Balsam Lake Water Quality Study

Prepared for
Balsam Lake Protection and Rehabilitation District

June 2011

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Acknowledgements

The Balsam Lake Water Quality Study was completed with the assistance of the Balsam Lake Protection and Rehabilitation District (BLPRD), Alec Larson and Kari Larson, Polk County Land and Water, and the Wisconsin Department of Natural Resources. A special thanks to the following for their help during the project:

Dave Wagner	BLPRD Commissioner Overall Project Manager
Karen Aubin	BLPRD Commissioner WDNR contact for project grant and project treasurer
Alec Larson	Employed by Village of Balsam Lake Tributary and In-Lake Monitoring and Data Summary
Kari Larson	Employed by Village of Balsam Lake In-Lake Monitoring
Eric Wojchik	Conservation Planner, Polk County Land and Water Determine Land Uses in Watershed
Kris Larsen	Wisconsin Department of Natural Resources (WDNR) WDNR Project Manager
Pamela Toshner	Wisconsin Department of Natural Resources (WDNR) WDNR Lake and River Management Coordinator and Grants Coordinator

Thanks to the WDNR for providing lake planning grant funding which funded 75 percent of the monitoring program. The rest of the study was funded by the BLPRD.

Executive Summary

A water quality study of Balsam Lake was completed in 2010 to determine management recommendations to protect and improve water quality. The study determined that, on average, Balsam Lake water quality was acceptable and the lake was not impaired for aquatic recreation. Balsam Lake observed a lake wide summer average phosphorus concentration of 26 µg/L which met the Wisconsin State phosphorus standard of 30 µg/L. Although the intent of the state standard is to apply it to the lake wide summer average, the standard was compared to individual basins to detect water quality problems. This comparison indicated S1, also known as East Balsam Lake, experienced water quality problems in 2010 due to high phosphorus concentrations. The S1 summer average total phosphorus concentration was 48 µg/L, which is higher than the State Standard of 30 µg/L. The other five monitored basins observed summer average total phosphorus concentrations ranging from 20 µg/L to 23 µg/L. Because these concentrations were less than the State Standard, it was concluded that these basins did not experience water quality problems in 2010.

The good water quality observed in much of Balsam Lake in 2010 has resulted from good management of the lake's watershed. Precipitation, flow, and water quality data were monitored in three of the lake's tributaries in 2010. The data were used to compute the phosphorus "yield" from the watershed land areas. The computations revealed that the phosphorus export rates from the Otter Creek, Lower Rice Creek, and Harder Creek watersheds were low, ranging from 0.03 to 0.05 pounds per acre, and are comparable to the expected rate of export from heavily forested watersheds (Panuska, 1995). The low rates indicate that the lake's watershed land uses are well managed and result in minimal phosphorus export to Balsam Lake. The phosphorus export rates were more than two orders of magnitude (100 times) lower than Wisconsin phosphorus regulations which restrict phosphorus runoff from fields to 6 pounds per acre annually.

A trend analysis showed that significant improvement in water transparency occurred during the 1988 through 2010 period at S6, also known as Little Balsam Lake. The improvement rate was about 2 inches per year. The lake's improved water quality indicates watershed management efforts, including construction of a sedimentation basin and purchasing property adjacent to Rice Creek, were successful. The other lake basins have maintained a stable water quality over time and did not exhibit significant changes in Secchi disc during the 1988 to 2010 period.

Water quality models determined the annual hydrologic (water) and phosphorus budget for Balsam Lake as well as annual hydrologic and phosphorus budgets for the six monitored lake basins. The modeling effort indicated that half of the annual phosphorus load to S1, also known as East Balsam Lake, is from internal loading during the summer period (June through August). Internal loading resulted from anoxic conditions (oxygen less then 2 mg/L) at the sediment water interface which enabled sediments to pump phosphorus into the overlying waters. Frequent mixing of this shallow basin regularly brought the internal load to the lake's surface where algae could use it for growth. S1 consistently observed high phosphorus and chlorophyll concentrations and poor water clarity during the summer period when internal loading was occurring. Modeling indicates that elimination of the internal load would reduce the summer average phosphorus concentration of S1 from 48 µg/L to 31 µg/L and would improve the lake's water clarity by more than 3 feet.

Modeling predictions did not indicate summer internal loading at the other basins. However, an evaluation of lake water quality changes during September reveals that some internal loading appears to have occurred at five of the six monitored lake basins during the fall mixing period. The loading occurred as surface waters cooled and the heavier, cooler surface waters sank, thus allowing the warmer, lighter, deeper waters to rise to the surface. The internal loading rate for the lake's basins was computed, based upon modeled predictions and monitoring data. S1 (Figure 1) observed the highest loading rate of 27.7 mg/m^2/day and was estimated to load 737 pounds of phosphorus to Balsam Lake during the June through September period. The internal loading rate for S6 (Figure 1) of 3.8 mg/m^2/day is nearly an order of magnitude lower than the S1 loading rate. It is estimated that internal loading in S6 added 149 pounds of phosphorus to the lake during September when mixing began. S4 observed an internal loading rate of 2.9 mg/m^2/day and it is estimated that internal loading added 862 pounds of phosphorus to the lake during September. S3 and S4 (Figure 1) observed internal loading rates of 0.3 and 0.03 mg/m^2/day, respectively, and internal loading added 42 and 0.1 pounds of phosphorus to the lake in September, respectively. The model did not detect an internal loading contribution from S5 (Figure 1).

Monitoring and modeling results were used to identify management recommendations to improve and protect the water quality of Balsam Lake, including:

- S1 sediment study to detail the lake's internal loading problem and design an alum treatment to solve the problem
- Periodic inspection and maintenance of Rice Creek sedimentation basin to protect the water quality of Little Balsam Lake and downstream basins.
- Monitor Secchi disc annually at S1, S2, S4, and S6 to detect changes in water clarity.

- Trend analysis of Secchi disc data every 3 years to detect significant changes in water clarity.

- Work with Polk County Land and Water to periodically review cropland management practices in S1 and S4 watersheds to determine changes that could adversely impact land water quality and identify and implement management practices to address the adverse changes.

- Periodic water quality monitoring of Balsam Lake to (1) track changes in internal loading in S4 and S6 (2) track the results of an S1 alum treatment should it occur (3) determine management needs for the lake, (4) provide a sound scientific basis for management decisions (5) collect total phosphorus and chlorophyll *a* data so that a trend analysis to identify significant changes in phosphorus and chlorophyll *a* concentrations can occur when at least 5 years of data have been collected.

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1.0 Introduction

A water quality study of Balsam Lake was completed to protect and improve lake quality. Above, a lake resident enjoys skiing on Balsam Lake during 2010.

A water quality study of Balsam Lake was completed to determine management recommendations to protect and improve lake water quality. The study included monitoring inflow streams (Otter Creek, Lower Rice Creek, and Harder Creek), and lake level during the period October through November 2009 and March through September 2010. The inflow data were used in water quality models (FLUX and WILMS) to predict the amount of phosphorus that reached Balsam Lake via stormwater runoff. Lake level data were used to determine changes in lake storage during the monitoring period. Precipitation data were collected from inflow locations during March through September of 2010. Precipitation data were compared with inflow data to determine watershed water yield. Lake water quality data were collected from six locations twice per month during May through September of 2010. The inflow, precipitation, lake level, and lake water quality data were used to calibrate an in-lake model (BATHTUB). The in-lake model computed hydrologic and phosphorus budgets, determined when internal loading occurred and internal loading rate when it occurred, and modeled lake response to phosphorus loading from watershed and internal sources. The in-lake model helped understand in-lake processes including phosphorus transport within the lake, both one way movement from one basin to another and two way movement between basins. This report discusses the study results and provides recommendations for future management efforts. A section on general concepts in water quality precedes the study discussion. Details of study methods and data collected in the study are found in the appendices to this report.

2.0 General Concepts in Water Quality

There are many concepts and terminology that are necessary to describe and evaluate a lake or pond's water quality. This section is a brief discussion of those concepts, divided into the following topics:

- Eutrophication
- Trophic states
- Limiting nutrients
- Nutrient recycling and internal loading
- Watershed

To learn more about these five topics, one can refer to any text on limnology (the science of lakes and streams).

2.1 Eutrophication

Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in lakes. As a lake naturally becomes more fertile, algae and weed growth increases. The increasing biological production and sediment inflow from the lake's watershed can eventually fill the lake's basin. Over a period of many years, the lake can successively become a pond, a marsh and, ultimately, a terrestrial site. This process of eutrophication is natural and results from the normal environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural process caused by human activities. Nutrient and sediment inputs (i.e., loadings) from wastewater treatment plants, septic tanks, and stormwater runoff can far exceed the natural inputs to the lake. The accelerated rate of water quality degradation associated with these pollutants results in unpleasant consequences, including profuse and unsightly growths of algae (algal blooms) and/or the proliferation of rooted aquatic weeds (macrophytes).

2.2 Trophic States

Not all lakes are at the same stage of eutrophication; therefore, criteria have been established to evaluate the nutrient "status" of lakes. Trophic state indices (TSIs) are calculated for lakes on the basis of total phosphorus, chlorophyll *a* concentrations, and Secchi disc transparencies. A TSI value is obtained from any one of these three parameters. TSI values range upward from zero, describing the condition of the lake in terms of its trophic status (i.e., its degree of fertility). Four trophic status designations for lakes are listed below with corresponding TSI value ranges:

1. ***Oligotrophic* – [TSI ≤ 37]** Clear, low productivity lakes with total phosphorus concentrations less than or equal to 10 ppb.

2. ***Mesotrophic* – [38 ≤ TSI ≤ 50]** Intermediate productivity lakes with total phosphorus concentrations greater than 10 ppb, but less than 24 ppb.

3. ***Eutrophic* – [51 ≤ TSI ≤ 63]** High productivity lakes generally having 25 to 57 ppb total phosphorus.

4. ***Hypereutrophic* – [TSI ≥ 64]** Extremely productive lakes which are highly eutrophic, disturbed and unstable (i.e., can fluctuate in their water quality on a daily and seasonal scale, can produce gases and toxic substances, can experience periodic anoxia and fish kills, etc.) with total phosphorus concentrations above 57 ppb.

Trophic state classifications for total phosphorus and chlorophyll a concentrations as well as Secchi disc transparency are shown in Table 1.

Table 1 Trophic State Classifications for Total Phosphorus, Chlorophyll *a*, and Secchi Disc Transparency

Trophic State	**Total Phosphorus (TP)**	**Chlorophyll *a***	**Secchi Disc Transparency**
Oligotrophic (nutrient poor)	less than 10 ppb	less than 2 ppb	greater than 15 ft (4.6 m)
Mesotrophic (moderate nutrient levels)	10 ppb – 24 ppb	2 ppb - 7.5 ppb	6.6 ft - 15 ft (2.0 m - 4.6 m)
Eutrophic (nutrient rich)	24 ppb – 57 ppb	7.5 ppb - 26 ppb	2.8 ft - 6.6 ft (0.85 m - 2.0 m)
Hypereutrophic (extremely nutrient rich)	greater than 57 ppb	greater than 26 ppb	less than 2.8 ft (0.85 m)

Determining the trophic status of a lake is an important step in diagnosing water quality problems. Trophic status indicates the severity of a lake’s algal growth problems and the degree of change needed to meet its recreational goals. Additional information, however, is needed to determine the cause of algal growth and a means of reducing it.

2.3 Limiting Nutrients

The quantity or biomass of algae in a lake is usually limited by the water's concentration of an essential element or nutrient—the "limiting nutrient." (For rooted aquatic plants, the nutrients are derived from the sediments.) The limiting nutrient concept is a widely applied principle in ecology and in the study of eutrophication. It is based on the idea that plants require many nutrients to grow, but the nutrient with the lowest availability, relative to the amount needed by the plant, will limit plant growth. It follows then, that identifying the limiting nutrient will point the way to controlling algal growth.

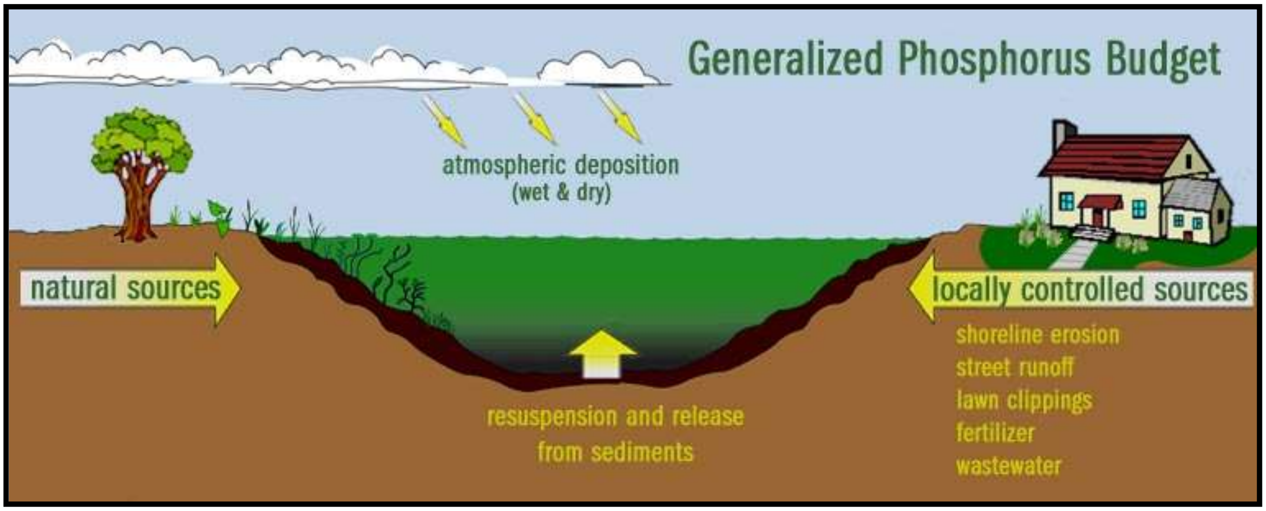
Nitrogen (N) and phosphorus (P) are generally the two growth-limiting nutrients for algae in most natural waters. Analysis of the nutrient content of lake water and algae provides ratios of N:P. By comparing the ratio in water to the ratio in the algae, one can estimate whether a particular nutrient may be limiting. Algal growth is generally phosphorus-limited in waters with N:P ratios greater than 12. Laboratory experiments (bioassays) can demonstrate which nutrient is limiting by growing the algae in lake water with various concentrations of nutrients added. Bioassays, as well as fertilization of in-situ enclosures and whole-lake experiments, have repeatedly demonstrated that phosphorus is usually the nutrient that limits algal growth in fresh waters. Reducing phosphorus in a lake, therefore, is required to reduce algal abundance and improve water transparency. Failure to reduce phosphorus concentrations will allow the process of eutrophication to continue at an accelerated rate.

2.4 Nutrient Recycling and Internal Loading

Phosphorus enters a lake from either runoff from the watershed or direct atmospheric deposition. Direct atmospheric deposition is generally minimal and control of it is not feasible. It would, therefore, seem reasonable that phosphorus in a lake can decrease by reducing watershed loads of phosphorus to the lake. All lakes, however, accumulate phosphorus (and other nutrients) in the sediments from the settling of particles and dead organisms. In some lakes this reservoir of phosphorus can be reintroduced in the lake water and become available again for plant uptake. This resuspension or release of nutrients from the sediments to the lake water is known as "internal loading." The relative amounts of phosphorus coming from internal and external loads vary with each lake. Phosphorus released from internal loading can be estimated from depth profiles (measurements from surface to bottom) of dissolved oxygen and phosphorus concentrations.

The figure below illustrates the 3 sources of phosphorus to a lake:

- Watershed loading (natural sources and locally controlled sources),
- Atmospheric deposition (wet and dry), and
- Internal loading (resuspension and release from sediments).



2.5 Watershed

The land area that drains to the lake is called a watershed. The watershed may be small, as is the case of small seepage lakes. Seepage lakes have no stream inlet or outlet and, consequently, their watersheds include the land draining directly to the lake. A lake's watershed may be large, as in drainage lakes. Drainage lakes have both stream inlets and outlets and, consequently, their watersheds include the land draining to the streams in addition to the land draining directly to the lake. Balsam Lake is a drainage lake. Water draining to a lake may carry pollutants that affect the lake's water quality. Consequently, water quality conditions of the lake are a direct result of the land use practices within the entire watershed. Good water quality conditions suggest that proper land uses are occurring in the watershed.

All land use practices within a lake's watershed impact the lake and determine its water quality. Impacts result from the export of sediment and nutrients, primarily phosphorus, to a lake from its watershed. Each land use contributes a different quantity of phosphorus to the lake, thereby, affecting the lake's water quality differently. An understanding of a lake's water quality, therefore, must go beyond an analysis of the lake itself. An understanding of a lake's watershed, phosphorus exported from the watershed, and the relationship between the lake's water quality and its watershed must be understood.

3.0 Balsam Lake Watershed

3.1 Watershed Area

The Balsam Lake watershed is comprised of Balsam Lake and the land area draining to Balsam Lake A land area totaling 26,691 acres contributes water and phosphorus to Balsam Lake (Figure 1 and Table 1). The surface area of Balsam Lake totals 1,954 acres. The watershed land area is approximately 14 times larger than the surface area of Balsam Lake.

Table 2 Balsam Lake Watershed Summary (acres)[1]

Watershed ID	Area (acres)
Harder Creek – A	3,642
Harder Creek	3105
Otter Creek	2,927
Lower Rice – A	2,995
Lower Rice	2,443
S1	2,664[1]
S2	403[1]
S3	380[1]
S4	1,688[1]
S4 – A	307
4 – B	1,030
S4 – C	3,861
S4 – D[2]	4,077
S5	265[1]
S6	982[1]
Total Into Balsam Lake	**26,691**

[1] Includes land area draining to Balsam Lake and does not include Balsam Lake.
[2] The "S4 - D" sub-watershed is landlocked and is not counted in the contributing area to Balsam Lake.

3.2 Watershed Land Use

Land uses in the Balsam Lake watershed are shown in Figures 2 through 4 and Tables 2 and 3. The four largest land uses in the watershed (cropland, forest, wetland, and grassland) comprise 80 percent of the watershed. The remaining 20 percent of the watershed is comprised of residential (9 percent), lakes and open water areas (4 percent), forage and pasture areas (3 percent) commercial (1 percent), the City of Mill (1 percent) and several other land uses that collectively comprise 2 percent.

