depths were measured in 1986-1988 and ranged from 1.5 to 1.9 feet. The reason for the low values those years is unknown.

Mean summer Secchi depths in North Spirit Lake are higher and range from 3.2 to 7.3 feet. Secchi depths for 2008-2010 have been some of the lowest measured, ranging from 3.2 to 3.8 feet. Variability in internal phosphorus release may account for much of the year to year variation in Secchi depths.

A comparison of TP concentrations for spring (April) and summer (June 1- Sept 15) is shown below:

Lake	Spring (April) TP(ug/l)	Summer (June 1-Sept 15) TP (ug/l)
Spirit	71	115
North Spirit	55	77

TP concentrations in both lakes increase greatly from spring to summer.

Internal TP loading is substantial in North Spirit Lake. In 1994 an increase in TP in the near-bottom water was shown in both winter and summer. On March 28<sup>th</sup> 1994, with ice cover, top TP was 75 ug/l while bottom TP was 240. On July 26<sup>th</sup> 1994 top TP was 80 ug/l while bottom TP was 620 ug/l. The bottom 6 to 10 feet of the water column had dissolved oxygen (D.O.) concentrations less than 1 mg/l during March, June, July, and August (table 4).

Anoxic conditions allow iron bound phosphorus in the sediment to dissolve and be released to the overlying water. When partial mixing events occur, the phosphorus that builds up in the hypolimnion is partially transported to the epilimnion. Large monthly increases in top TP, sometimes >100%, can frequently be correlated with downward movements of the thermocline or other evidence of partial mixing (hypolimnetic warming). For example, in 2009, downward movement of the thermocline in June through August resulted in TP concentrations climbing from 72 ug/l in June to 82 ug/l in July to 130 ug/l in August (table 3). In contrast, in 2003 when no downward movement of the thermocline occurred, TP concentrations declined from 50 ug/l in June to 36 ug/l in July to 24 ug/l in August. Without internal TP loading, TP concentrations decline due to sedimentation of phosphorus to the lake bottom.

Inflowing groundwater with high TP concentrations might also partially contribute to high bottom TP concentrations in North Spirit Lake if thermal and density differences between groundwater and lake water are sufficient to cause inflowing groundwater to flow to the lake bottom.

Inputs of TP to North Spirit Lake from the watershed during the summer are not sufficient to cause increases in lake TP concentrations. Estimated inflow of surface and groundwater would take 17 months to flush the lake. Sedimentation of TP is likely to

balance the inputs that occur. Groundwater inputs occur throughout the year, and so would not cause additional increases in lake TP concentrations in summer.

Spirit Lake has a maximum depth of only 9 feet, and so is usually mixed. However, calm periods with rapid D.O. depletion near the sediment surface can allow TP release from sediment in this lake. Large monthly increases in top TP, sometimes >100%, are observed during the summer. Peak TP concentrations occur in July and August.

TP concentrations in the main tributary stream also tend to be higher in summer. A June 30, 1994 sample had a TP concentration of 120 ug/l. A July 22, 2010 sample had a TP concentration of 179 ug/l. These concentrations are similar to peak summer TP concentrations observed in Spirit Lake (table 1).

Main tributary samples collected on other dates in those 2 years had TP concentrations ranging from 53 to 78 ug/l. The higher mid-summer TP concentrations in the tributary stream are probably due to wetland phosphorus release. Extensive wetland areas drain to this stream.

Stream inflow to Spirit Lake during summer months is substantial enough to contribute to increases in lake TP concentrations. Estimated summer stream inflow could flush the lake in 31 days.

Summer increases in TP concentrations in Spirit Lake are probably due to a combination of sediment phosphorus release, and wetland phosphorus release delivered via streamflow. Both of these phosphorus sources would not be controlled by watershed best management practices.