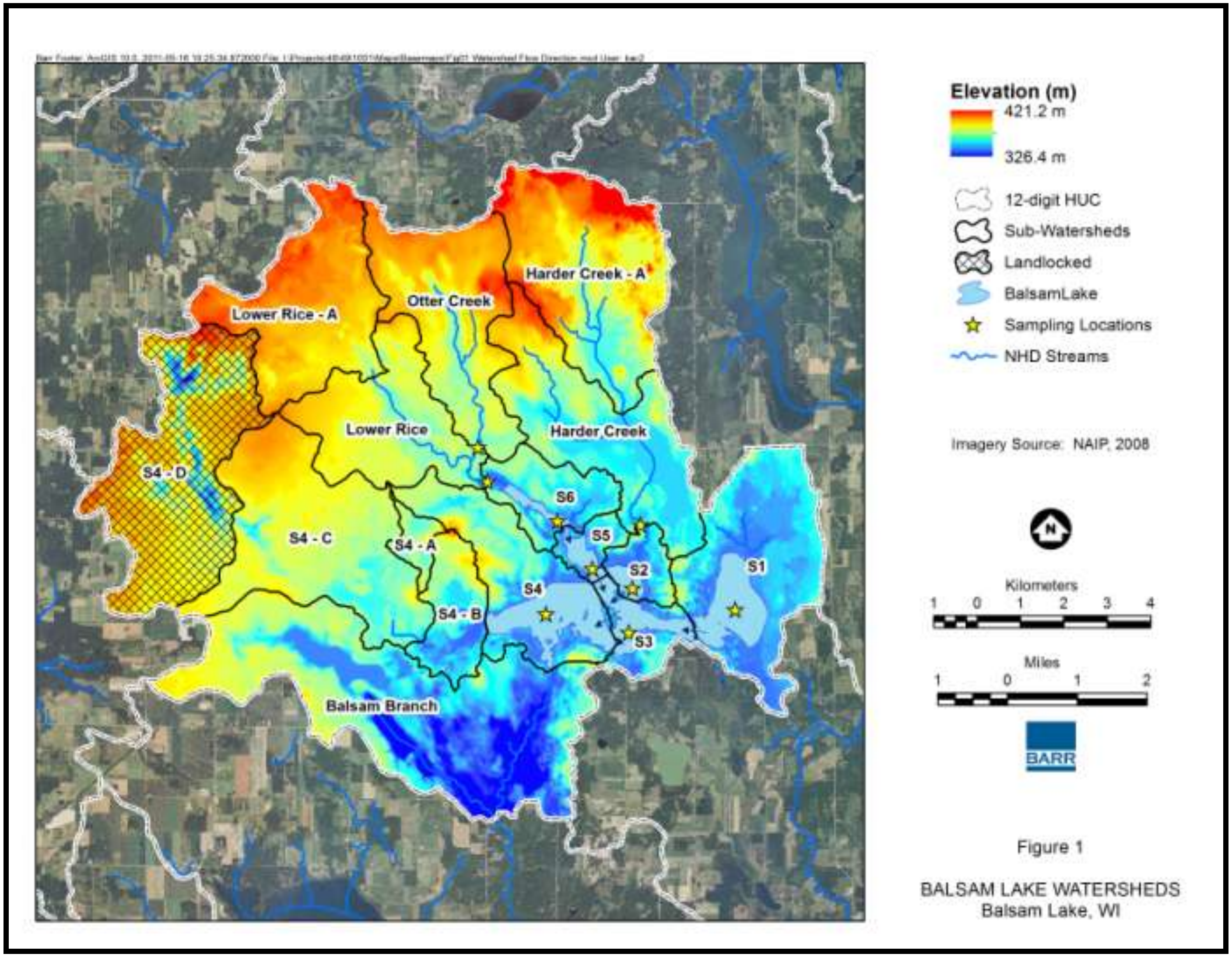


Figure 1 Balsam Lake Watersheds

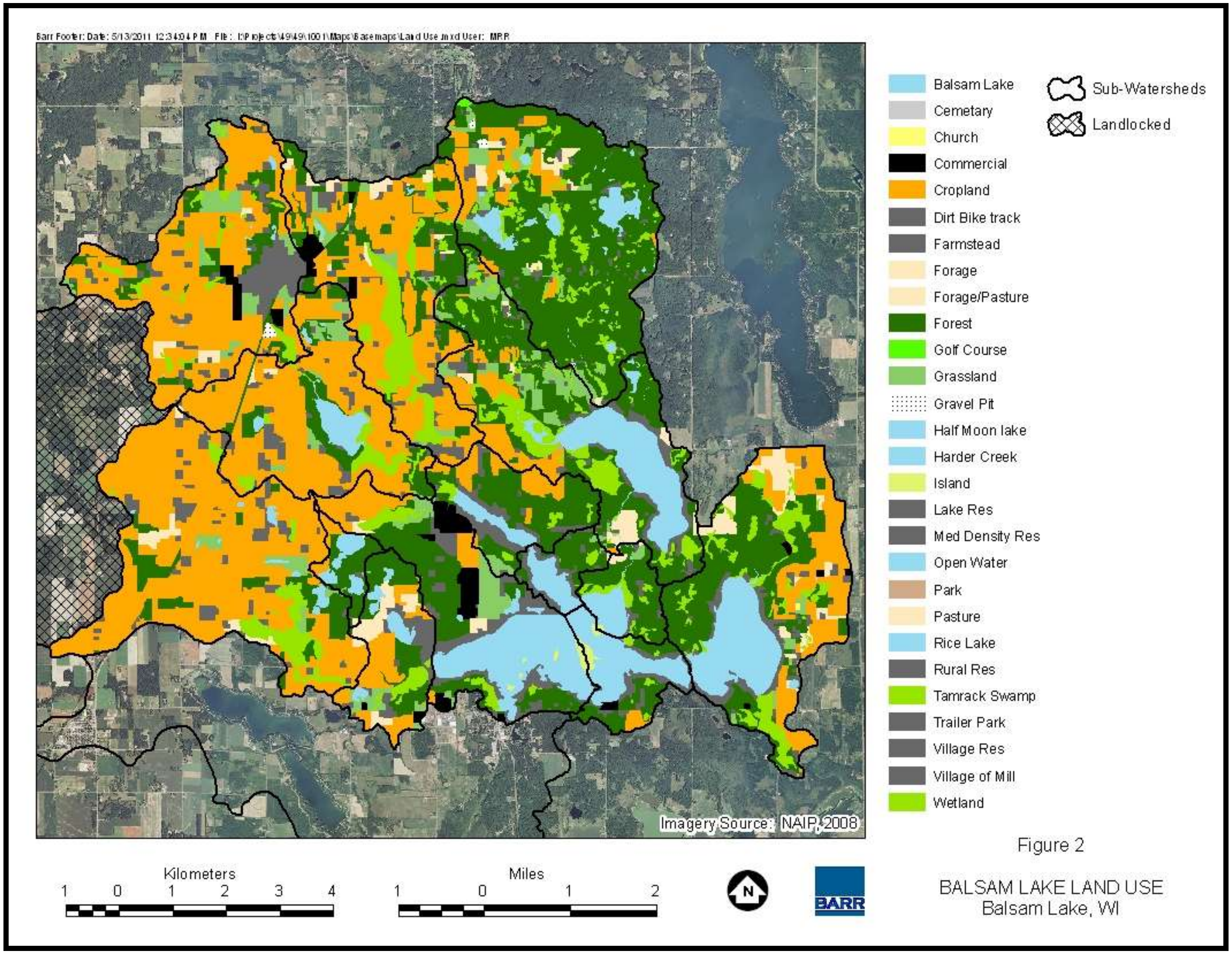


Figure 2 Balsam Lake Land Use

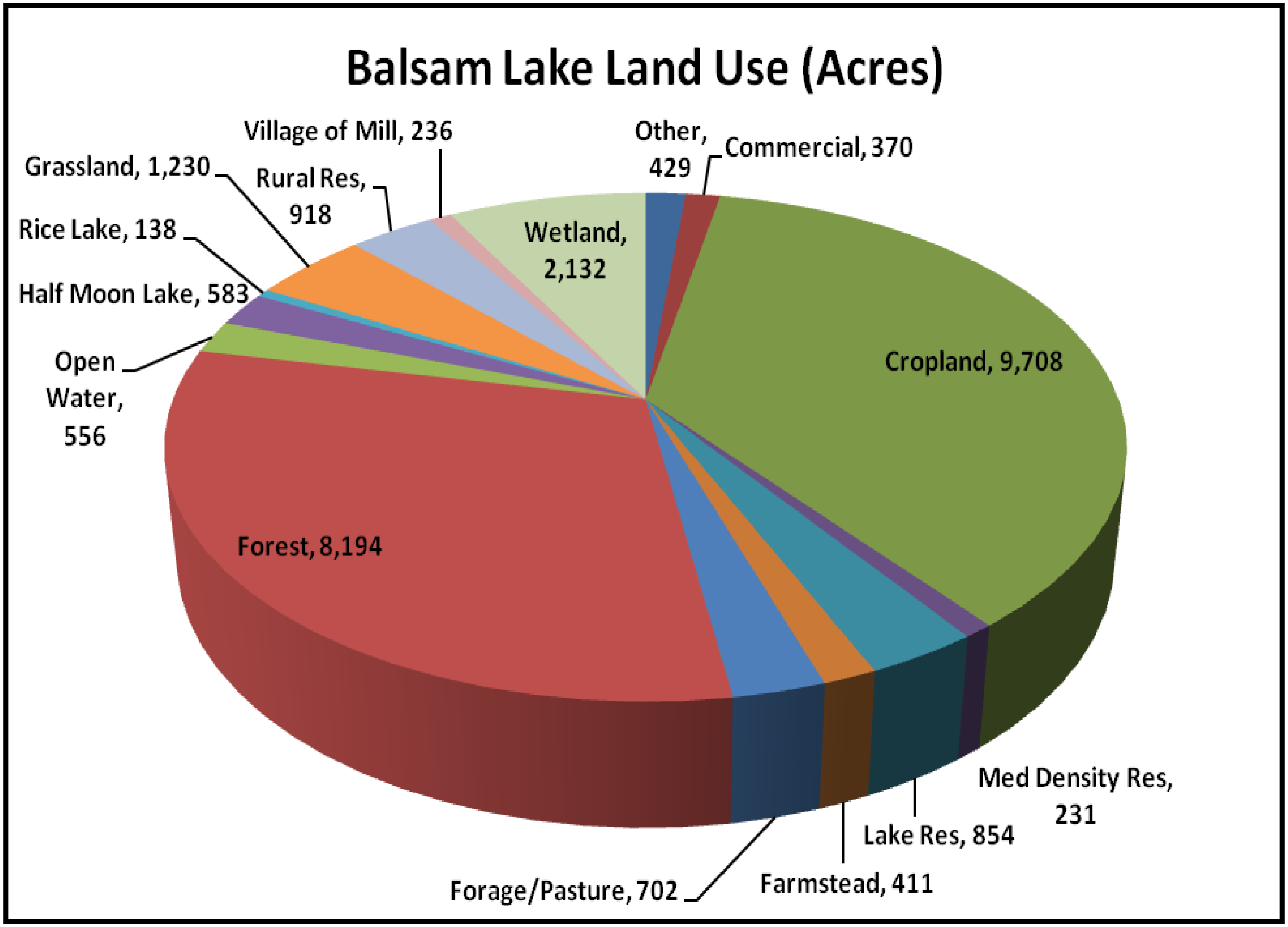


Figure 3 **Balsam Lake Watershed Land Use (acres) (Excludes Balsam Lake)**

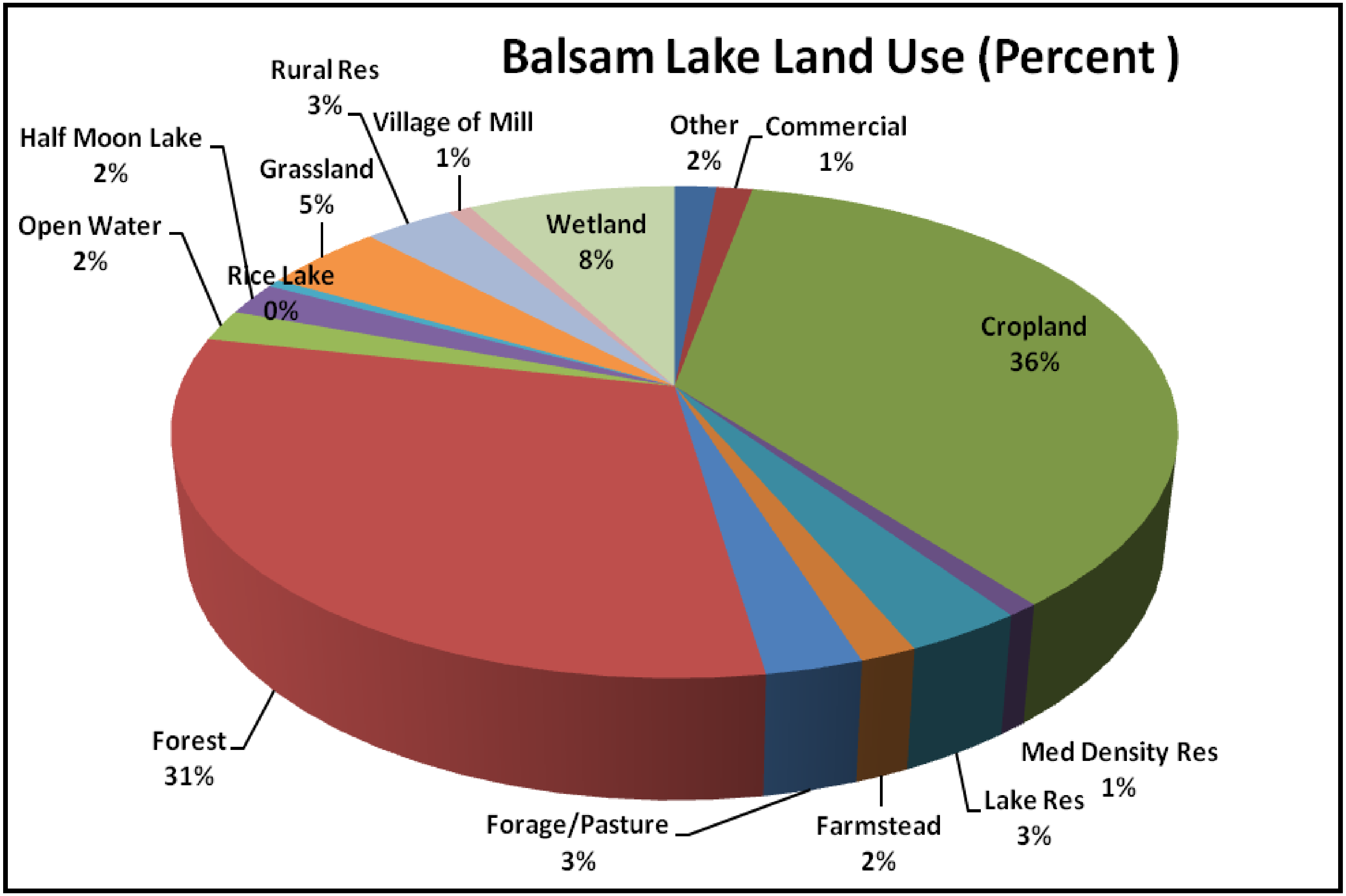


Figure 4 Balsam Lake Watershed Land Use (Percent) (Excludes Balsam Lake)

Table 3 Balsam Lake Watershed Land Use (acres) (Includes Balsam Lake)

Land Use	Harder Creek	Harder Creek - A	Lower Rice	Lower Rice - A	Otter Creek	S1	S2	S3	S4	S4 - A	S4 - B	S4 - C	S5	S6
Balsam Lake	0	0	0	0	0	565	124	351	686	0	0	0	134	93
Cemetary	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Church	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Commercial	0	0	0	69	67	19	0	13	161	0	12	0	0	29
Cropland	332	336	1536	1765	1437	767	1	30	260	56	274	2729	1	186
Dirt Bike track	15	0	0	0	5	0	0	0	0	0	0	0	0	0
Farmstead	26	41	18	64	45	24	0	6	0	0	10	172	3	2
Forage	21	20	0	0	0	5	0	0	0	0	0	2	0	0
Forage/Pasture	70	0	15	49	89	214	14	0	32	5	126	85	2	0
Forest	1120	2377	312	326	556	1028	276	182	575	150	265	357	150	520
Golf Course	0	10	0	0	0	0	0	0	0	0	0	0	0	0
Grassland	250	178	99	200	90	39	11	0	165	3	60	94	6	31
Gravel Pit	1	12	0	12	0	0	1	0	0	0	0	0	0	0
Half Moon lake	583	0	0	0	0	0	0	0	0	0	0	0	0	0
Harder Creek	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Island	0	0	0	0	0	0	4	27	24	0	0	0	0	0
Lake Res	158	23	0	0	0	138	17	85	215	0	19	0	75	124
Med Density Res	0	0	37	21	83	1	0	0	49	0	0	0	8	31
Open Water	23	221	20	13	10	10	3	0	26	88	87	55	0	0
Park	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Pasture	17	77	0	0	0	0	0	0	0	0	0	0	0	0
Rice Lake	0	0	138	0	0	0	0	0	0	0	0	0	0	0
Rural Res	84	65	135	103	122	85	16	20	48	5	104	108	9	14
Tamrack Swamp	122	0	0	0	0	0	0	0	0	0	0	0	0	0
Trailer Park	0	0	0	0	0	0	0	0	1	0	8	0	0	0
Village of Mill	0	0	0	236	0	0	0	0	0	0	0	0	0	0
Village Res	0	0	0	0	0	0	0	0	32	0	1	0	0	0
Wetland	281	278	131	135	423	330	60	18	99	0	63	259	11	44
Total Area (Acres) (Includes Balsam Lake	3,105	3,642	2,443	2,995	2,927	3,229	528	732	2,374	307	1,030	3,861	399	1,075
Total Area (Acres) (Excludes Balsam Lake)	3,105	3,642	2,443	2,995	2,927	2,664	403	380	1,688	307	1,030	3,861	265	982

Table 4 Balsam Lake Watershed Land Use (Percent) (Includes Balsam Lake)

Land Use	Harder Creek	Harder Creek - A	Lower Rice	Lower Rice - A	Otter Creek	S1	S2	S3	S4	S4 - A	S4 - B	S4 - C	S5	S6
Balsam Lake	0.00%	0.00%	0.00%	0.00%	0.00%	17.50%	23.57%	48.03%	28.91%	0.00%	0.00%	0.00%	33.63%	8.63%
Cemetary	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Church	0.00%	0.00%	0.00%	0.00%	0.00%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Commercial	0.00%	0.00%	0.01%	2.31%	2.30%	0.57%	0.00%	1.72%	6.79%	0.00%	1.15%	0.00%	0.00%	2.68%
Cropland	10.68%	9.22%	62.88%	58.92%	49.09%	23.76%	0.14%	4.05%	10.97%	18.15%	26.64%	70.67%	0.13%	17.30%
Dirt Bike track	0.49%	0.00%	0.00%	0.00%	0.16%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Farmstead	0.83%	1.11%	0.76%	2.15%	1.53%	0.74%	0.01%	0.77%	0.00%	0.00%	0.95%	4.46%	0.78%	0.21%
Forage	0.67%	0.55%	0.00%	0.00%	0.00%	0.15%	0.00%	0.00%	0.00%	0.00%	0.01%	0.05%	0.00%	0.00%
Forage/Pasture	2.25%	0.00%	0.62%	1.64%	3.05%	6.64%	2.58%	0.00%	1.35%	1.67%	12.23%	2.21%	0.62%	0.00%
Forest	36.06%	65.28%	12.79%	10.89%	19.00%	31.83%	52.39%	24.91%	24.22%	48.77%	25.71%	9.23%	37.66%	48.39%
Golf Course	0.00%	0.27%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Grassland	8.06%	4.89%	4.05%	6.69%	3.09%	1.22%	2.16%	0.00%	6.97%	1.13%	5.86%	2.45%	1.44%	2.93%
Gravel Pit	0.04%	0.34%	0.00%	0.41%	0.00%	0.00%	0.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Half Moon lake	18.78%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Harder Creek	0.00%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Island	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.68%	3.71%	1.03%	0.00%	0.00%	0.00%	0.00%	0.00%
Lake Res	5.07%	0.64%	0.00%	0.00%	0.00%	4.26%	3.32%	11.55%	9.04%	0.00%	1.88%	0.00%	18.70%	11.58%
Med Density Res	0.00%	0.00%	1.53%	0.71%	2.82%	0.04%	0.00%	0.00%	2.07%	0.00%	0.00%	0.00%	1.92%	2.92%
Open Water	0.73%	6.07%	0.82%	0.44%	0.34%	0.30%	0.54%	0.00%	1.10%	28.76%	8.43%	1.44%	0.00%	0.00%
Park	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Pasture	0.54%	2.11%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Rice Lake	0.00%	0.00%	5.67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Rural Res	2.71%	1.78%	5.51%	3.44%	4.18%	2.63%	3.07%	2.73%	2.01%	1.52%	10.10%	2.80%	2.31%	1.29%
Tamrack Swamp	3.93%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Trailer Park	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.05%	0.00%	0.81%	0.00%	0.00%	0.00%
Village of Mill	0.00%	0.00%	0.00%	7.87%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Village Res	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.33%	0.00%	0.13%	0.00%	0.00%	0.00%
Wetland	9.06%	7.62%	5.37%	4.52%	14.45%	10.23%	11.37%	2.52%	4.17%	0.00%	6.09%	6.70%	2.81%	4.07%

3.3 Water Yield, Phosphorus, and Sediment Loading

Using the precipitation, flow, and water quality data, calculations were performed to further understand the water, phosphorus, and sediment yields in the monitored watersheds (Table 5). Water quality data used for the calculations are presented in Appendices A through E. Yield is a term that is typically used to describe flow and water quality data on a per acre of watershed area basis. The use of "yield" assists in the interpretation of data and allows for comparisons between different watershed systems.

Using the flow monitoring data, the inches of runoff (water yield) that were generated during the 2010 water year are given in Table 5. The water yield for the Otter Creek watershed was 0.6 inches which was 2 percent of the 36.5 inches of precipitation falling on the Otter Creek watershed (Table 5). The water yield from the Harder Creek watershed was 19 percent of the 36.7 inches of precipitation falling on the watershed, a water yield of 7.1 inches (Table 5). The water yield from the Lower Rice Creek watershed was 32 percent of the 36.1 inches of precipitation falling on the watershed, a water yield of 11.6 inches (Table 5).

Table 5 2010 Water Yield and Phosphorus, and Sediment Loading to Balsam Lake from Otter Creek, Lower Rice Creek, and Harder Creek Watersheds

Watershed	Water Yield (Inches Over Watershed	Aerial Total Phosphorus Loading (lbs/ac)	Aerial Soluble Reactive Phosphorus Loading (lbs/ac)	Aerial Total Suspended Solids Loading (lbs/ac)
Otter Creek	0.6	0.03	0.01	1.35
Lower Rice Creek	11.6	0.05	0.01	9.30
Harder Creek	7.1	0.03	0.01	0.97

Water quality monitoring data were used to calculate phosphorus and sediment loads to Balsam Lake during the 2010 water year. The loading data were then used to estimate phosphorus and sediment yields from the monitored watersheds. The phosphorus yield from the Otter Creek and Harder Creek watersheds were similar and the phosphorus yield from the Lower Rice Creek watershed was higher. Each acre of watershed exported 0.03 pounds of total phosphorus from the Otter Creek and Harder Creek watersheds and 0.05 pounds of total phosphorus from the Lower Rice Creek watershed for the entire 2010 water year. The 2010 phosphorus export rate for the Lower Rice Creek watershed of 0.05 pounds per acre is the same total phosphorus export rate estimated for an average annual precipitation (32 inches) year based upon monitoring data collected in 2006 (Barr 2007). The phosphorus export rates from the Otter Creek, Lower Rice Creek, and Harder Creek watersheds are very low and are comparable to the expected rate of phosphorus export from heavily forested watersheds (Panuska, 1995). The low export rates indicate that watershed land uses are well managed and result in minimal phosphorus export to Balsam Lake. The phosphorus export rates from Otter Creek, Harder Creek, and Lower Rice Creek are more than two orders of magnitude (100 times) lower than Wisconsin phosphorus regulations adopted September 24, 2010 which restrict phosphorus run off from fields to 6 pounds per acre annually.

Because Balsam Lake watershed land uses are well managed, the lake has good water quality and fully supports all recreational uses, including skiing, shown above.

4.0 Balsam Lake Water Quality

4.1 Trophic State Indices (TSIs)

Trophic state indices (TSIs) were calculated from 2010 Balsam Lake water quality on the basis of total phosphorus, chlorophyll *a* concentrations, and Secchi disc transparencies to determine the lake's stage of eutrophication. As noted in Section 2.2 of this report, TSIs express water quality data on a scale of 1 to 100. TSIs are then used to determine whether the water quality of a lake is good or problematic. Clear, low productivity lakes, termed oligotrophic, have TSIs up to 37. Moderate productivity, good water quality lakes, termed mesotrophic, have TSIs from 38 to 50. Nutrient rich lakes with algal blooms, termed eutrophic, have TSIs from 51 to 63. Lakes in this category have water quality problems ranging from very mild at the low end of the range to severe at the high end of the range. Very nutrient rich lakes with very severe algal blooms and very severe water quality problems, termed hypereutrophic, have TSIs of 64 and greater. Balsam Lake TSIs in 2010 are shown in Table 6. All TSIs were computed from summer average (June through August) water quality values. Lake sample locations are shown in Figure 1. Lake water quality data are presented in Appendices F through K.