### 303d Impairment Thresholds

The tables below compare existing TP and chlorophyll *a* (CHL) concentrations in the Spirit Lakes with the 303d recreational use, and fish and aquatic life use impairment thresholds:

303d Recreational Use Impairment Thresholds					
Lake	Natural Community	TP threshold (ug/l) (Jun 1-Sept 15)	Existing TP (ug/l)	CHL threshold (ug/l)(Jul 15-Sept 15)	Existing CHL (ug/l)
Spirit	Shallow lowland drainage	40	115	25	68
North Spirit	Deep headwater drainage*	30	77	14	59

303d Fish and Aquatic Life Use Impairment Thresholds					
Lake	Natural Community	TP threshold (ug/l) (Jun 1-Sept 15)	Existing TP (ug/l)	CHL threshold (ug/l)(Jul 15-Sept 15)	Existing CHL (ug/l)
Spirit	Shallow lowland drainage	100	115	60	68
North Spirit	Deep headwater drainage*	60	77	27	59

\*North Spirit Lake is currently listed as a shallow headwater drainage lake. However, the data shows the lake is frequently stratified. Complete spring turnover does not occur in some years. The lake is “Y” shaped, with each arm of the Y having a deep hole of similar depth (21-24 ft). The area/depth formula that was used to identify it as a shallow (mixed) lake does not account for its unusual configuration. It should be listed as a deep headwater drainage lake.

Both lakes exceed the TP and CHL impairment thresholds for both recreational use and fish and aquatic life use. The potential to lower existing TP and CHL concentrations below threshold concentrations can be evaluated using a combination of 2010 monitoring data and lake phosphorus modeling.

Lake Phosphorus Modeling

WILMS was used to model spring TP in the two lakes. The following inputs were used:

Model input	Spirit Lake	North Spirit Lake
Lake area (acres)	126.4 (599*)	213.3
Lake volume (acre-feet)	701.5	2,527
Average runoff (in.)	11.8	11.8
Av. Pptn. – Evap. (in.)	5.4	5.4
Drainage area (acres (ha))	9,521 (3,853)	1,910 (773)**
Watershed TP load (kg)	1,036 kg***	215 kg***
Septic systems	100 yr-round residents assumed	100 yr-round residents assumed
Spring TP	71	55
Growing Season Mean TP	96	77

\*599 acres is the combined area of the four largest lakes in the watershed. It was used to adjust the hydrology appropriately. The atmospheric TP loading rate was reduced from 0.30 kg/ha/yr to 0.063 kg/ha/yr (21% = 126.4/599) to produce a corrected value.

\*\*The drainage area to North Spirit Lake includes both the direct drainage area for the lake (958 acres), and 10% of the drainage area for the total watershed (952 acres), assuming some backflow of the main tributary stream into North Spirit Lake.

\*\*\*Watershed TP loads were based on the TP export rate measured at the mouth of the main tributary stream (site SB-7)(0.278 kg/ha/yr). This stream represents drainage from land uses typical for the entire watershed. It is assumed that groundwater discharge influence to the stream is also typical for the entire watershed. Watershed TP load for Spirit Lake is calculated as: 0.278 kg/ha/yr x 3,853 ha = 1,071 kg; this is reduced by 35.4 kg to 1036 kg to account for TP loss due to passage though North Spirit Lake (15.3 ug/l (92.3 – 77 ug/l) in 1,878 acre-ft).

\*\*\*Watershed TP load to North Spirit Lake is calculated as: 0.278 kg/ha/yr x 387.7 ha = 108 kg, plus 10% of 1,071 kg = 107 kg. Total = 108 kg + 107 kg = 215 kg.

Two of the three spring TP models in WILMS produce good estimates of existing lake TP concentrations for Spirit Lake and fair estimates for North Spirit Lake:

Spring TP model	Spirit Lake		North Spirit Lake	
	Predicted TP (ug/l)	Existing TP (ug/l)	Predicted TP (ug/l)	Existing TP (ug/l)
Walker, 1977 general	71	71	53	55
Larsen – Mercier, 1976	70	71	47	55

The model fit for North Spirit Lake can be improved by adding an additional TP load from the input of high phosphorus groundwater. Conductivity in Spirit Lake (96-100 umhos) is higher than in Spirit Lake (71-81 umhos). This indicates groundwater has a greater impact on North Spirit Lake. The difference between the model-predicted and existing spring TP can be used to calculate an additional groundwater TP load. The average of the additional load indicated by the two models (24 kg) was used. This results in the model-predicted spring TP for North Spirit Lake being 58 ug/l for the Walker model and 52 ug/l for the Larsen-Mercier model.