Table 6 2010 Balsam Lake Trohic State Indices (TSIs) from Summer Average (June – August) Total Phosphorus, Chlorophyll *a*, and Secchi Disc Values

Sample Location	Total Phosphorus	Chlorophyll a	Secchi Disc Transparency
S1	60	69	54
S2	48	52	47
S3	49	53	46
S4	47	51	44
S5	48	50	46
S6	49	53	46
Lake Wide Average	**51**	**58**	**47**

On average, the total phosphorus TSI values for Balsam Lake were mildly eutrophic, the chlorophyll *a* TSI values were eutrophic, and the Secchi disc TSI values were mesotrophic. Sample locations S2 through S6 had similar water quality and S1 had much poorer water quality than the other locations. Total phosphorus TSIs ranged from 47 to 49 at S2 through S6 indicating mesotrophic trophic status and moderate levels of phosphorus. S1 had a total phosphorus TSI of 60 indicating a eutrophic status or a high level of phosphorus. Chlorophyll *a* TSIs ranged from 50 to 53 at S2 through S6 indicating a mildly eutrophic status or mild algal blooms. S1 had a TSI value of 69 indicating a hypereutrophic status or very severe algal blooms. Secchi disc transparency TSIs ranged from 44 to 47 at S2 through S6 indicating a mesotrophic trophic status or good water transparency. S1 had a TSI value of 54 indicating a eutrophic status or problematic water transparency.

4.2 Total Phosphorus, Chlorophyll a, and Secchi Disc Transparency

2010 Balsam Lake total phosphorus, chlorophyll *a*, and Secchi disc transparency data are shown in Figures 5 through 10. Figures 5, 7, and 9 show values from S1 through S6 and Figures 6, 8, and 10 show lake wide average values. Trophic state categories are also shown in each graph. Water quality data are presented in Appendices F through K.

4.2.1 Total Phosphorus

Lake phosphorus levels typically increase throughout the growing season due to the addition of phosphorus conveyed to the lake in stormwater runoff or added to the lake from in-lake processes. Balsam Lake followed this typical seasonal pattern, but increases at S1 were much greater than increases at S2 through S6. Total phosphorus concentrations at S2 through S6 ranged from 17 to 23 µg/L during early May and all values were in the mesotrophic category. Increases during the summer resulted in total phosphorus concentrations at S2 through S6 ranging from 27 through 43 µg/L in late September. These values were in the eutrophic category. S1 began the growing season with a total phosphorus concentration of 29 µg/L which was in the eutrophic category. Phosphorus increases during the growing season increased total phosphorus concentrations at S1 to 65 µg/L in late September. This value was in the hypereutrophic category.

Phosphorus concentrations from the six monitoring locations were averaged to obtain a lake wide average phosphorus concentration. This average was within the mesotrophic category during May through early July and then increased to the eutrophic category from late July through September (Figure 6). The 2010 lake wide summer average phosphorus concentration was 26 µg/L, which is mildly eutrophic (Figure 6).

Wisconsin adopted a State phosphorus standard for Wisconsin lakes on September 24, 2010. The State total phosphorus standard for Balsam Lake is 30 µg/L because Balsam Lake is a stratified drainage lake (NR102.06). If the average lake wide summer average total phosphorus concentration meets the State standard, the lake's water quality is considered acceptable and the lake is not impaired for aquatic recreation. The 2010 Balsam Lake S1 through S6 average summer total phosphorus concentration of 26 µg/L meets the State standard. Hence, the water quality of Balsam Lake is considered acceptable and the lake is not impaired.

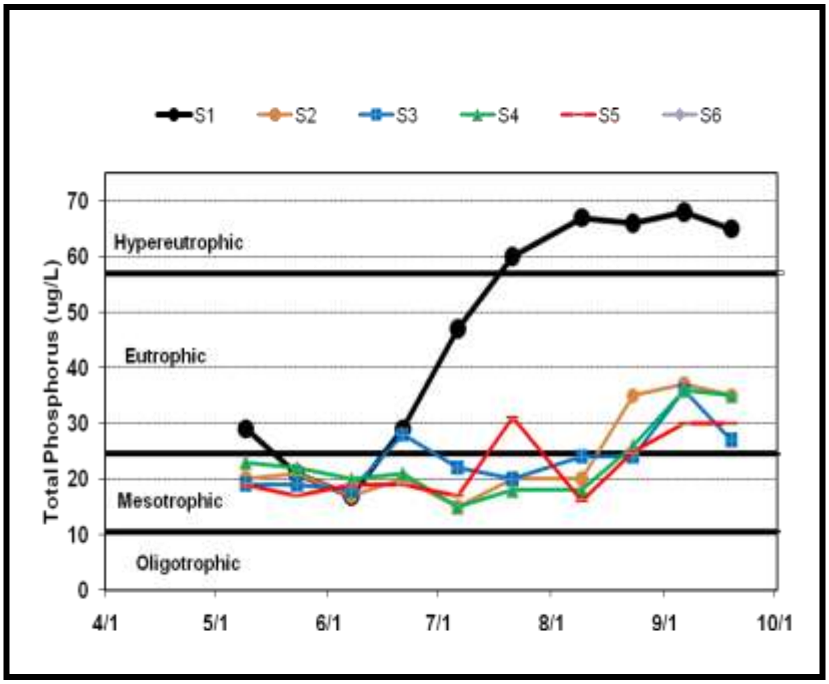


Figure 5 2010 Balsam Lake Total Phosphorus Concentrations in the 0-2 Meter Depth

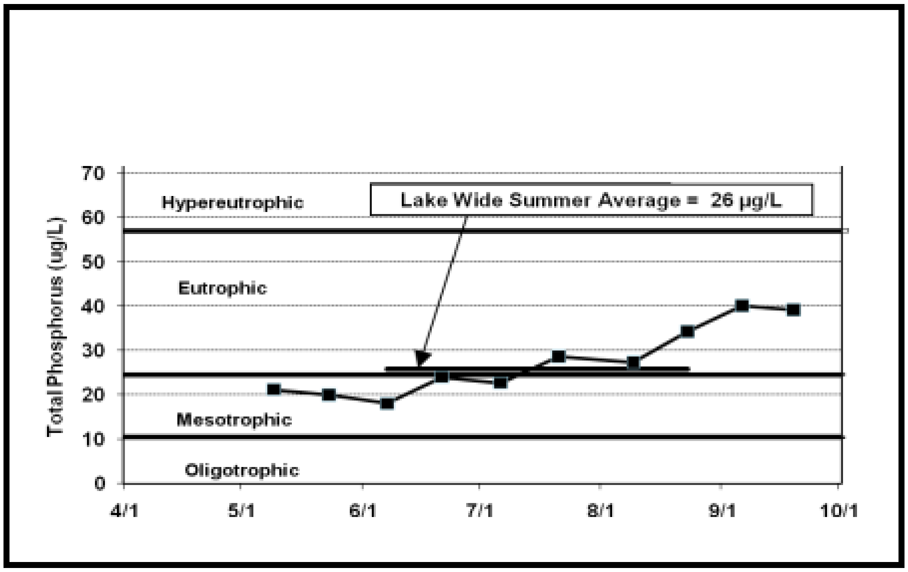


Figure 6 2010 Balsam Lake Total Phosphorus Concentrations in the 0-2 Meter Depth (Lake Wide Average)

S2 through S6 did not experience water quality problems during the summer of 2010. Hence, the lake fully supported all recreational uses. Pictured above is a resident skiing on Balsam Lake in 2010.

Although the intent of the standard is to apply it to the lake wide average, comparing the standard against the averages of individual basins can provide an indication of whether or not individual basins are experiencing water quality problems. The 2010 summer average total phosphorus concentrations from S2 through S6 ranged from 20 µg/L to 23 µg/L and met the State standard. Hence, these basins did not experience water quality problems in 2010. The 2010 summer average total phosphorus concentration from S1 of 48 µg/L did not meet the State standard. The failure of S1 to meet the State standard indicates S1 experienced water quality problems in 2010 due to high phosphorus concentrations.

4.2.2 Chlorophyll *a*

As shown in Figure 7, Balsam Lake chlorophyll *a* concentrations followed a similar seasonal pattern as total phosphorus concentrations in 2010. This similar pattern followed by total phosphorus and chlorophyll *a* indicates the lake's algal growth in 2010 was determined by the lake's phosphorus concentration. Lower phosphorus concentrations during the spring and early summer were associated with reduced algal growth while higher phosphorus concentrations during the late summer were associated with increased algal growth. Phosphorus and chlorophyll data both told the story of the problematic water quality observed at S1 during much of the summer.

Chlorophyll *a* concentrations at S2 through S6 ranged from 3.8 µg/L to 10.3 µg/L in early May. These values ranged from mesotrophic to mildly eutrophic. In early August, chlorophyll *a* concentrations at S-2 to S-6 had increased only slightly and ranged from 4.6 µg/L to 12 µg/L. These values ranged from mesotrophic to mildly eutrophic. Late summer increases in algal growth resulted in late September chlorophyll *a* concentrations of 19.5 to 37.5 µg/L at S2 through S6. These values range from eutrophic to hypereutrophic.

In early May, the chlorophyll *a* concentration at S1 was 6.2 µg/L. This value was in the mesotrophic category and within the range of concentrations found at S2 through S6. By early August, the chlorophyll *a* concentration at S1 had increased to 83 µg/L and was in the hypereutrophic category. This value was about 7 times greater than the highest value observed at S2 through S6. Chlorophyll *a* concentrations declined to 25 µg/L at S1 by late September. This value is in the eutrophic category.

As shown in Figure 8, chlorophyll concentrations from the six monitoring locations were averaged to obtain a lake wide average chlorophyll concentration. This average was within the mesotrophic category during May through late June. Then increased algal growth associated with increased lake phosphorus concentration changed the lake's water quality to eutrophic from late June through early August. During late August and late September, the average was in the mildly hypereutrophic category. The 2010 lake wide summer average chlorophyll *a* concentration was 16 µg/L, which is in the eutrophic category.

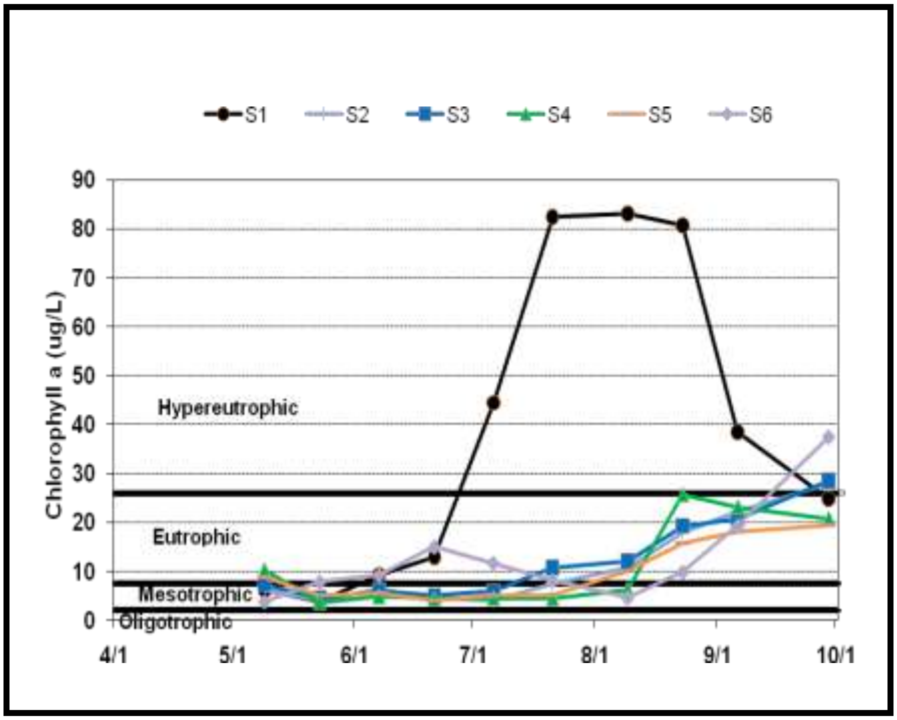


Figure 7 2010 Balsam Lake Chlorophyll *a* Concentrations in the 0-2 Meter Depth

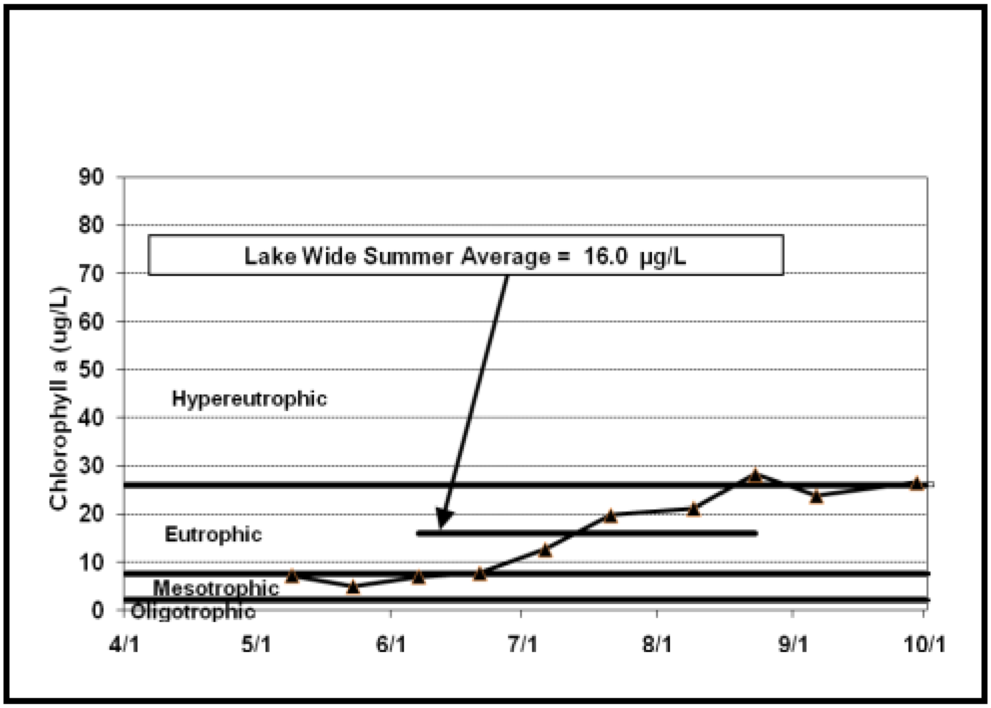


Figure 8 Balsam Lake Chlorophyll *a* Concentrations (Lake Wide Average)

4.2.3 Secchi Disc Transparency

As shown in Figure 9, reduced algal growth early in the growing season resulted in good water transparency throughout the lake. Secchi disc depth at the six monitoring locations ranged from 6.9 to 12.1 feet (2.1 meters to 3.7 meters) and was in the mesotrophic category during May through late June. However, as the growing season progressed, increased algal growth associated with increased phosphorus concentrations reduced water transparency throughout the lake. Because S1 observed much higher phosphorus and chlorophyll concentrations than the rest of the lake, it also experienced much lower water transparency than the rest of the lake during July through September. Secchi disc depth at S2 through S6 ranged from 4.3 to 12.1 feet (1.3 meters to 3.7 meters) during July through September. These values range from eutrophic to mesotrophic. S1 experienced Secchi disc depths ranging from 2.0 to 3.6 feet (0.6 meters to 1.1 meters) during this period. These values range from eutrophic to hypereutrophic.

Secchi disc depth from the six monitoring locations was averaged to obtain a lake wide average. This average was within the mesotrophic category during May through early August and then deteriorated to the eutrophic category from late August through September (see Figure 10). The 2010 lake wide summer average Secchi disc depth was 8.2 feet (2.5 meters), which is in the mesotrophic category (Figure10). The data indicate that, on average, Balsam Lake water transparency was good during the summer of 2010.

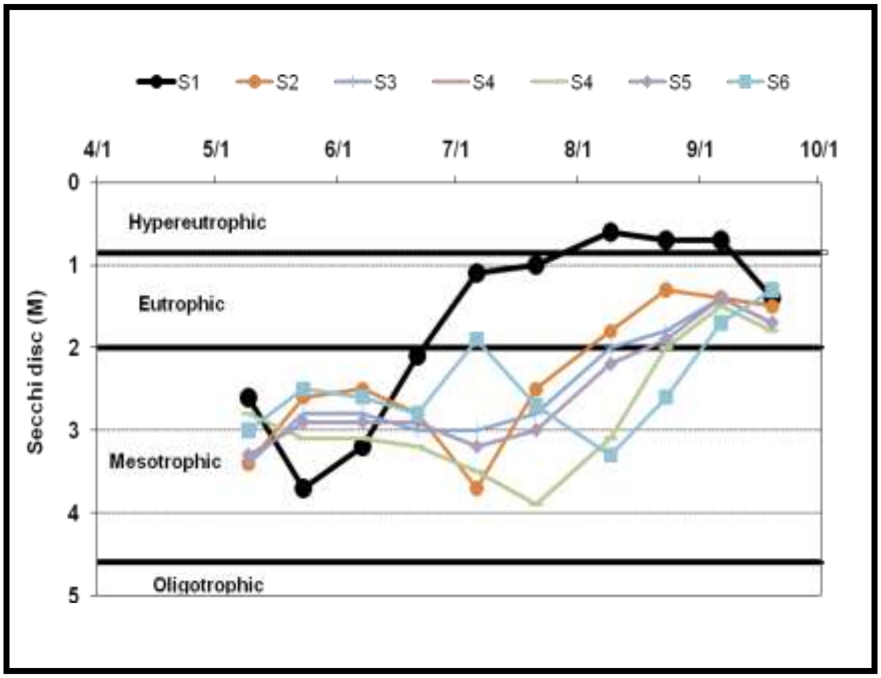


Figure 9 2010 Balsam Lake Secchi Disc Depth

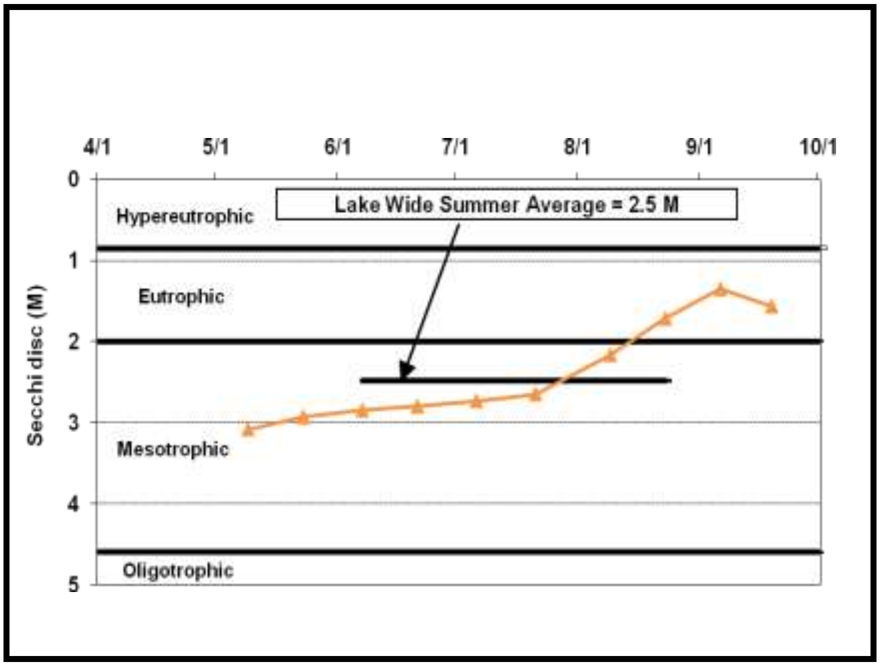


Figure 10 2010 Balsam Lake Secchi Disc Transparency (Lake Wide Average)

4.2.4 Relationship between Secchi Disc Transparency and Total Phosphorus

The 2010 data indicated Secchi disc transparency was primarily determined by lake total phosphorus concentrations. To confirm this relationship between total phosphorus and Secchi disc transparency, 2010 Balsam Lake total phosphorus concentrations and Secchi disc depths were graphed and then compared with a total phosphorus and Secchi disc relationship developed by Carlson (1977) from evaluations of large numbers of lakes in the United States. The data were also compared with a relationship developed by Heiskary and Wilson (1990) from a large number of Minnesota lakes. As shown in Figure 11, most Balsam Lake data points either fall on or are very close to the line depicting the Carlson or Heiskary and Wilson relationship between total phosphorus concentration and Secchi disc transparency. The agreement between Balsam Lake data and the Carlson and/or Heiskary and Wilson relationships confirms Balsam Lake Secchi disc water transparency is primarily determined by lake phosphorus concentrations. The data indicate lower phosphorus concentrations result in higher water clarity and higher phosphorus concentrations result in reduced water clarity. This relationship indicates management of phosphorus is the key to managing Balsam Lake water clarity and it will be necessary to reduce phosphorus concentrations in S1 (East Balsam Lake) to improve water transparency.

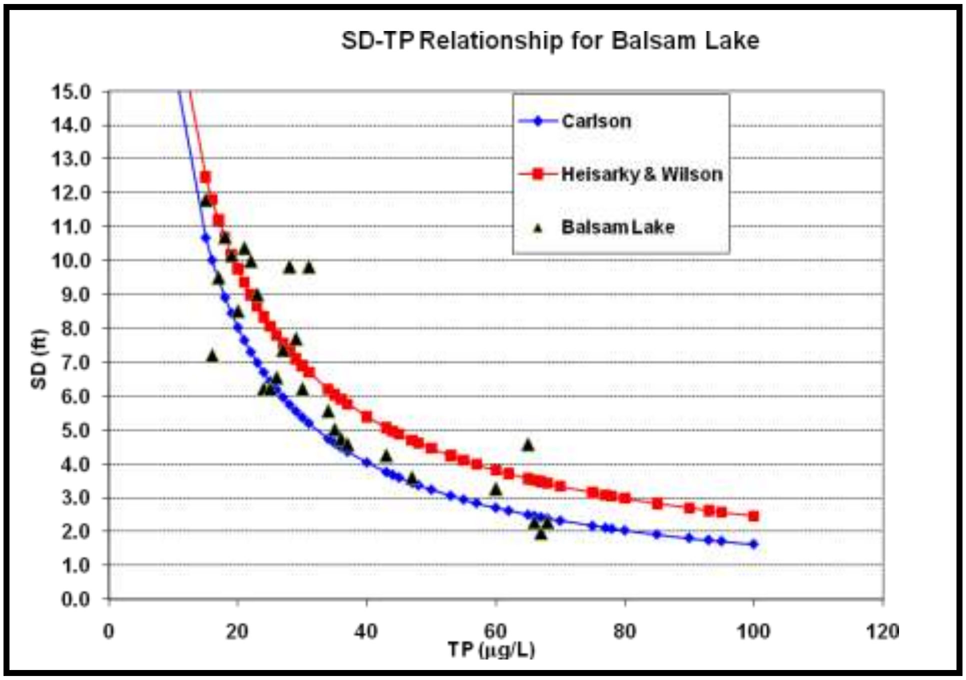


Figure 11 Secchi Disc-Total Phosphorus Relationsip: Compare Balsam Lake Data with Carlson and Heiskary & Wilson Relationships

5.0 Trend Analysis

A trend analysis indicated the water transparency of Little Balsam Lake has improved significantly. The improved water transparency has increased the enjoyment experienced by lake users while engaging in recreational uses, such as skiing, pictured above.