Attainable Lake TP Reduction Estimates

Examining likely TP export rates for the land uses in the watershed provides a method for estimating potential watershed TP loading reductions. Land uses and likely TP export rates for the two lake watersheds are shown below:

Spirit Lake Watershed Data

Land Use	Hectares	TP Export (kg/ha/yr)	TP Load (kg/yr)	% of Total Watershed Load
Agriculture	189.5	1.05	199	24.0
Residential	91.3	0.55	50.2	6.1
Grass/pasture	38.0	0.35	13.3	1.5
Undeveloped	3,777	0.15	566.6	63.4
Total =	4,096	Total =	829.1	

North Spirit Lake Immediate Watershed Data

Land Use	Hectares	TP Export (kg/ha/yr)	TP Load (kg/yr)	% of Total Watershed Load
Agriculture	5.8	1.05	6.1	5.2
Residential	21.2	0.55	11.7	10.0
Grass/pasture	41.2	0.35	14.4	12.3
Undeveloped	405.7	0.15	60.9	52.0
Groundwater +			24	20.5
Total =	473.9	Total =	117.1	

Undeveloped land and groundwater provide the majority of TP loading to both lakes. TP loading reductions from grassland and pastured areas are generally not feasible. Maximum achievable TP loading reductions from other developed land uses are about 50%. This level of reduction has rarely been achieved in a watershed of this size.

Reducing agricultural and residential TP export by 50% in the Spirit Lake watershed would reduce TP loading to the lake by 15%. Reducing agricultural and residential TP export by 50% in the North Spirit Lake immediate watershed would reduce TP loading to the lake by 7.6%. Since North Spirit Lake also receives a similar TP load from the entire watershed, an averaged reduction of 11.3% is indicated. If the TP export rate from undeveloped areas is higher (0.20 kg/ha/yr), as discussed previously, the loading reductions to the lakes would be even smaller (12.2% for Spirit and 6.5% for North Spirit).

Using the land use and TP export rate estimates that indicate a 15% TP loading reduction to Spirit Lake and an 11.3% reduction to North Spirit Lake, predicted spring and summer lake TP concentrations are shown below:

Lake	Current Spring TP(ug/l)	Spring TP(ug/l) with watershed TP load reductions of 15% - Spirit L. and 11.3% - North Spirit L.*	Internal and/or wetland TP(ug/l) load impact (Summer TP minus Spring TP)	Summer TP with 15% (Spirit) and 11.3% (N. Spirit)watershed load reduction**
Spirit	71	61	44	105
North Spirit	55	49	22	71

\*based on Walker (1977) model, adjusted to existing conditions

\*\*Summer TP = spring TP plus internal and/or wetland TP load impact

As discussed earlier, internal loading (sediment phosphorus release) in North Spirit Lake and a combination of internal loading and wetland phosphorus release in Spirit Lake cause a substantial increase in lake TP concentrations from spring to summer. These phosphorus sources would not be controlled with watershed loading reductions.

The estimated summer TP concentrations after maximum achievable watershed loading reductions are made, still exceed both the recreational use impairment thresholds (Spirit – 40 ug/l, North Spirit – 30 ug/l) and the fish and aquatic life use impairment thresholds (Spirit – 100 ug/l, North Spirit – 60 ug/l).

Since impairment thresholds for TP and CHL are based on different summer time periods, it is difficult to accurately predict the reductions in CHL that would result from the reductions in TP. CHL reductions are probably roughly proportional to TP reductions within the narrow range of TP reduction estimated. This suggests achievable CHL concentrations would also still exceed both the recreational use and the fish and aquatic life use thresholds.

Impairment thresholds are goals based on average statewide conditions. For the Spirit Lakes, the thresholds don't apply well because of the atypical naturally occurring background TP loads due to high groundwater and wetland drainage TP concentrations. This does not imply that nothing can be done to protect and improve water quality in these lakes, but rather that lake specific goals are needed.

### Lake Sediment Core Assessment

Sediment cores were collected from Spirit and North Spirit Lake to provide an estimate of lake TP concentrations prior to development. Diatom frustules in the top layer of the core indicate current conditions, while those in the bottom layer of the core indicate pre-development conditions. Lead-210 dating of the bottom layer was done to verify that the sediment pre-dates development. The dating of the bottom layer of the Spirit Lake core indicated that the sediment layer was not old enough to be useful. Another core from this lake is planned to be collected in 2011.