Trend analysis determines whether significant long-term changes in water quality conditions have occurred. Balsam Lake summer average (June through August) Secchi disc data from 2010 were combined with data from previous years and analyzed for long-term trends. Data have been collected from S1 (East Balsam), S4 (Main Balsam), and S6 (Little Balsam) since 1987. However, only summer averages from years in which at least 4 Secchi disc measurements occurred during the summer period were included in the trend analysis. Historical Secchi disc data from S1 (East Balsam Lake), S4 (Main Balsam Lake) and S6 (Little Balsam Lake) are presented in Appendix L.

To estimate the trend in Secchi disc transparency for Balsam Lake, the nonparametric seasonal Mann-Kendall trend analysis was used. WQ Stat Plus software was used for the analysis and the Sen's slope was used for the trend line. The trend was evaluated for the period 1988 through 2010. A separate trend analysis was completed for S1 (East Balsam), S4 (Main Balsam), and S6 (Little Balsam) (See Figure 1 for locations). The response variable, Secchi disc, was plotted versus the independent variable, time (in years) since 1988, along with the predicted trend line. Secchi disc was only considered to have a significant change over time if the slope of the trend line was significantly different from zero. The standard 95 percent confidence level was used, although the 99 percent, 90 percent, and 80 percent confidence levels were also calculated. If the analysis indicates a 95 percent confidence that the slope of the Secchi disc trend line is different from zero, the trend is considered statistically significant. If there is a 95 percent confidence that the Secchi disc trend line is not different from zero, the changes in Secchi depth over time are not considered significant.

5.1 East Balsam Lake (S1) Trend Analysis

As shown in Figure 12, average summer Secchi disc transparency in East Balsam Lake has remained relatively stable except for 1990 through 1992 when much improved water transparency was observed. Average summer Secchi disc transparency ranged from 5.9 to 6.6 feet (1.8 meters to 2.0 meters) during 1988 through 1989, improved to 12.5 to 13.5 feet (3.8 meters to 4.1 meters) during 1990 to 1992, was 6.2 feet (1.9 meters) in 1993, and ranged from 4.6 to 8.5 feet (1.41 meters to 2.6 meters) during 2000 through 2010. The improved water transparency during 1990 through 1992 caused the trend line to have a downward slope, but the slope of this line was not significantly different from zero at the 95 percent confidence level. Hence the trend analysis indicates there was no significant change in Secchi disc transparency during the 1988 through 2010 period of record.

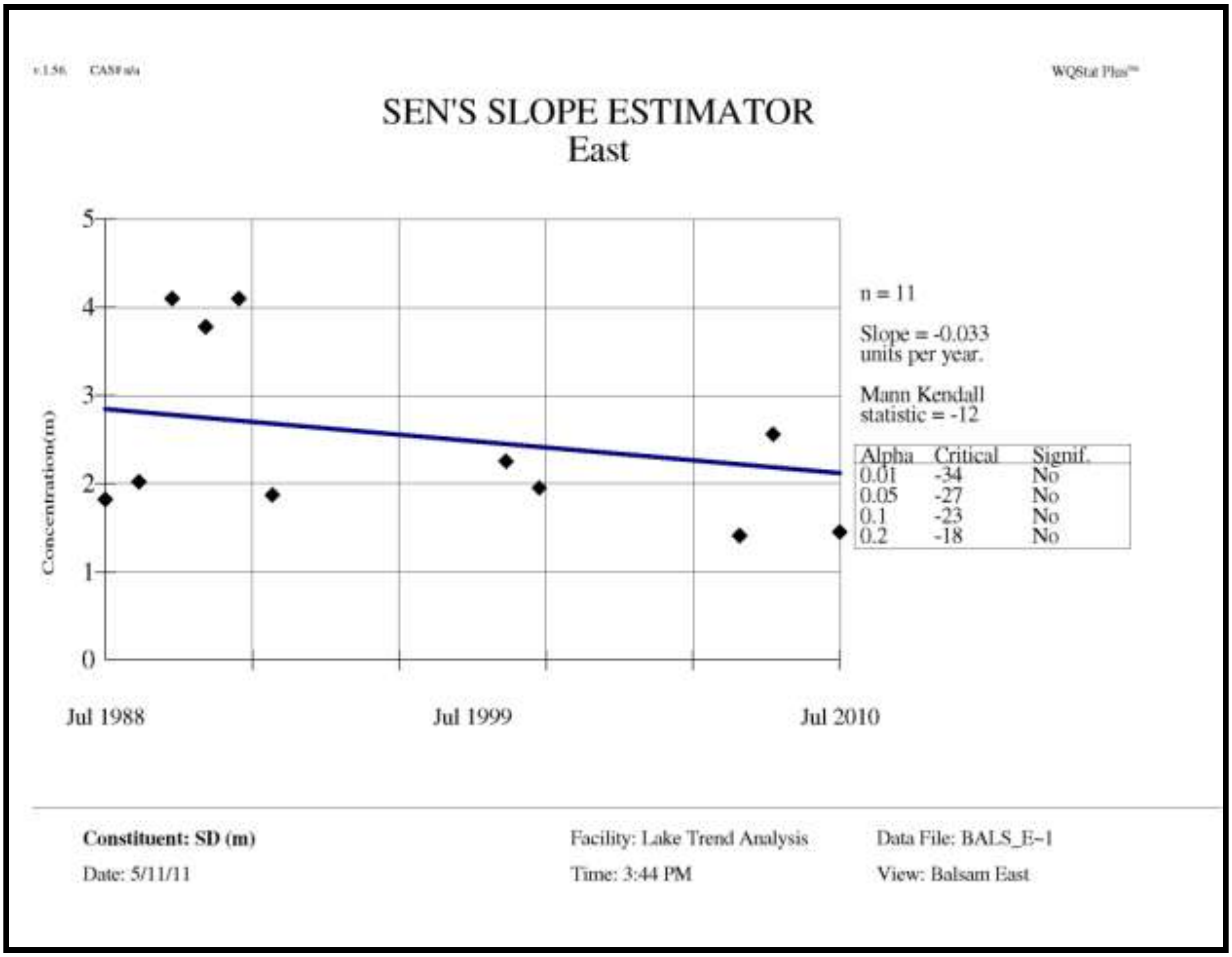
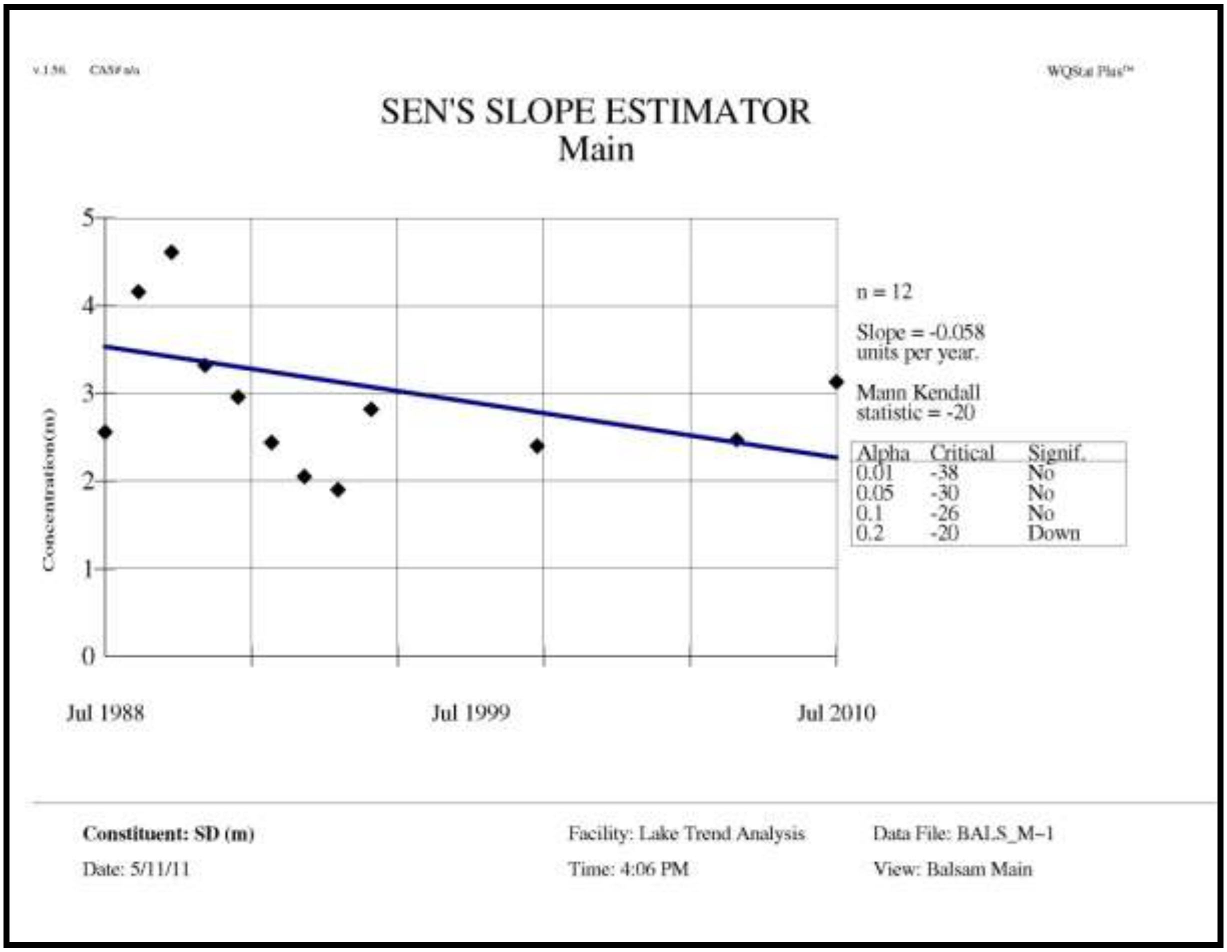


Figure 12 East Balsam Lake Trend Analysis: Secchi Disc Depth

5.2 Main Balsam Lake (S4) Trend Analysis

As shown in Figure 13, average summer Secchi disc transparency in Main Balsam Lake has remained relatively stable except for 1989 and 1990 when much improved water transparency was observed. Average summer Secchi disc transparency was 8.5 feet (2.6 meters) during 1988, improved to 13.7 feet to 15.1 feet (4.2 meters to 4.6 meters) during 1989 to 1990, was 10.8 feet (3.3 meters) in 1991, and ranged from 6.2 feet to 10.2 feet (1.9 meters to 3.1 meters) during 1992 through 2010. The improved water transparency during 1989 through 1990 caused the trend line to have a downward slope, but the slope of this line was not significantly different from zero at the 95 percent confidence level. Hence the trend analysis indicates Secchi disc transparency did not significantly change during the 1988 through 2010 period of record.



Alpha	Critical	Signif.
0.01	-38	No
0.05	-30	No
0.1	-26	No
0.2	-20	Down

Constituent: SD (m)
Date: 5/11/11
Facility: Lake Trend Analysis
Time: 4:06 PM
Data File: BALS_M-1
View: Balsam Main

Figure 13 Main Balsam Lake Trend Analysis: Secchi Disc Depth

5.3 Little Balsam Lake (S6) Trend Analysis

As shown in Figure 14, average summer Secchi disc transparency in Little Balsam Lake has consistently improved during the 1988 through 2010 period of record at a rate of 2 inches (0.051 meters) per year. The slope of the trend line was significantly different from zero at the 95 percent confidence level indicating this improvement was significant.

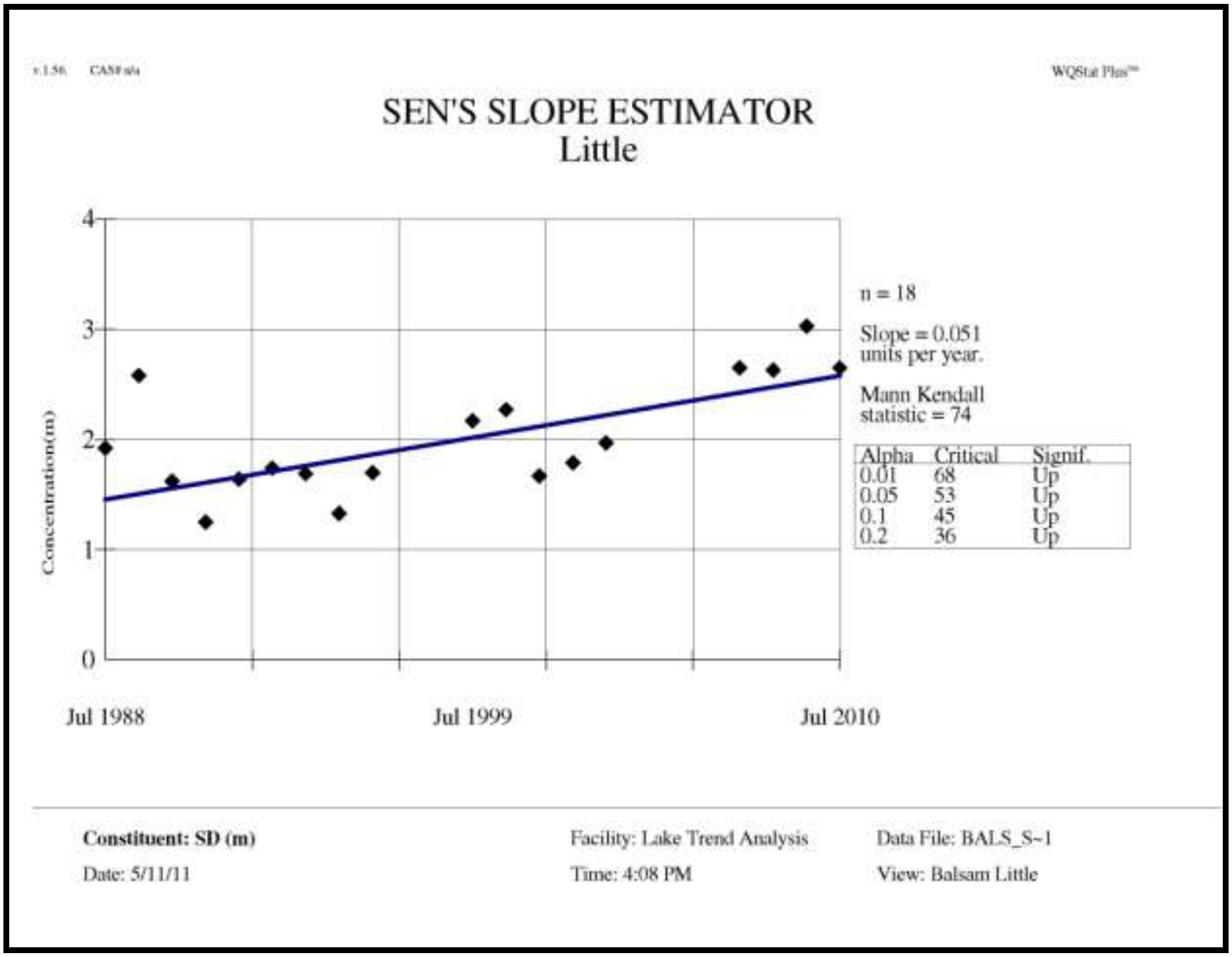


Figure 14 Little Balsam Lake Trend Analysis: Secchi Disc Depth

6.0 Modeling Results

Water quality models are useful predictive tools for assessing the nutrient loading to lakes and the response of lakes to nutrient loading, their water quality. A model is defined as a simplified (often mathematical) description of a system that assists in calculations and predictions of the condition of that system in a given situation (Concise Oxford Dictionary, 1990). Two different models were used to estimate phosphorus loading to Balsam Lake and a third model was used to predict lake response to phosphorus loading.

The FLUX model was used to estimate phosphorus loading from the monitored Otter Creek, Harder Creek, and Lower Rice Creek watersheds. The model uses continuous flow data and observed phosphorus data to estimate phosphorus load. FLUX modeling inputs, results, and modeling methods are presented in Appendix M.

The Wisconsin Lake Modeling Suite (WILMS) was used to estimate phosphorus loading from the unmonitored S1 through S6 watersheds. The model uses watershed water yield and phosphorus export coefficients to estimate phosphorus load from the watershed. The model also estimates phosphorus load from septic systems based upon number of residences and estimated soil retention. Modeling methods and results are presented in Appendix N.

The BATHTUB model was used to predict lake response to phosphorus load. BATHTUB modeling inputs, methods, and results are in presented in Appendix O. The lake response predicted by the BATHTUB model was compared to the observed 2010 Balsam Lake average summer data to determine how closely the modeled results agree with observed data. As shown in Figures 15 through 17, observed and modeled summer average total phosphorus, chlorophyll *a*, and Secchi disc data are in close agreement. The close agreement between observed and modeled lake data indicate the BATHTUB input parameters are correct, including watershed phosphorus loads, and the modeling results are reliable. Because observed and modeled data are in close agreement, the observed data points are behind modeled data points in Figures 15 through 17 and only a slight glimpse of the edges of the observed points can be seen in the figures.

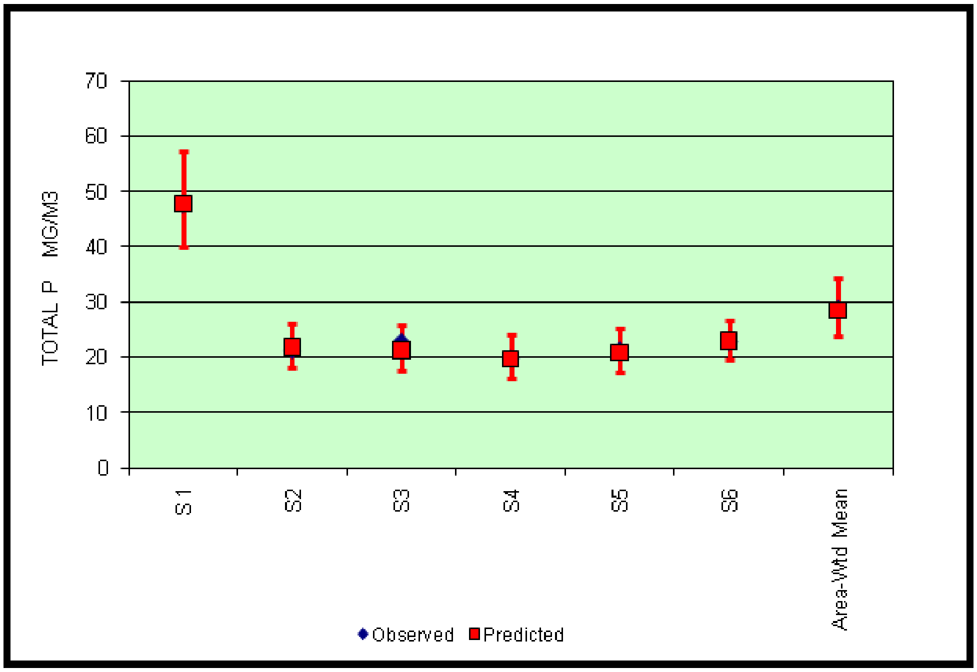


Figure 15 2010 Balsam Lake Summer Average Total Phosphorus Concentrations (0-2 Meters): Comparison between Observed and Modeled Concentrations

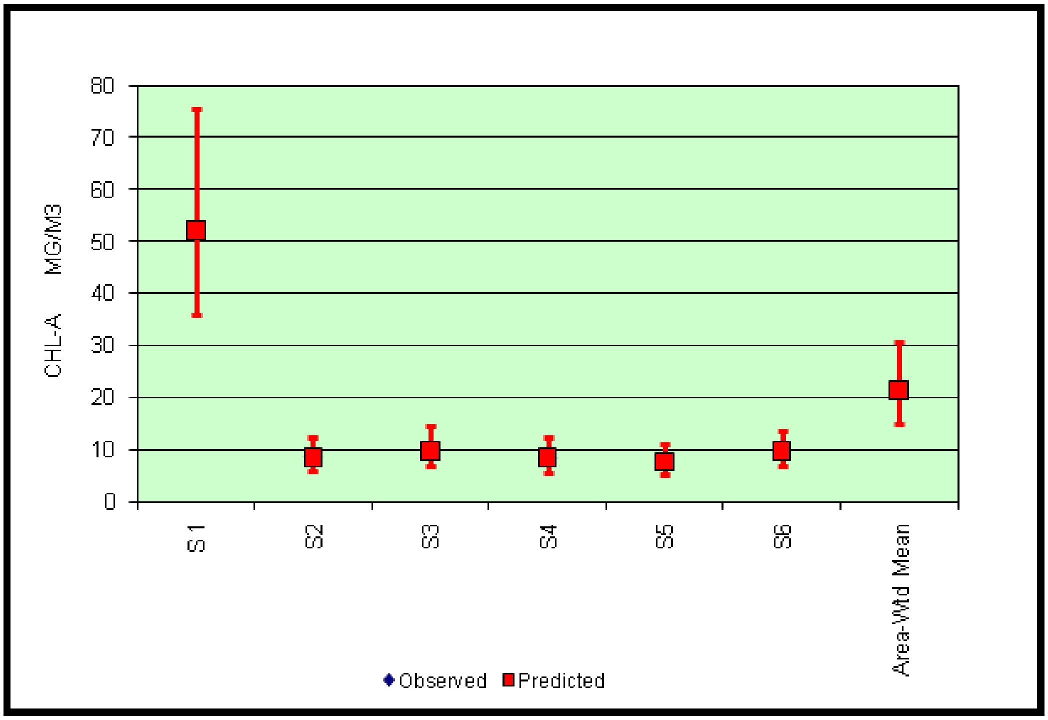


Figure 16 2010 Balsam Lake Summer Average Chlorophyll *a* Concentrations (0-2 Meters): Comparison between Observed and Modeled Concentrations

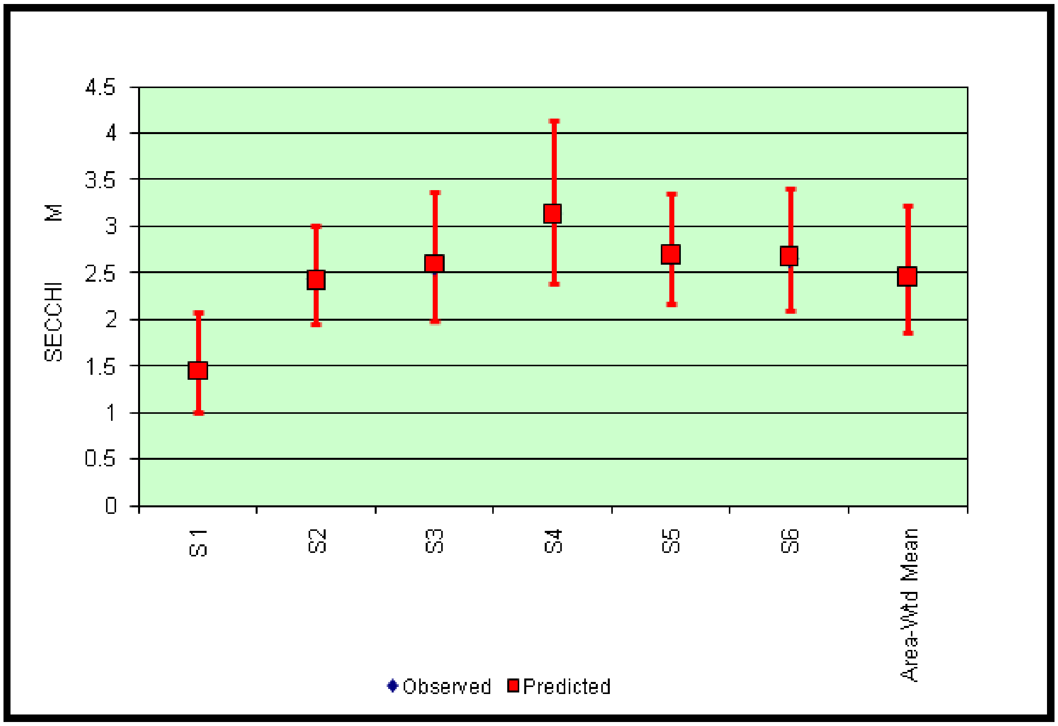


Figure 17. 2010 Balsam Lake Summer Average Secchi Disc Transparency: Comparison between Observed and Modeled Data

BATHTUB modeling results included a compilation of water and phosphorus loads to the lake from the six monitored lake segments (S1 through S6, locations shown in Figure 1). In-lake processes were also estimated by the model including conveyance of phosphorus from one basin to another by one way flow and the net change in phosphorus resulting from mixing between lake basins. Internal load was also estimated by BATHTUB. The model results included water and phosphorus loading information computed for the lake as a whole as well as the individual basins. Modeling results are discussed in the sections that follow.

6.1 Balsam Lake Hydrologic (Water) Budget

The Balsam Lake hydrologic budget is an accounting of the water inflows to, outflow and evaporation from, and storage in Balsam Lake. The 2010 hydrologic budget of Balsam Lake is shown in Table 7. Sources of water to Balsam Lake are shown in Figure 18. The lake residence time in 2010 was 1 ½ years. Lake residence time is the time required for a volume equal to the full lake volume to be replaced by inflowing waters. Hence, the volume of inflowing waters in 2010 would result in replacement of the full lake volume in 1 ½ years.

Table 7 2010 Balsam Lake Hydrologic Budget

Name	Flow (ac ft/yr)
Lower Rice Creek	3,758
Harder Creek	1,966
S1 Watershed	2,579
S2 Watershed	390
S3 Watershed	368
S4 Watershed	6,667
S5 Watershed	256
S6 Watershed	951
Tributary Inflow	16,935
Precipitation	5,655
Total Inflow	22,590
Advective Outflow	17,594
Total Outflow	17,594
Evaporation	3,492
Storage Increase	1,504

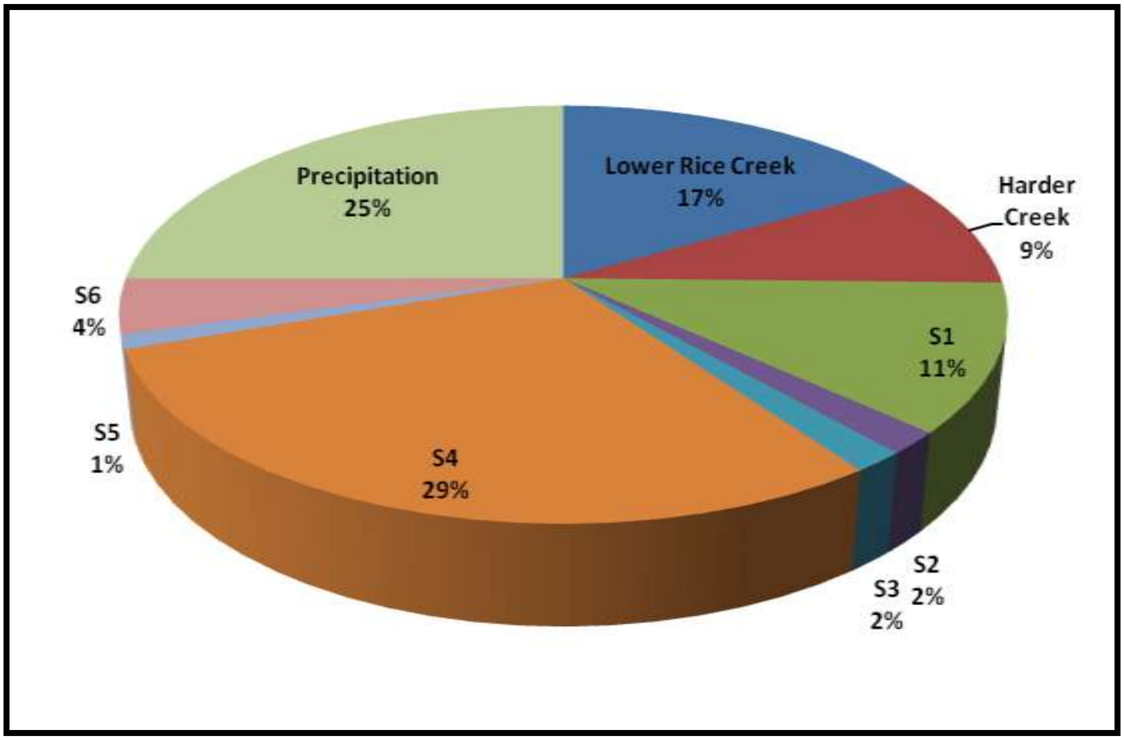


Figure 18 2010 Sources of Water to Balsam Lake (Percent of Total)

6.2 Balsam Lake Phosphorus Budget

The Balsam Lake phosphorus budget is an accounting of the phosphorus inflows to, outflow from, and storage in Balsam Lake. The 2010 Balsam Lake phosphorus budget is shown in Table 8. Sources of phosphorus to Balsam Lake are shown in Figure 19. The Balsam Lake phosphorus budget only includes internal loading that impacted the lake's surface water quality during the summer period (June through August). Internal loading from sediment added to the lake's surface waters in September when the lake began its annual fall mixing is discussed in Section 7.3 of this report.

Table 8 2010 Balsam Lake Total Phosphorus Budget

	Total Phosphorus			
Name	**Load (lbs/yr)**	**% of Total Load**	**Conc. (µg/L)**	**Export (lbs/ac/yr)**
Lower Rice Creek	432	11.7%	42	0.05
Harder Creek	207	5.6%	39	0.03
S1 Watershed	432	11.6%	62	0.16
S2 Watershed	42	1.1%	40	0.11
S3 Watershed	57	1.5%	57	0.15
S4 Watershed	1,255	33.8%	69	0.19
S5 Watershed	55	1.5 %	78	0.21
S6 Watershed	157	4.2%	60	0.16
Precipitation	498	13.4%	32	0.27
Internal Load	576	15.5%		
Tributary Inflow	2,635	71.0%	57	0.10
Total Inflow	3,711	100.0%	61	
Advective Outflow	942	26.1%	20	
Total Outflow	942	26.1%	20	
Storage Increase	117	3.1%	29	
Retention	2,650	70.7%		

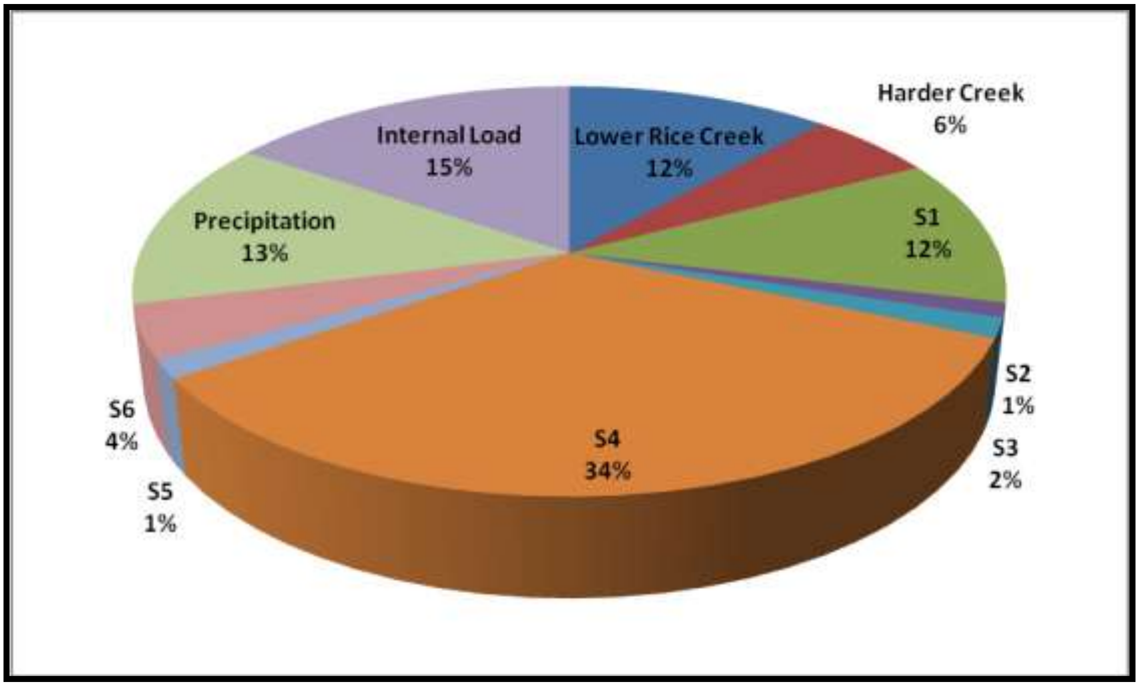


Figure 19 2010 Sources of Total Phosphorus to Balsam Lake (Percent of Total)

In addition to computing an overall hydrologic and phosphorus budget for Balsam Lake, the BATHTUB model computed hydrologic and phosphorus budgets for S1 through S6. These budgets are presented in the sections that follow. The phosphorus budgets for S1 through S6 only include the internal phosphorus load that impacted the lake's surface water quality during the summer period (June through August). Internal loading from sediment added to the lake's surface waters in September when the lake began its annual fall mixing is discussed in Section 7.3 of this report.

6.3 S1 Hydrologic and Phosphorus Budget

The S1 hydrologic and phosphorus budget is shown in Table 9. Sources of phosphorus are shown in Figure 20. The location of S1 is shown on Figure 21.

S1, also known as East Balsam Lake, is a shallow basin with a mean depth of 9.5 feet. The basin has a fairly long residence time. In 2010, S1 had a residence time of 1.6 years.

Modeling results indicate the main source of phosphorus to S1 in 2010 was internal loading which comprised half of the basin's annual phosphorus load. In 2010, watershed load and atmospheric deposition comprised the other half of the S1 phosphorus load. Phosphorus loading from the S1 watershed comprised 37 percent of the basin's annual phosphorus load. Phosphorus added by atmospheric deposition comprised 13 percent of the basin's annual phosphorus load.

Table 9 2010 S1 Hydrologic and Total Phosphorus Budget

Name	Flow (ac ft/yr)	Flow (%Total)	Load (lbs/yr)	Load (%Total)	Conc. (µg/L)
S1 Watershed	2,579	61.1%	432	37.4 %	62
Precipitation	1,641	38.9%	146	12.6%	32
Internal Load	0	0.0%	576	50.0%	
Tributary Inflow	2,579	61.1%	432	37.4%	61
Total Inflow	4,220	100.0%	1,153	100.0%	100
Advective Outflow to S3(1)	2,770	65.6%	359	31.3 %	48
Net Diffusive Outflow to S3(2)	0	0.0%	82	7.1 %	
Total Outflow	2,770	65.6%	441	38.3%	59
Evaporation	1,014	24.0%	0	0.0%	
Storage Increase	437	10.3%	57	4.9%	48
Retention	0	0.0%	655	56.7%	
Hyd. Residence Time	1.6 yrs				
Overflow Rate	5.9 ft/yr				
Mean Depth	9.5 ft				

(1)Advective Outflow is one way flow from S1 to the next downstream basin which is S3.

(2)Net Diffusive Outflow is the net result of back and forth mixing between S1 and S3, basins located adjacent to one another.

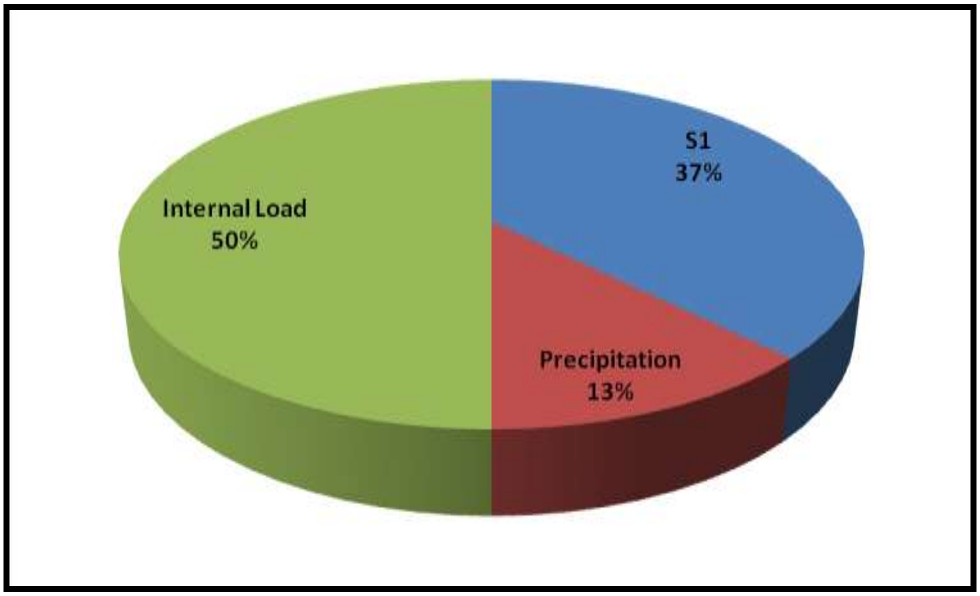


Figure 20 2010 Sources of Total Phosphorus to S1

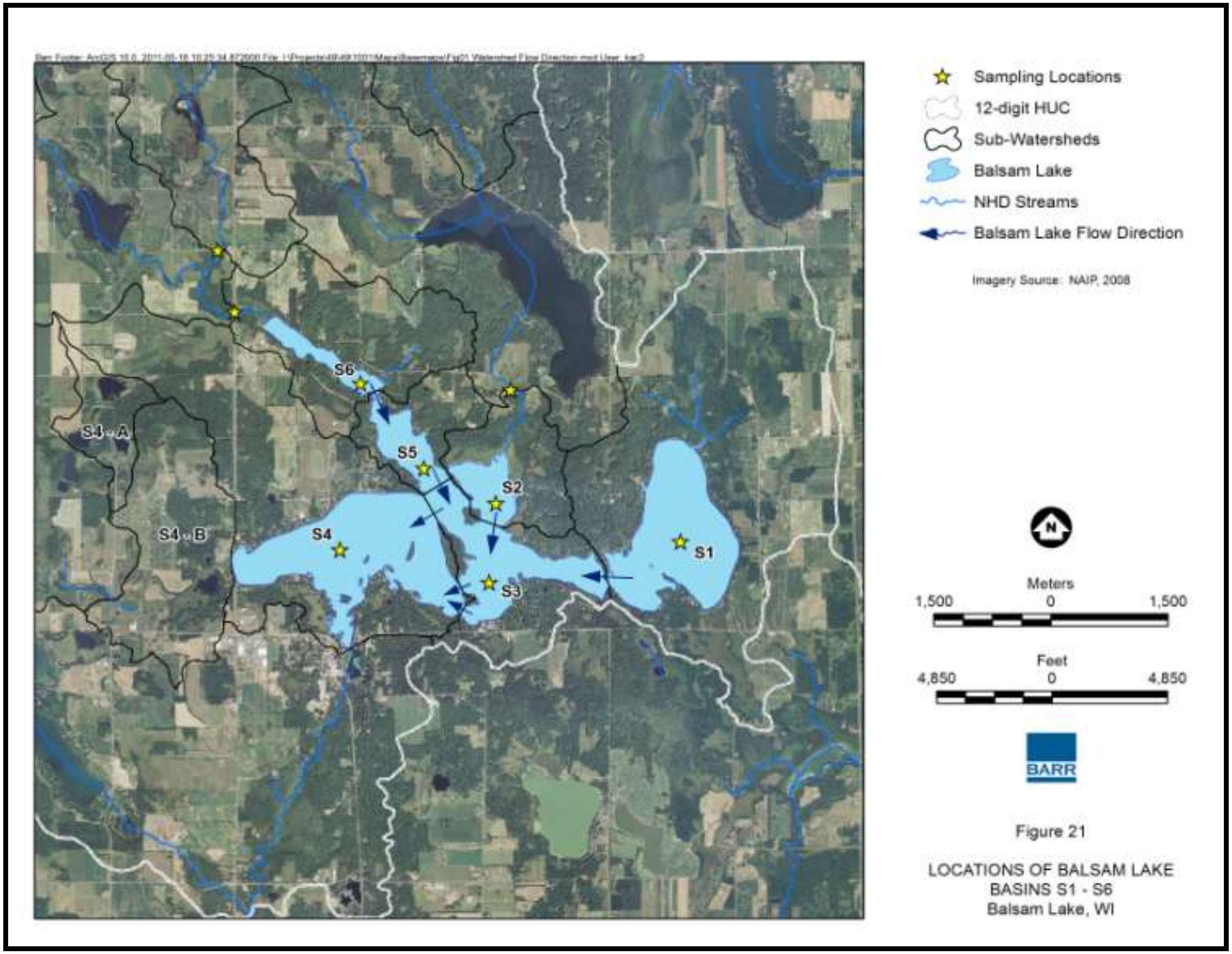


Figure 21 Locations of Balsam Lake Basins S1 - S6

Data collected from S1 in 2010 indicate the likely source of the internal phosphorus load was the release of phosphorus from sediments (Appendix F). Dissolved oxygen data indicate that anoxic conditions were consistently observed at the bottom of the lake during July and August (Appendix F). When oxygen concentrations are less than 2 mg/L (anoxic conditions), sediments pump phosphorus into the lake. The rate of pumping and the amount of phosphorus added to the lake under anoxic conditions is determined by the phosphorus concentration of the sediment. Temperature data indicate the lake sometimes weakly stratified or formed temperature layers, but frequently mixed completely. In shallow lake basins such as S1 in which frequent mixing occurs, phosphorus added from sediment is mixed throughout the lake. When this phosphorus is added to the lake's surface waters, it becomes available to algae and causes increased algal growth. During the July and August period, S1 surface phosphorus concentrations more than doubled, chlorophyll concentrations increased six fold, and Secchi disc transparency was less than half of June transparency. Because S1 has a fairly long residence time, phosphorus added from sediments has an opportunity to stay in the basin and impact its water quality for a long period of time. The phosphorus budget for S1 indicates the key to improving its water quality is reduction of the basin's internal phosphorus load from sediment.

S1 flows into S3, a downstream basin, and conveys a portion of its phosphorus load to S3. In 2010, S1 conveyed nearly 40 percent of its annual phosphorus load to S3. Hence, the addition of phosphorus to S1 by internal loading impacted the water quality of S3 in 2010.

6.4 S2 Hydrologic and Phosphorus Budget

The S2 hydrologic and phosphorus budget is shown in Table 10. Sources of phosphorus are shown in Figure 22. The location of S2 is shown on Figure 21.

S2 is a shallow basin with a mean depth of 5.2 feet and a relatively short residence time. In 2010, S2 had a residence time of about 3 months.

In 2010, the primary source of phosphorus to S2 was Harder Creek which comprised 74 percent of the basin's annual phosphorus load. The S2 watershed and atmospheric deposition comprised 15 and 11 percent of the basin's annual phosphorus load, respectively.

Water from S2 flows into S3, a downstream basin. In 2010, approximately 94 percent of the S2 phosphorus load flowed to S3.