The bottom layer from the North Spirit Lake core was old enough. The diatom assessment of this core indicated a current TP concentration of 94 ug/l (compared to the observed 77 ug/l), and a pre-development TP concentration of 52 ug/l (Garrison 2011). The diatom assessment indicates the TP concentration in North Spirit Lake has increased by about 81%.

Changes in the hydrology of North Spirit Lake as a result of the dam at the Spirit Lake outlet may be a major reason for this change. The dam has raised the level of the two lakes by 1 ½ feet. Some backflow into North Spirit Lake from the main tributary that enters the channel between the two lakes is observed under current conditions. It is estimated to be about 10% of the total inflow. That amount of backflow is estimated to roughly double the TP load to North Spirit Lake, which will produce higher lake TP concentrations.

Little backflow from the main tributary into North Spirit Lake may have occurred prior to the existence of the dam. With a water level 1 ½ ft lower, the cross-sectional area of the passage between North Spirit Lake and the tributary is greatly reduced. Observations cited at a Public Service Commission hearing in 1948, when no dam was present, noted that a "natural obstruction" between the lakes caused a 0.1 ft. higher elevation in North Spirit Lake than in Spirit Lake. This suggests the potential for tributary backflow into North Spirit Lake is lessened at lower lake levels.

Agricultural and residential development in the North Spirit Lake watershed has also increased TP loading to the lake. Additionally, sediment phosphorus release tends to be enhanced by increases in external TP loading, since increased production of algae promotes dissolved oxygen depletion in the hypolimnion.

## References

Garrison, Paul. 2011. Personal communication. WI Dept. of Natural Resources

Roesler, Craig. 2007. Background Total Phosphorus Export Rates in the Jump River and Main Creek Watersheds. WI Dept. of Natural Resources. Unpublished report.

TABLE 1. SUMMARIZED ANNUAL TP AND CHLOROPHYLL DATA FOR SPIRIT LAKES										
NORTH SPIRIT LAKE										
		GSM AND SUMMER TP MEANS (ug/l)					PEAK	CHL MEANS (ug/l)		
SPRING TP	TP		MAY-	(n)	June1-	(n)	PEAK	(month)	June-Aug	Jul 15-Sept 15
DATE	(ug/l)	YEAR	OCT		Sept.15		TP			
04/18/2010	49	2010	82.3	3	82.3	3	84	AUG	63.7	81.2
05/08/2009	55	2009	84.8	4	94.7	3	130	AUG	41.3	46.6
05/08/2008	93	2008	92	4	91.7	3	118	JUNE	32	42.8
04/30/2007	61	2007	70	3	68	2	74	JUNE	55.7	79.5
05/16/2006	51	2006	90	4	96	2	117	OCT	ins. data	ins. data
05/30/2005	28	2005	48.2	5	40.3	3	92	OCT	19.5	24.8
05/26/2004	37	2004	93.2	5	102.7	3	124	AUG	67.5	81.5
05/15/2003	51	2003	54.6	5	36.7	3	112	OCT	10.2	ins. data
April mean =	55	MEAN =	76.9		76.6		106.4		41.4	59.4
April/May mean =	53.1									
SPIRIT LAKE										
		GSM AND SUMMER TP MEANS (ug/l)					PEAK	CHL MEANS (ug/l)		
SPRING TP	TP		MAY-	(n)	June1-	(n)	PEAK	(month)	June-Aug	Jul 15-Sept 15
DATE	(ug/l)	YEAR	OCT		Sept.15		TP			
04/18/2010	78	2010	91	3	91	3	101	JUL	32.5	40.4
05/08/2009	58	2009	94.8	5	107	3	151	JUL	58	79.9
05/08/2008	53	2008	117	4	138.3	3	174	JUL	53.4	57.2
04/30/2007	67	2007	131.3	3	156	2	166	JUL	69.5	91.6
05/16/2006	48	2006	101.6	5	131	3	199	JUL	32.6	ins. data
05/30/2005	47	2005	84.8	5	106	3	133	AUG	58	68.2
05/26/2004	52	2004	68	5	85.7	3	117	AUG	50.3	70.8
05/15/2003	43	2003	78	5	99.7	3	146	AUG	69.1	97.5
05/19/2002	53	2002	80.6	5	99.3	3	120	JUL	46.2	ins. data
04/24/2001	69	2001	113.2	5	135	3	158	AUG	27.7	36
April mean =	71.3	MEAN =	96.0		114.9		146.5		49.7	67.7
April/May mean =	56.8									