Table 10 2010 S2 Hydrologic and Total Phosphorus Budget

Name	Flow (ac ft/yr)	Flow (%Total)	Load (lbs/yr)	Load (%Total)	Conc. (µg/L)
Harder Creek	1,966	72.7%	206	73.9%	39
S2 Watershed	390	14.4%	42	15.1%	40
Precipitation	347	12.8%	31	11.0%	32
Tributary Inflow	2,356	87.2%	248	89.0%	39
Total Inflow	2,703	100.0%	279	100.0%	38
Advective Outflow to S3	2,396	88.6%	142	50.8%	22
Net Diffusive Outflow to S3	0	0.0%	66	23.5%	
Total Outflow	2,396	88.6%	208	74.3%	32
Evaporation	214	7.9%	0	0.0%	
Storage Increase	92	3.4%	6	2.0%	22
Retention	0	0.0%	66	23.7%	
Hyd. Residence Time	0.24 yrs				
Overflow Rate	21.7 ft/yr				
Mean Depth	5.2 ft				

(1) Advective Outflow is one way flow from S2 to the next downstream basin which is S3.

(2) Net Diffusive Outflow is the net result of back and forth mixing between S2 and S3, basins located adjacent to one another.

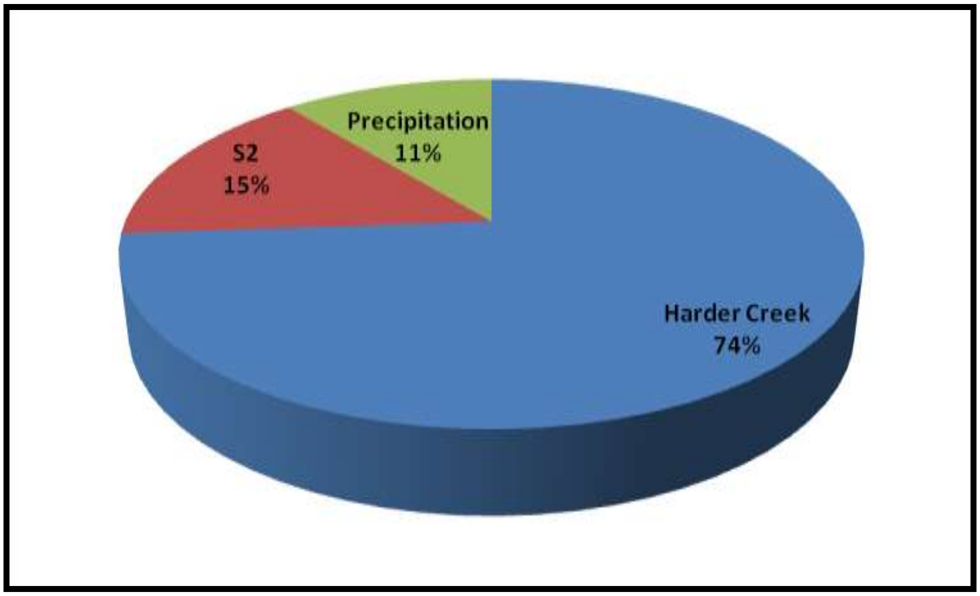


Figure 22 2010 Sources of Total Phosphorus to S2

6.5 S3 Hydrologic and Phosphorus Budget

The S3 hydrologic and phosphorus budget is shown in Table 11. Sources of phosphorus are shown in Figure 23. The location of S3 is shown on Figure 21.

S3 has a mean depth of 18 feet and had a residence time of about 7 months in 2010. The primary sources of water and phosphorus to S3 are adjacent basins. In 2010, adjacent basins contributed approximately 88 percent of the annual water load and 84 percent of the annual phosphorus load. The basin's watershed contributed 6 percent and atmospheric deposition contributed 10 percent of the basin's 2010 annual phosphorus load.

S3 flows into S4, a downstream basin. In 2010, 77 percent of the S3 annual phosphorus load flowed into S4.

Table 11 2010 S3 Hydrologic and Total Phosphorus Budget

Name	Flow (ac ft/yr)	Flow (%Total)	Load (lbs/yr)	Load (%Total)	Conc. (µg/L)
S3 Watershed	368	3.2%	57	6.1%	57
Precipitation	1,022	8.8%	90	9.6%	32
Tributary Inflow	368	3.2%	57	6.1%	57
Advective Inflow(1)	10,206	88.0%	788	84.2%	28
Total Inflow	11,597	100.0%	935	100.0%	30
Advective Outflow(2)	10,693	92.2%	621	66.4%	21
Net Diffusive Outflow(3	0	0%	97	10.3%	
Total Outflow	10,693	92.2%	717	76.7%	25
Evaporation	631	5.4%	0	0.0%	
Storage Increase	272	2.3%	16	1.7%	21
Retention	0	0.0%	202	21.6%	
Hyd. Residence Time	0.55 yrs				
Overflow Rate	32.5 ft/yr				
Mean Depth	18.0 ft				

(1)Advective Inflow is one way flow into S3 from upstream basins S1 and S2.

(2)Advective Outflow is one way flow from S3 to the next downstream basin which is S4.

(3)Net Diffusive Outflow is the net result of back and forth mixing between S3 and adjacent basins.

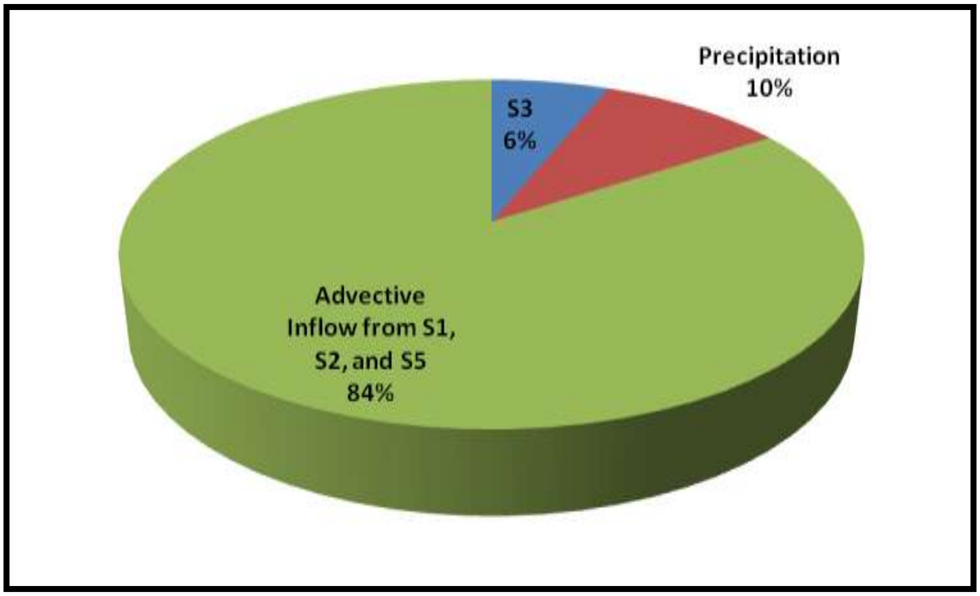


Figure 23 2010 Sources of Total Phosphorus to S3

6.6 S4 Hydrologic and Phosphorus Budget

The S4 hydrologic and phosphorus budget is shown in Table 12. Sources of phosphorus are shown in Figure 24. The location of S4 is shown on Figure 21.

S4 has a mean depth of 19 feet and had a residence time of about 8 months in 2010. The primary source of phosphorus to S4 is the basin's watershed. In 2010, the S4 watershed contributed 55 percent of the basin's annual phosphorus load. S3, an upstream basin, contributed 37 percent, and atmospheric deposition contributed the remaining 8 percent of the basin's annual phosphorus load.

S4 flows into the lake's outflow. In 2010, 41 percent of the basin's annual phosphorus left the lake via its outflow.

Table 12 2010 S4 Hydrologic and Total Phosphorus Budget

Name	Flow (ac ft/yr)	Flow (%Total)	Load (lbs/yr)	Load (%Total)	Conc. (mg/m^3)
S4 Watershed	6,667	34.4%	1,255	54.9%	69
Precipitation	2,007	10.4%	176	7.7%	32
Tributary Inflow	6,667	34.4%	1,255	54.9%	69
Advective Inflow(1)	10,693	55.2%	622	27.1%	21
Net Diffusive Inflow(2)	0	0	236	10.3%	
Total Inflow	19,367	100.0%	2,289	100.0%	43
Advective Outflow(3)	17,594	90.8%	944	41.2%	20
Total Outflow	17,594	90.8%	944	41.2%	20
Evaporation	1,239	6.4%	0	0.0%	
Storage Increase	534	2.8%	29	1.2%	20
Retention	0	0.0%	1,316	57.5%	
Hyd. Residence Time	0.70 yrs				
Overflow Rate	27.6 ft/yr				
Mean Depth	19.0 ft				

(1) Advective Inflow is one way inflow from S3, the basin upstream from S4

(2) Net Diffusive Inflow is the net result of back and forth mixing between S3 and S4, basins located adjacent to one another.

(3) Advective Outflow is one way flow from S4 to the lake outflow.

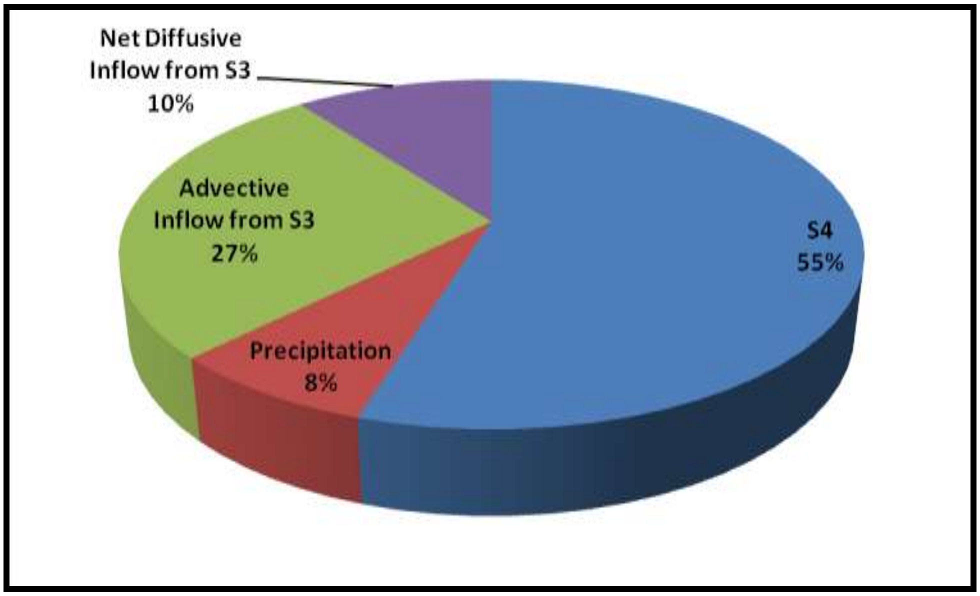


Figure 24 2010 Sources of Total Phosphorus to S4

6.7 S5 Hydrologic and Phosphorus Budget

The S5 hydrologic and phosphorus budget is shown in Table 13. Sources of phosphorus are shown in Figure 25. The location of S5 is shown on Figure 21.

S5 has a mean depth of 22 feet and had a residence time of about 6 months in 2010. The primary source of phosphorus is flow from S6, an upstream basin. In 2010, S6 contributed 74 percent of the basin's annual phosphorus load. The basin's watershed contributed 14 percent and atmospheric deposition 8 percent of the basin's annual phosphorus load. The remaining 4 percent was the net gain from mixing with adjacent basins.

S5 flows into S3, a downstream basin. In 2010, 72 percent of the S5 annual phosphorus load flowed into S3.

Table 13 2010 S5 Hydrologic and Total Phosphorus Budget

Name	ac Flow (ft/yr)	Flow (%Total)	Load (lbs/yr)	Load (%Total)	Conc. (mg/m^3)
S5 Watershed	256	4.8%	54	13.6%	78
Precipitation	386	7.2%	34	8.5%	32
Tributary Inflow	256	4.8%	54	13.6%	78
Advective Inflow(1)	4,738	88.1%	295	74%	23
Net Diffusive Inflow(2)	0	0.0%	15	3.8%	
Total Inflow	5,380	100.0%	399	100.0%	27
Advective Outflow(3)	5,039	93.7%	286	71.6%	21
Total Outflow	5,039	93.7%	286	71.6%	21
Evaporation	238	4.4%	0	0.0%	
Storage Increase	103	1.9%	6	1.5%	21
Retention	0	0.0%	107	26.9%	
Hyd. Residence Time	0.54 yrs				
Overflow Rate	40.4 ft/yr				
Mean Depth	22.0 ftm				

(1)Advective Inflow is one way inflow from S6, the basin upstream from S5

(2)Net Diffusive Inflow is the net result of back and forth mixing between S5 and adjacent basains.

(3)Advective Outflow is one way flow from S5 to the next downstream basin which is S3.

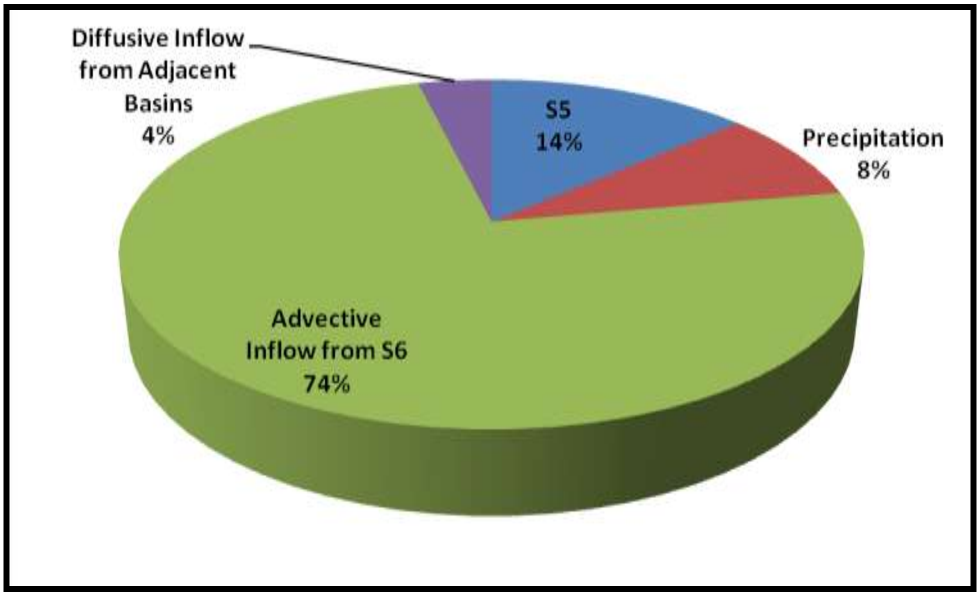


Figure 25 **2010 Sources of Total Phosphorus to S5**

6.8 S6 Hydrologic and Phosphorus Budget

The S6 hydrologic and phosphorus budget is shown in Table 14. Sources of phosphorus are shown in Figure 26. The location of S6 is shown on Figure 21.

S6, also known as Little Balsam Lake, has a mean depth of 14.4 feet and had a residence time of about 3 months in 2010. The primary source of phosphorus is flow from Lower Rice Creek. In 2010, Rice Creek contributed 71 percent of the basin’s annual phosphorus load. The S6 watershed contributed 25 percent and atmospheric deposition 4 percent of the basin’s annual phosphorus load.

S6 flows into S5, a downstream basin. In 2010, 49 percent of the basin’s annual phosphorus load flowed into S5.

Table 14 2010 S6 Hydrologic and Total Phosphorus Budget

Name	Flow (ac ft/yr)	Flow (%Total)	Load (lbs/yr)	Load (%Total)	Conc. (mg/m^3)
Lower Rice Creek	3,758	75.8%	432	70.8%	42
S6 Watershed	951	19.2%	156	25.5%	60
Precipitation	252	5.1%	22	3.6%	32
Tributary Inflow	4,709	94.9%	588	96.4%	46
Total Inflow	4,961	100.0%	611	100.0%	45
Advective Outflow(1)	4,738	95.5%	295	48.3%	23
Net Diffusive Outflow(2)	0	0.0%	6	1.0%	
Total Outflow	4,738	95.5%	301	49.4%	23
Evaporation	155	3.1%	0	0.0%	
Storage Increase	67	1.3%	4	0.7%	23
Retention	0	0.0%	305	50.0%	
Hyd. Residence Time	0.25 yrs				
Overflow Rate	58.1 ft/yr				
Mean Depth	14.4 ft				

(1)Advective Outflow is one way flow from S6 to the next downstream basin which is S5.

(2)Net Diffusive Outflow is the net result of back and forth mixing between S6 and S5, basins located adjacent to one another.

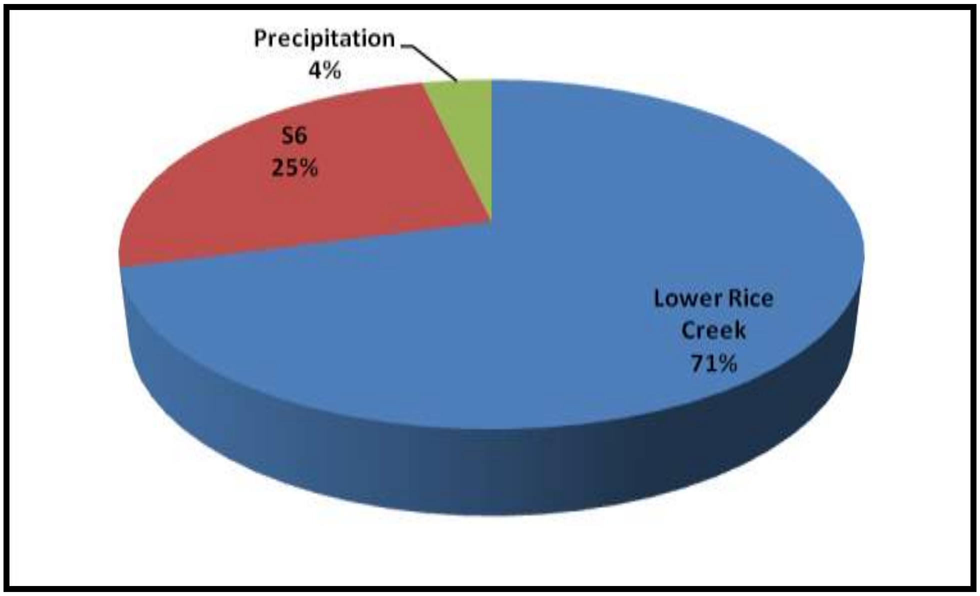


Figure 26 2010 Sources of Total Phosphorus to S6

7.0 Internal Loading

Internal loading is a natural process in lakes resulting from the release of phosphorus from lake sediments to the overlying water when oxygen is absent or very low (anoxia) at the sediment water interface. Internal loading occurs when oxygen concentrations at the sediment water interface are less than 2 mg/L.

7.1 Stratification

In deeper lake basins, the low oxygen conditions at the bottom generally occur following stratification which prevents the mixing of oxygen from the air with the bottom lake water. Temperature changes in the water during the ice-free portion of the year cause stratification. After ice out in the spring, the surface layer of the lake warms as air temperatures warm, but the temperature of the bottom water remains cool since sunlight does not penetrate to the lake bottom. The lake forms two different layers, a warm top layer called the epilimnion and a cool bottom layer called the hypolimnion. The area between the two layers is a layer of varying depth that has a temperature gradient. This area is called the thermocline. Because of the density differences between the lighter warm water and the heavier cold water, lake water becomes resistant to mixing and stratifies.

In Balsam Lake, S4, S5, and S6 were stratified during 2010. Figures 27 through 29 show the temperature layers occurring in the basins in 2010. The figures show time on the horizontal axis and lake depth on the vertical axis. Each line on the figure depicts a temperature value. Hence, a line labeled 24 shows the lake depths where a temperature of 24 was measured in the lake over time. Each line is called an isopleth. The lines on the graph show that S4 through S6 noted warmer temperatures near the surface and cooler temperatures near the bottom. The different lines from the lake surface to lake bottom depict the temperature layers of the lake.

Shallower basins may not stratify (form temperature layers) or may weakly stratify (note small temperature differences between the top and bottom). S1 through S3 are shallower basins and were generally mixed during 2010. However, all three basins observed a relatively short period of weak stratification during August (Figures 30 to 32). When the basins were well mixed, the water was the same temperature from the surface to the bottom. The figures show the basins were mixed by a vertical line that depicts a homogeneous water temperature from the lake surface to lake bottom (Figures 30 to 32). However, as sunlight warmed the water during the summer, the entire basin warmed up. The warming of the lake is shown by steadily increasing temperature lines (isopleths). The period of weak stratification in August is shown by a different temperature line near the lake surface (about 26 °C) than the lake bottom (24 °C) (Figures 30 to 32).

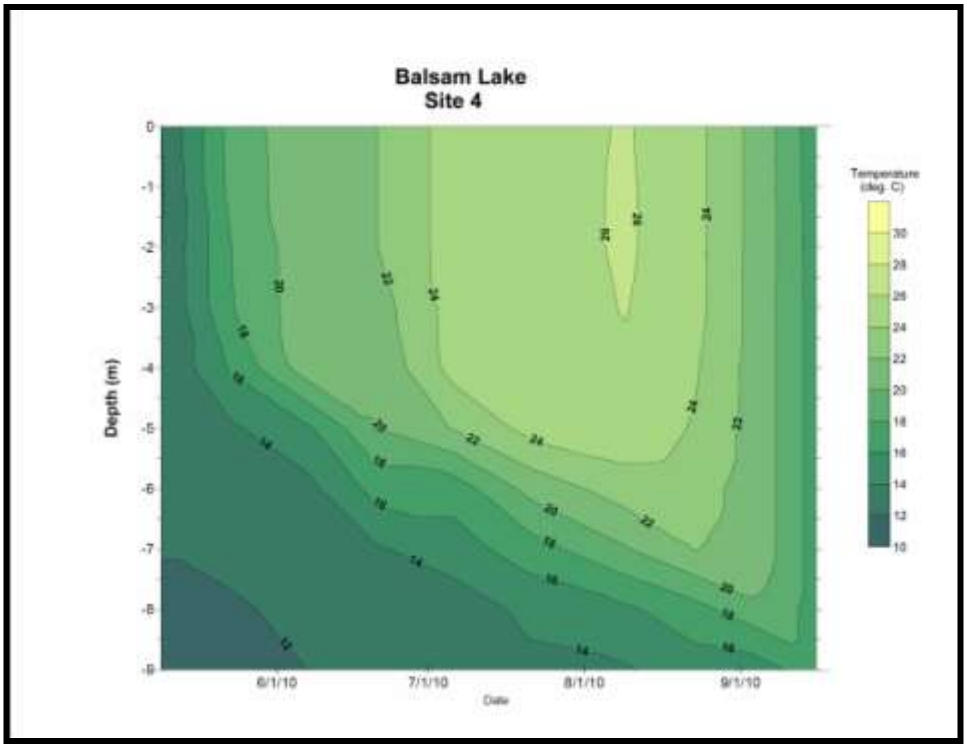


Figure 27 2010 S4 Temperature Isopleth

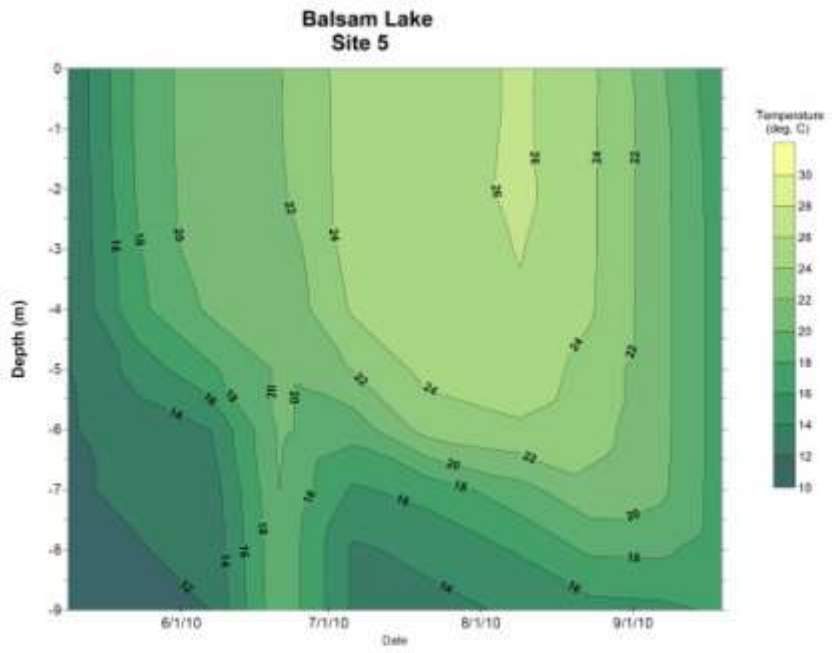


Figure 28 2010 S5 Temperature Isopleth

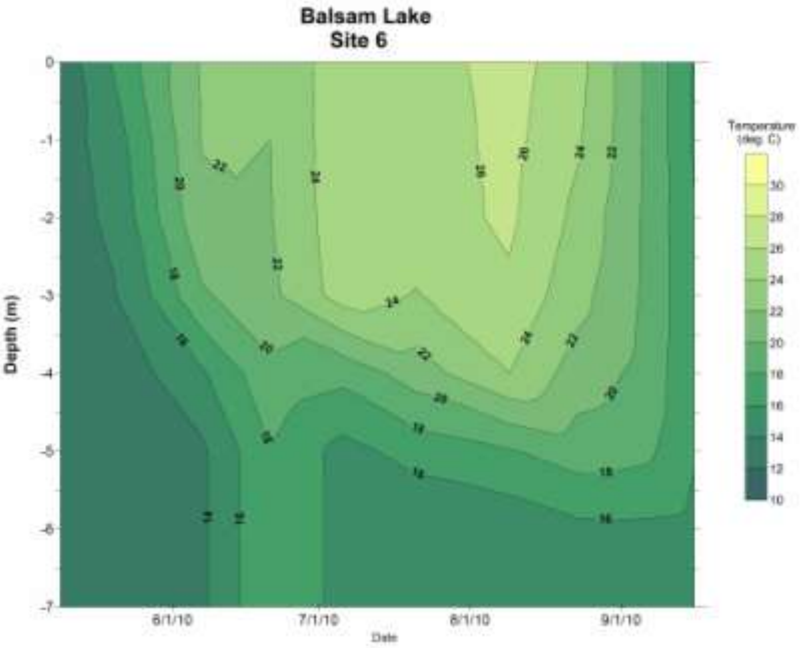


Figure 29 2010 S6 Temperature Isopleth

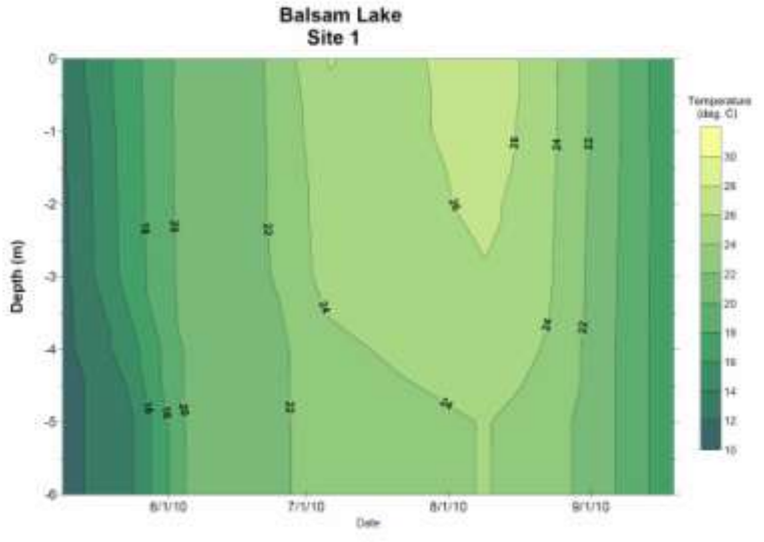


Figure 30 2010 S1 Temperature Isopleth

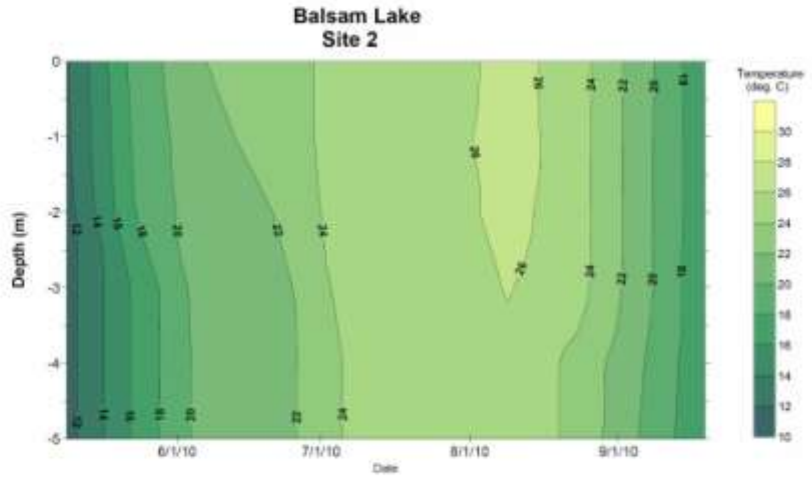


Figure 31 2010 S2 Temperature Isopleth

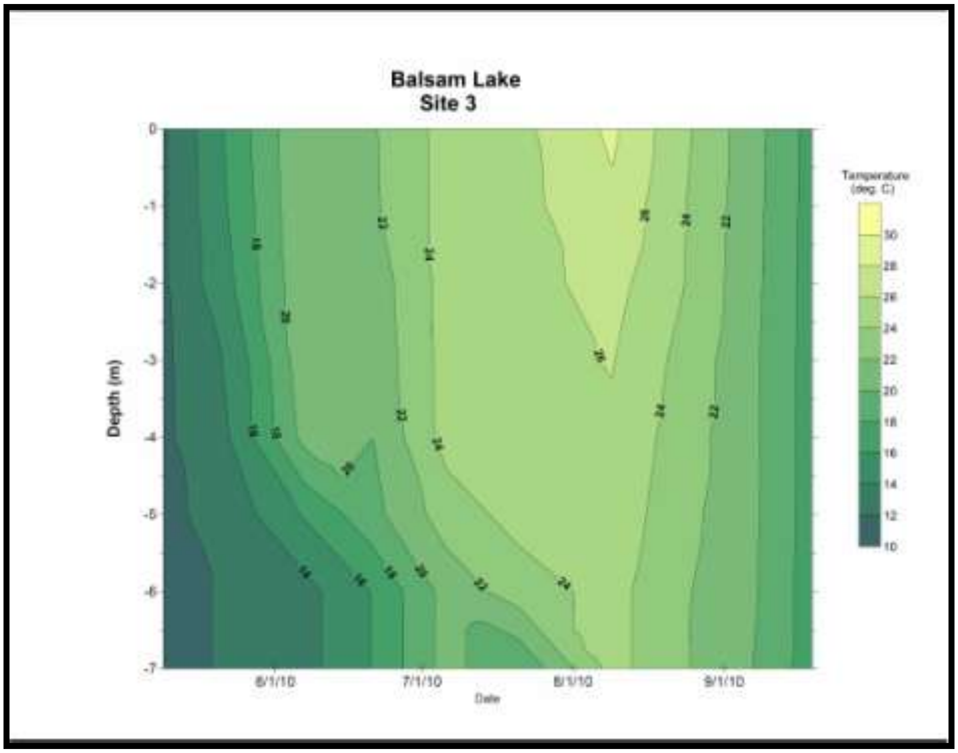


Figure 32 2010 S3 Temperature Isopleth

7.2 Anoxic Conditions

When stratification occurs, oxygen from the air cannot reach the bottom lake water and, if the lake sediments have sufficient organic matter, degradation of the organic matter by biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well-oxygenated, while dissolved oxygen supplies can be reduced to low levels in the hypolimnion creating anoxic conditions at the sediment water interface. Loss of oxygen changes the chemical conditions in the water and sediment, allowing phosphorus that would normally remain bound to the sediments to re-enter the water column. Although only a portion of this phosphorus reaches the surface water in summer due to diffusion or partial mixing events (storms and/or high wind), fall mixing distributes this phosphorus throughout the water column. In Balsam Lake, S4 through S6 were stratified and exhibited anoxic conditions (oxygen concentration less than 2 mg/L) in the hypolimnion during the summer. The area near the lake bottom beneath the 2 mg/L isopleth line depicted by a lighter color on Figures 33 through 35 is the area that observed anoxic conditions.

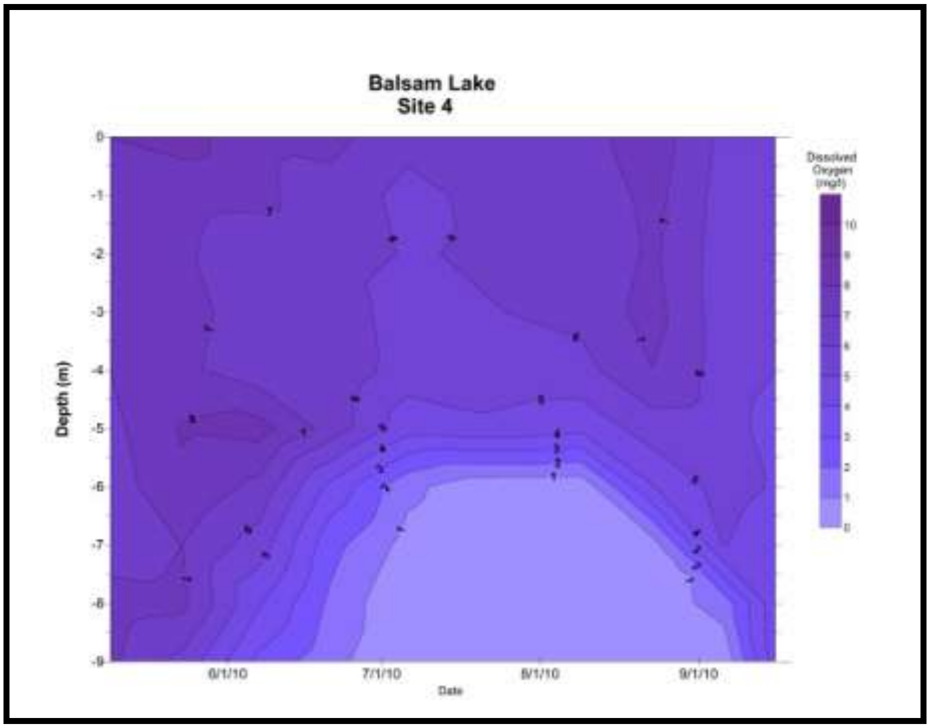


Figure 33 2010 S4 Dissolved Oxygen Isopleth

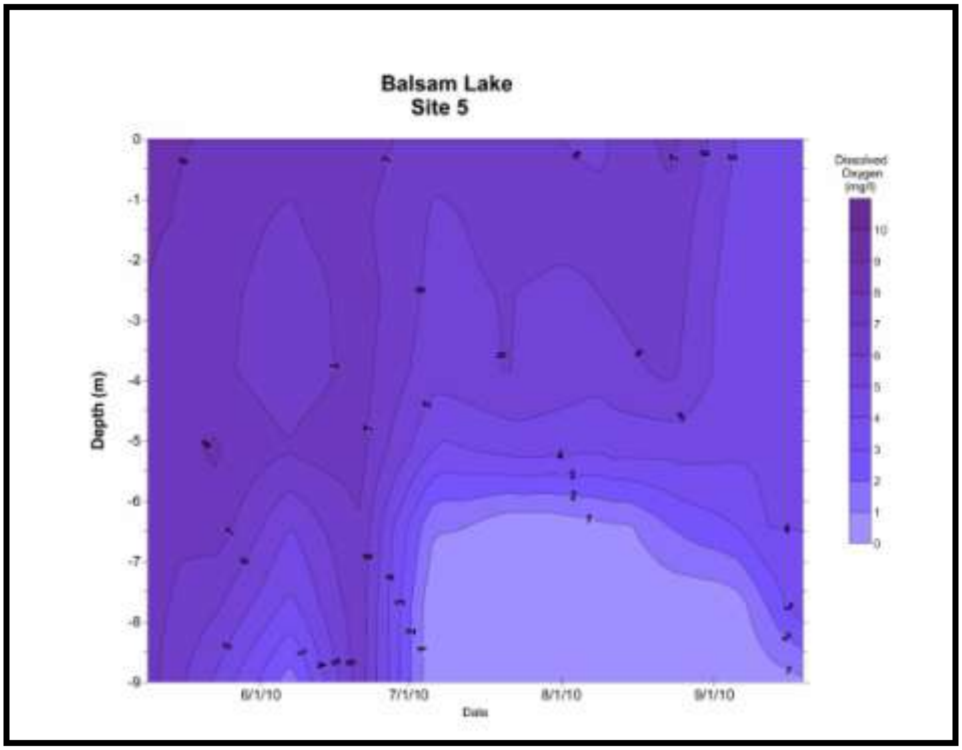


Figure 34 2010 S5 Dissolved Oxygen Isopleth

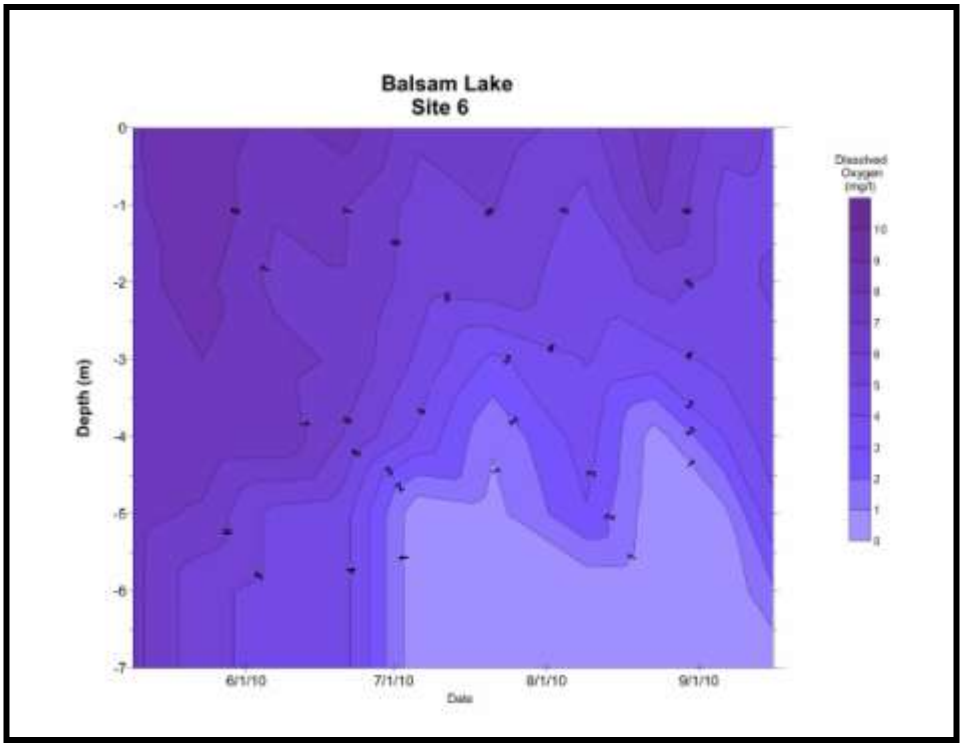


Figure 35 S6 2010 Dissolved Oxygen Isopleth

Anoxic conditions can occur in shallow basins that are generally mixed. During periods of little wind when the basin is not mixed, depletion of oxygen at the bottom can occur resulting in anoxic conditions. Although generally well mixed during 2010, S1 through S3 observed anoxic conditions during the summer. The area beneath the 2 mg/L isopleth line on Figures 36 through 38 is the area that observed anoxic conditions. S1 observed anoxic conditions sooner than the other 2 basins. Anoxic conditions were observed in early July at S1 and not until later in July at S3 and August at S2 (Figures 36 through 38).

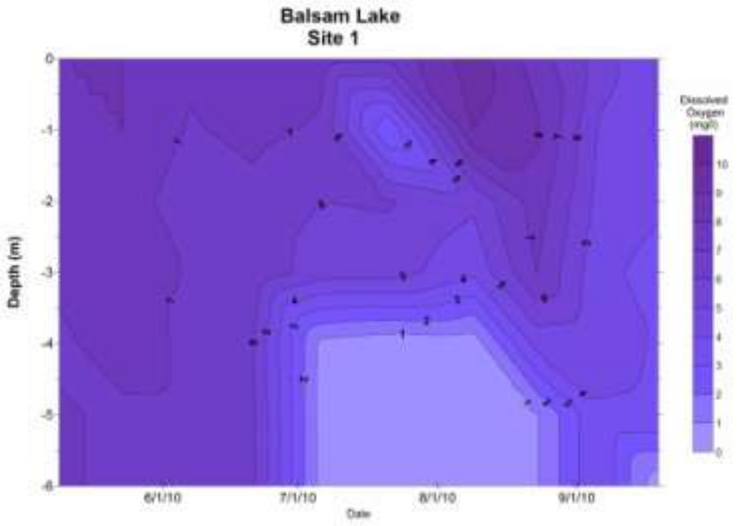


Figure 36 2010 S1 Dissolved Oxygen Isopleths

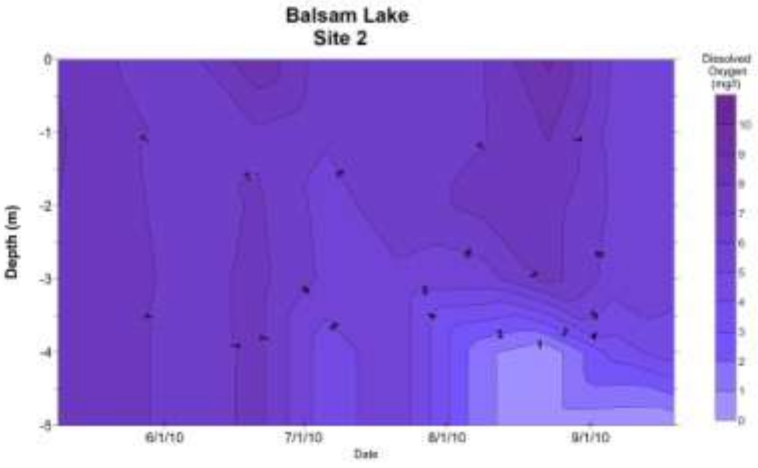


Figure 37 2010 S2 Dissolved Oxygen Isopleths

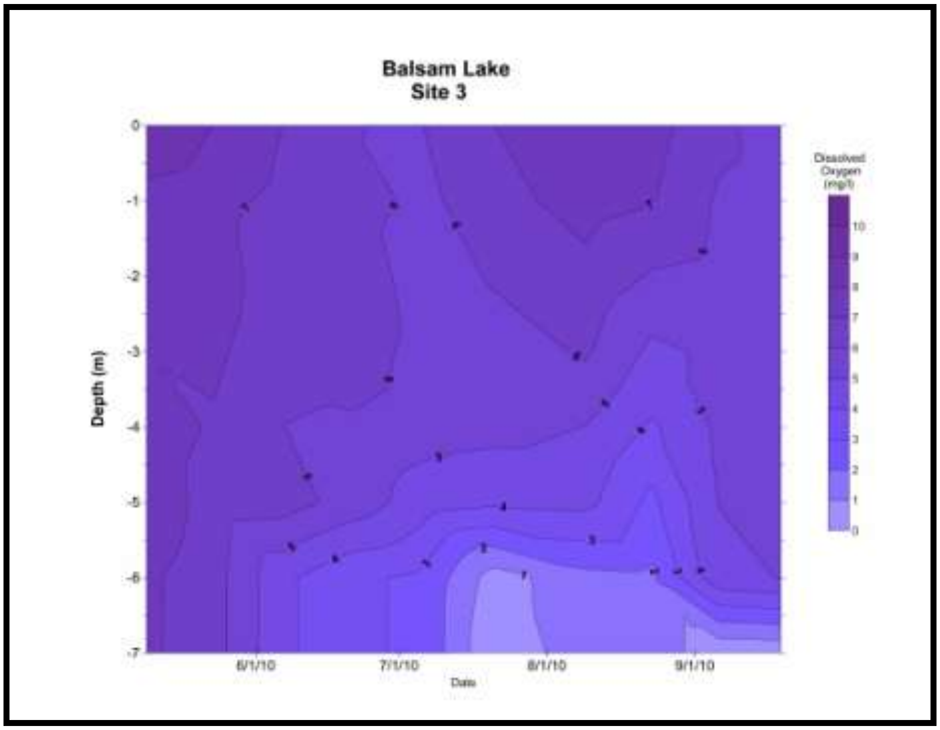


Figure 38 **2010 S3 Dissolved Oxygen Isopleths**

7.3 Internal Phosphorus Loading from Sediment

Phosphorus released from the sediment through internal loading processes is considered immediately available because it is in a dissolved form that algae and plants (e.g., coontail) can use directly. Watershed phosphorus loading is generally 35 to 45 percent dissolved (on average in Minnesota) while the remaining portion is in the form of particles (either soil or organic matter) that becomes part of the lake sediment. The particulate form of phosphorus cannot be directly used by algae or plants until it is released from the particles or organic matter.