**TABLE 2. SPIRIT LAKE TROPHIC STATE DATA**

Date	Total Phosphorus (ug/l)	Chlorophyll a (ug/l)	Secchi Depth (ft)
04/18/2010	78		5
06/21/2010	73	16.6	3
07/30/2010	101	35.6	2.5
08/23/2010	99	45.2	2
05/08/2009	58		
06/13/2009	73	14.1	4
07/24/2009	151	104	2
08/23/2009	97	55.8	2
09/15/2009			3
05/08/2008	53		4.5
06/23/2008	94	45.7	4
07/24/2008	174	24.8	5
08/17/2008	147	89.6	2.5
04/30/2007	67		4
05/29/2007	82	25.3	3.5
07/04/2007	166	49.2	2.5
08/07/2007	146	134	1.2
05/16/2006	48		4
06/23/2006	37	22.3	4
07/24/2006	199	43	2.5
08/15/2006	157		2.5
10/01/2006	67	30.4	4
05/30/2005	47		3.5
06/27/2005	68	37.7	3.5
07/18/2005	117	45.7	2
08/22/2006	133	90.7	2
10/12/2006	59	13.9	4
05/26/2004	52		2.5
06/19/2004	70	9.3	2.5
07/17/2004	70	57.5	2.5
08/15/2004	117	84.1	1.5
10/28/2004	31	5	7
05/15/2003	43		4.5
06/14/2003	60	12.2	3
07/13/2003	93	59	1.5
08/16/2003	146	136	1.5
10/20/2003	48	22.8	4.5

**TABLE 2. SPIRIT LAKE TROPHIC STATE DATA (cont.)**

<u>Date</u>	Total Phosphorus ( <u>ug/l</u> )	Chlorophyll a ( <u>ug/l</u> )	Secchi Depth ( <u>ft</u> )
05/19/2002	53		4
06/15/2002	69		4
07/13/2002	120	25.7	1.5
08/10/2002	109	66.6	2
10/26/2002	52	5.4	4.5
04/24/2001	69	10	3
06/12/2001	96	11	3.75
07/22/2001	151	65	1.6
08/17/2001	158	7	2.5
10/21/2001	48	9	5
07/26/2000	131		
08/29/2000	100		
06/17/1999			2
06/22/1999			2.5
Jun-98			2
Jul-98			1.5
Aug-98			1.4
Jun-97			3.2
Jul-97			2.1
Aug-97			3
Jun-96			4.2
Jul-96			2.25
Aug-96			3.5
Jun-95			4.6
Jul-95			1.6
Aug-95			2.6
Jun-94			4.1
Jul-94			3.7
Aug-94			3.5
03/27/1994	81(ice)		
05/03/1994	55	21.7	3.3
06/30/1994	70	17.6	3.3
08/30/1994	78	34.3	3.3
10/13/1994	81	1.5	3.6
Jun-93			3.5
Jul-93			3.5
Aug-93			2.4

**TABLE 2. SPIRIT LAKE TROPHIC STATE DATA  
(cont.)**

<u>Date</u>	Total Phosphorus ( <u>ug/l</u> )	Chlorophyll a ( <u>ug/l</u> )	Secchi Depth ( <u>ft</u> )
Jun-92			3.5
Jul-92			4
Aug-92			2
Jun-91			2.2
Jul-91			1.75
Aug-91			1.9
Jun-90			2.9
Jul-90			1.5
Aug-90			2
Jun-89			3.5
Jul-89			1.8
Aug-89			1.25
Jun-88			1.75
Jul-88			1.5
Aug-88			2.5
Jun-87			2
Jul-87			1.5
Aug-87			1.5
Jun-86			1.5
Jul-86			1.5
Aug-86			1.4

**TABLE 3. NORTH SPIRIT LAKE TROPHIC STATE AND TEMPERATURE PROFILE DATA**

<u>Date</u>	Total Phosphorus (ug/l)	Chlorophyll a (ug/l)	Secchi Depth (ft)	Greatest Temp (F) Change	Depth(ft)of Greatest Change (Thermocline)
04/18/2010	49		9	4	6-9
06/20/2010	81	28.5	5	4.8	12-15
07/30/2010	82	95.5	2.5	7	15-18
08/23/2010	84	67	2	6	15-18
05/08/2009	55		4.5	3.6	9-12
06/13/2009	72	30.8	4	3	9-12
07/24/2009	82	44.7	4	2.7	15-18
08/23/2009	130	48.6	3.5	3.5	18-21
05/08/2008	93		4.5	2.9	18-21
06/23/2008	118	10.5	3.6	7.5	18-21
07/24/2008	89	22.8	3	4.9	18-21
08/17/2008	68	62.7	3	7.1	18-21
04/30/2007	61		3.5	3.4	18-21
05/29/2007	74	8.2	6.5	3	18-21
07/04/2007	67	62.7	3	5.1	15-18
08/07/2007	69	96.3	2.5	4	15-18
05/16/2006	51				
06/23/2006	104	49.6			
08/15/2006	88				
10/01/2006	117	20.2			
05/30/2005	28		10	2.4	15-18
06/27/2005	27	9.1	7	7.4	15-18
07/18/2005	26	16.5	8	9.4	9-12
08/22/2005	68	33	4.5	7.4	15-18
10/12/2005	92	43.3	4	0.4	18-21
05/26/2004	37		11	0.6	18-21
06/19/2004	61	39.5	4	3.9	9-12
07/17/2004	123	120	2.5	4.2	15-18
08/15/2004	124	43	3	4.3	18-21
10/28/2004	121	35.4	4.5	0.4	3-6
05/15/2003	51		11	1.5	21-24
06/14/2003	50	9.8	5.5	2.7	15-18
07/13/2003	36	14.4	5.5	5.4	12-15
08/16/2003	24	6.3	9	8.2	12-15
10/20/2003	112	16.5	5	0.4	3-6

**TABLE 3. NORTH SPIRIT LAKE TROPHIC STATE AND TEMPERATURE PROFILE DATA (CONT.)**

<u>Date</u>	Total Phosphorus ( <u>ug/l</u> )	Chlorophyll a ( <u>ug/l</u> )	Secchi Depth ( <u>ft</u> )	Greatest Temp (F) <u>Change</u>	Depth(ft)of <u>Greatest Change</u>
05/19/2002			9	5	12-15
06/15/2002	31		9	5	12-15
07/13/2002	27	4.7	10	6	12-15
08/10/2002	48	32	3	7	15-18
10/26/2002	51	14.8	6.5	0	
06/04/2001			8		
07/18/2001			8		
08/24/2001			3.5		
09/27/2001			3.5		
10/20/2001			5		
05/11/1995			6		
05/17/1995			6.5		
06/01/1995			8.5		
06/08/1995			7		
06/17/1995			5.75		
06/23/1995			5.5		
06/26/1995			5		
07/07/1995			5		
08/31/1995			4		
09/17/1995			3.5		
10/15/1995			3.5		
11/04/1995			5		
05/04/1994			7.5		
05/25/1994			8		
06/06/1994			6		
06/12/1994			7.5		
06/21/1994			9.5		
06/25/1994			8		
07/05/1994			5.5		
07/14/1994			2.5		
07/24/1994			2.5		
08/06/1994			4		
08/15/1994			5		
10/13/1994			5.5		

**TABLE 3. NORTH SPIRIT LAKE TROPHIC STATE AND TEMPERATURE PROFILE DATA (CONT.)**

<u>Date</u>	Total Phosphorus <u>(ug/l)</u>	Chlorophyll a <u>(ug/l)</u>	Secchi Depth <u>(ft)</u>	Greatest Temp (F) <u>Change</u>	Depth(ft)of <u>Greatest Change</u>
05/08/1993			8		
05/22/1993			7		
06/10/1993			8		
06/21/1993			8		
07/15/1993			7		
07/29/1993			6		
08/22/1993			3		
09/15/1993			5		
10/12/1993			4		
11/05/1993			4		
05/18/1992			6		
05/26/1992			8		
06/05/1992			8		
06/20/1992			3.5		
07/02/1992			5		
07/16/1992			7		
07/30/1992			6		
08/24/1992			7		
09/03/1992			6		
09/22/1992			6		
10/15/1992			4.5		
04/13/1991			4		
05/09/1991			8		
06/04/1991			5		
06/27/1991			5		
07/23/1991			4		
08/22/1991			2		
09/20/1991			3.5		
10/19/1991			2.5		
04/20/1990			4		
05/07/1990			10		
05/23/1990			7		
06/26/1990			7		
07/27/1990			4		
09/22/1990			4		
10/02/1990			5		

**TABLE 3. NORTH SPIRIT LAKE TROPHIC STATE AND TEMPERATURE PROFILE DATA (CONT.)**

<u>Date</u>	Total Phosphorus ( <u>ug/l</u> )	Chlorophyll a ( <u>ug/l</u> )	Secchi Depth ( <u>ft</u> )	Greatest Temp (F) <u>Change</u>	Depth(ft)of <u>Greatest Change</u>
04/27/1989			3		
05/13/1989			3.5		
06/15/1989			8		
07/20/1989			3.5		
08/08/1989			3.75		
08/29/1989			3.75		
10/13/1989			2		
11/11/1989			3.5		
04/22/1988			5		
05/04/1988			4		
05/28/1988			10		
06/09/1988			8		
06/26/1988			5		
07/22/1988			3.5		
09/08/1988			2.5		
11/07/1988			10.5		
04/15/1987			2.5		
06/05/1987			6.5		
06/15/1987			6		
07/21/1987			2		
09/26/1987			7		
10/21/1987			7.5		
06/04/1986			8		
06/14/1986			5.5		
07/15/1986			4.5		
07/21/1986			3.5		
07/28/1986			2.5		
09/13/1986			3		
09/22/1986			4		
10/17/1986			4.5		
11/07/1986			7.25		

TABLE 4. SUMMARIZED DATA FROM 1996 SPIRIT LAKES LMPG REPORT										
						NORTH SPIRIT LAKE				
	SPIRIT LAKE					NE BAY				
Sampling	TP top	TP bottom	D.O.<1mg/l		CHL	TP top	TP bottom	D.O.<1mg/l		CHL
<u>Date</u>	<u>(ug/l)</u>	<u>(ug/l)</u>	<u>Depth (ft)</u>	<u>SD(ft)</u>	<u>(ug/l)</u>	<u>(ug/l)</u>	<u>(ug/l)</u>	<u>Depth (ft)</u>	<u>SD(ft)</u>	<u>(ug/l)</u>
02/18/1994			3					6		
03/28/1994	103	81	bottom					7		
05/03/1994	55	59		3	21.7				6	
06/30/1994	70			3.3	17.6			16	5	
07/26/1994	140	100		5.5	13.9			13	2.3	
08/30/1994	78	82	bottom	3.3	34.3			14	3	
09/09/1994										
09/17/1994				3.9				12	1	
10/13/1994	46	40		3.5	1.5				4.6	
	NORTH SPIRIT LAKE					NORTH SPIRIT LAKE				
	S BAY					NW BAY				
Sampling	TP top	TP bottom	D.O.<1mg/l		CHL	TP top	TP bottom	D.O.<1mg/l		CHL
<u>Date</u>	<u>(ug/l)</u>	<u>(ug/l)</u>	<u>Depth (ft)</u>	<u>SD(ft)</u>	<u>(ug/l)</u>	<u>(ug/l)</u>	<u>(ug/l)</u>	<u>Depth (ft)</u>	<u>SD(ft)</u>	<u>(ug/l)</u>
02/18/1994			10					4		
03/28/1994	75	240	7			69	141	9		
05/03/1994	53	71	bottom	6	15.3	43	51		6	12.5
06/30/1994	40		14	6	23.2	40		15	7	17.7
07/26/1994	80	620	16	2.3	92.4	80	350	14	2.95	149
08/30/1994	72	225	12	4.5	39	95	313	16	3.7	58.4
09/09/1994			>12	3						
09/17/1994			11	4.3				13	2	
10/13/1994	45	58		4.6	14.3				4.6	
	North Spirit Lake 10/13/94 conductivity = 100, color = 25									
	Spirit Lake 10/13/94 conductivity = 81, color = 110									
	North Spirit Lake 5/3/94 conductivity = 96, color = 20-25									
	Spirit Lake 5/3/94 conductivity = 71, color = 60									
	TP (ug/l)	TP (ug/l)								
	N. trib	Olson Ck.								
06/30/2004	120	110	no pptn for several days prior							
05/03/2004	70	37								