Phosphorus taken up by organisms in lakes (including algae and plants) is returned to the sediment when the organisms die. Once in the sediment, much of this phosphorus can then be released again after the organic matter breaks down, continuing the internal loading process. While this is a natural process in all lakes, additional inputs of phosphorus due to human activity have caused increases in both the total amount and the rate of internal phosphorus loading in lakes.

Climate can affect water temperature and mixing in lakes and may be an important driver of increased internal phosphorus loading and changes in water column stability leading to increased mixing of phosphorus from deeper waters to the surface of lakes. Climate is variable and thus, the impacts it may have on lake water quality are variable as well. Research has shown that when lakes become warmer earlier in the season, the mechanism causing internal loading (bacterial growth and uptake of oxygen) begin earlier as well. This increases the duration of internal phosphorus loading in lakes. In addition, higher temperatures during the year will increase microbial activity, causing increased rates of sediment organic matter breakdown and oxygen uptake. This may increase both the rate of internal phosphorus loading and the area of the lake sediment susceptible to phosphorus release.

Anoxic conditions in Balsam Lake during the summer of 2010 resulted in the release of phosphorus from sediment. This release can be seen as increased phosphorus concentrations in the bottom waters of the lake as compared with phosphorus concentrations in the surface waters of the lake. Graphs depicting total phosphorus concentrations at the top and bottom of each lake basin throughout the monitoring period are shown in Figures 39 through 44.

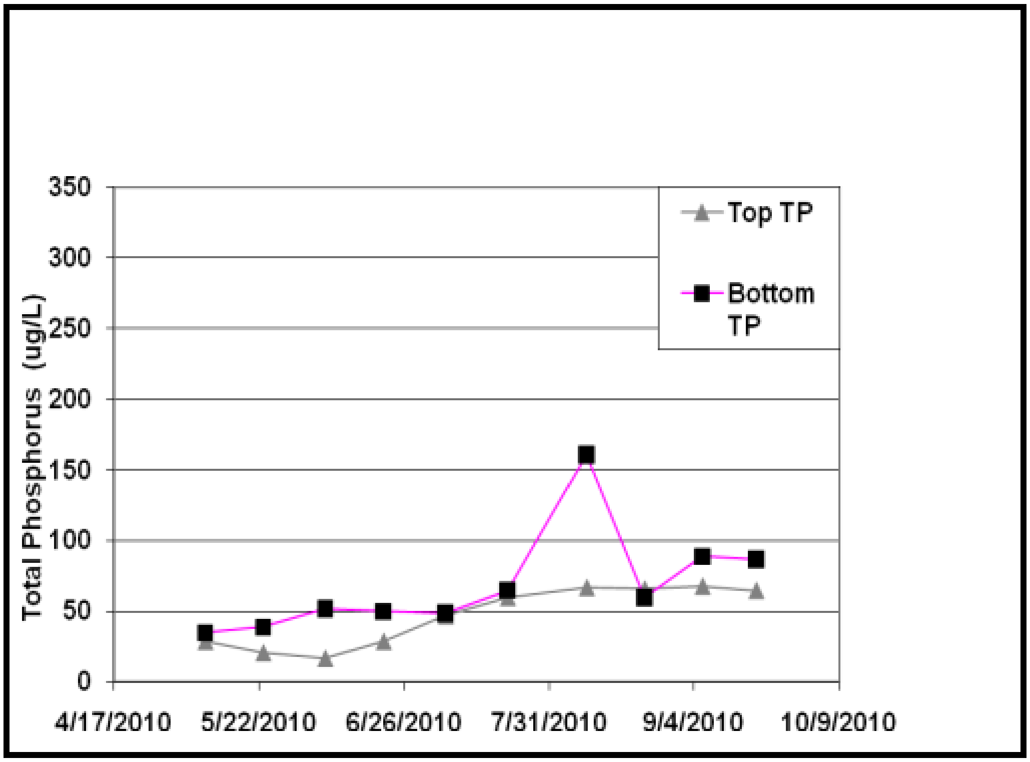


Figure 39 2010 Balsam Lake Site 1 – Surface and Bottom Total Phosphorus Concentrations

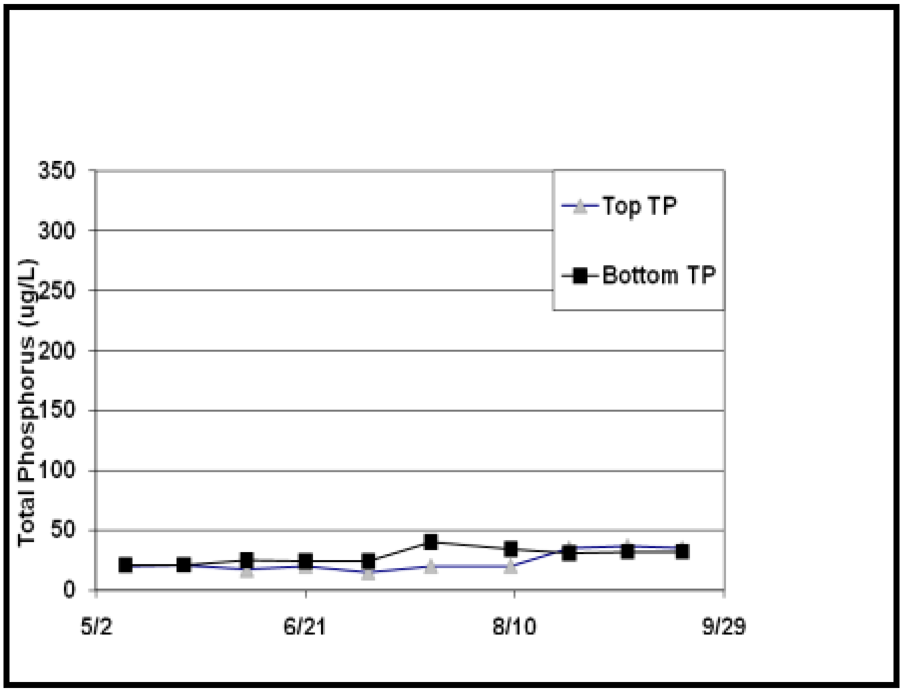


Figure 40 2010 Balsam Lake Site 2 – Surface and Bottom Total Phosphorus Concentrations

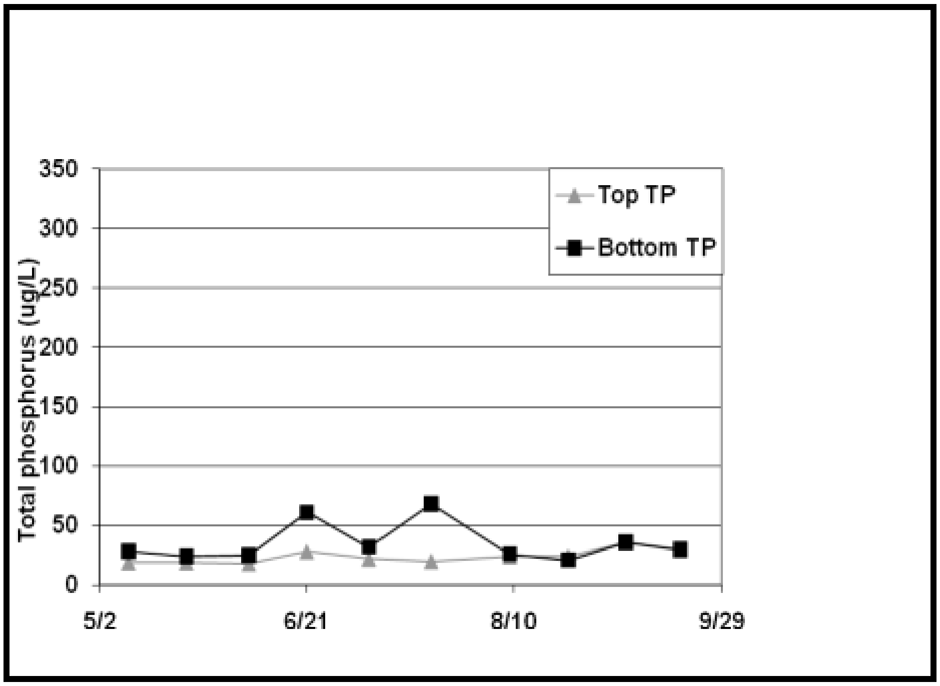


Figure 41 2010 Balsam Lake Site 3 – Surface and Bottom Total Phosphorus Concentrations

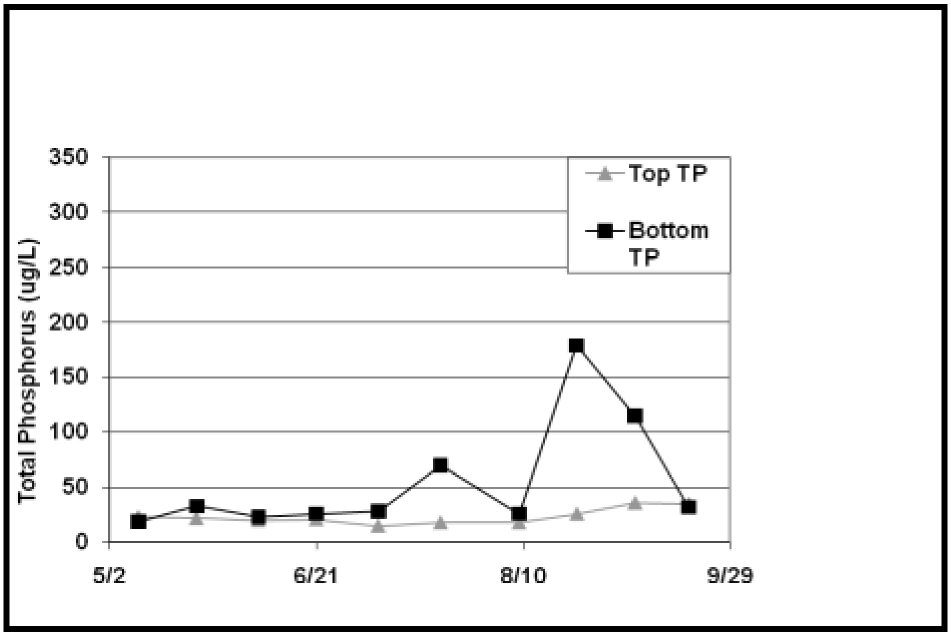


Figure 42 **2010 Balsam Lake Site 4 – Surface and Bottom Total Phosphorus Concentrations**

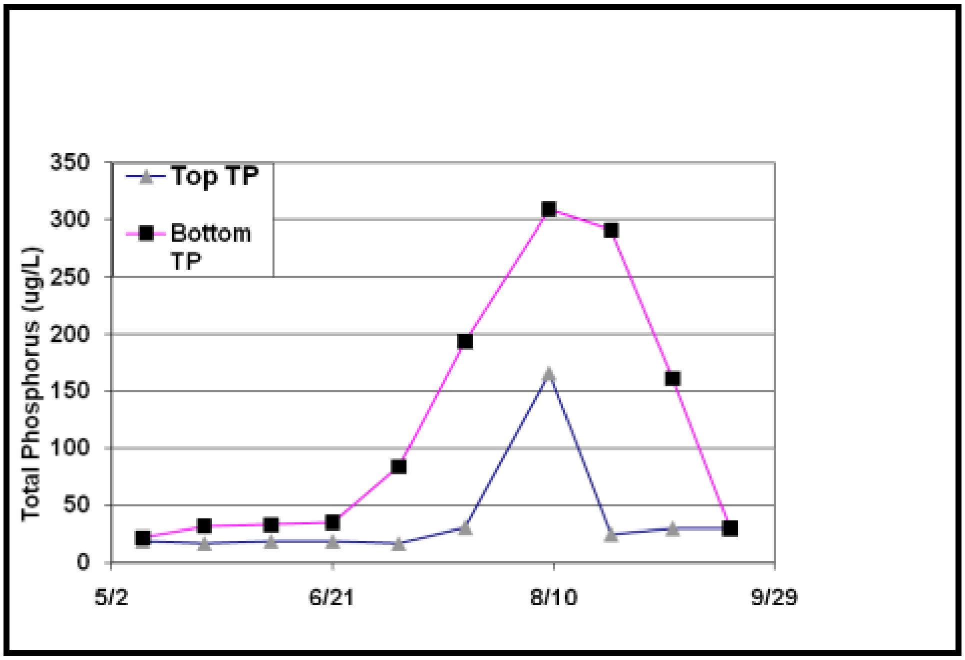


Figure 43 **2010 Balsam Lake Site 5 – Surface and Bottom Total Phosphorus Concentrations**

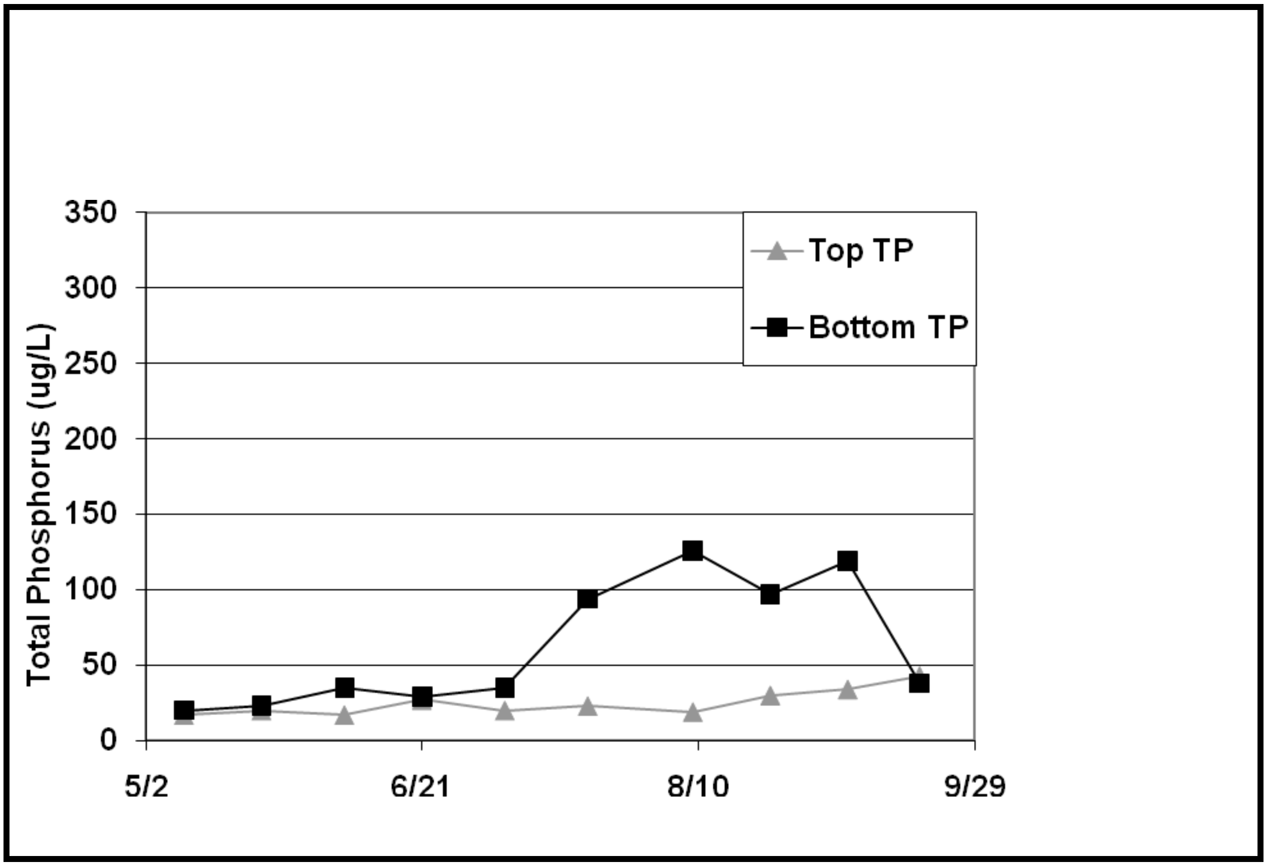


Figure 44 2010 Balsam Lake Site 6 – Surface and Bottom Total Phosphorus Concentrations

Although internal loading occurred throughout Balsam Lake, the effect of internal loading on surface water phosphorus concentrations during the summer of 2010 was greater at S1 (East Balsam Lake) than all of the other monitored lake basins. The data indicate the shallow depth of S1 resulted in frequent mixing of the internal load. Although frequent mixing also occurred at S2 and S3, the bottom phosphorus concentration at S1 was at least 2 to 4 times higher than the bottom phosphorus concentrations observed at S2 and S3 (Figures 39 through 41). Internal loading rate is directly related to the concentration of phosphorus in lake sediment. Hence, the data indicate the internal loads from S2 and S3 were small in comparison to the internal load at S1. In addition, the longer residence time of S1 caused the internal load to stay in the lake basin longer and have a greater impact on water quality than occurred in S2 and S3. Phosphorus loaded to S1 from sediment stayed in the lake for more than a year and a half. Phosphorus loaded to S2 and S3 was flushed from the lake within 3 to 7 months.

Stratification at S4 through S6 minimized the impact of internal loading on summer water quality. Thus, even though the bottom phosphorus concentration at S1 was comparable with or less than concentrations observed at S4 through S6, stratification at S4 through S6 prevented the mixing of bottom waters with surface waters until the lake cooled and the annual fall lake mixing began. Although some phosphorus from the bottom may have made its way to the top by the process of diffusion before mixing began, the internal loading occurring at S4 through S6 basically stayed at the bottom of the lake during the summer period. Hence, internal loading had a minimal impact on the summer surface water quality of S4 through S6. Frequent mixing throughout the summer in S1, however, maximized the impact of internal loading on the basin's summer water quality.

The apparent internal loading in S2 through S6, albeit small, and the absence of internal load in the phosphorus budget for S2 through S6 in Sections 6.4 through 6.8 may seem to be contradictory information. The model indicated that internal load did not impact the surface water quality of S2 through S6 during the summer period. However, an understanding of the model provides insight. The model is an empirical model based upon data collected from U.S. Army Corps of Engineers reservoirs. The reservoirs contained some internal loading. Hence, the relationships within the model are based upon reservoirs with some internal loading. Because some internal loading is included in the model, the model lacks the sensitivity to detect small internal loads of a similar nature as found in the reservoirs used to create the model. Hence, the model was unable to detect the small summer internal loads at S2 through S6. However, the summer internal phosphorus load at S1 was so large that the model easily detected it. Hence, a summer internal load is included in the phosphorus budget for S1 (Section 6.3), but not in the phosphorus budgets of S2 through S6 (Sections 6.4 through 6.8).

Internal loading had a small impact on the summer water quality of S2 through S6, but had a larger impact on their September water quality. An explanation of why this impact occurred and impact details follows.

When water temperatures increase in lakes during the summer, the potential for mixing of water between the surface and hypolimnion can increase as well. Stratification in the spring results in a stable stratified water column. As temperatures continue to increase during the summer, the added heat (increased energy) can destabilize the water column and mixing can occur more easily in the later part of the season when the water begins to cool down. As the water cools, the cooler surface water is heavier than the warmer waters beneath it. The heavier, cooler surface water sinks, thus allowing warmer lighter waters beneath the surface layer to rise to the surface. This process of heavy surface waters sinking and lighter deeper waters rising to the surface mixes the lake. When the deeper waters contain phosphorus loaded to the lake from sediment, this internal load is mixed into the surface waters by this process of heavy waters falling to the lake's bottom and lighter waters rising to the lake's surface. The sum of the effects from this mixing process can lead to higher surface concentrations of phosphorus because the internal load is transported to the surface where it can be used by algae for growth.

In Balsam Lake, cooling of the lake during the August through September period resulted in mixing of phosphorus from the bottom waters to the surface waters. Surface water temperatures in Balsam Lake ranged from 79 °F to 82 °F on August 9, cooled to 76 °F by August 23, cooled further to 68 °F to 70 °F by September 9, and cooled still further to 60 °F to 63 °F by September 19. During the process of cooling from 82 °F in August to 60 °F in September, the lake began its annual fall mixing process. As phosphorus from bottom waters was mixed into the lake's surface waters, surface phosphorus concentrations increased. On August 9, Balsam Lake surface phosphorus concentrations ranged from 16 µg/L to 24 µg/L. By September 9, lake surface phosphorus concentrations had increased to 30 to 43 µg/L.

A BATHTUB modeling scenario estimated the quantity of internal loading that occurred in Balsam Lake while the waters cooled and internal load was mixed into the lake's surface waters during the late summer/fall period. Figure 45 shows the results of this modeling effort. The graph depicts the internal load estimated by the model during the June through August period as well as the internal load estimated by the model during the June through September period. The difference in load between the two periods is the internal load occurring during September due to mixing. As shown on Figure 45, the model was unable to detect internal loading from S2 through S6 during the June through August period. Thus, the model estimated a load of 0 from these basins during the summer. The model estimated a summer internal load of 576 pounds from S1. The model estimated an internal load of 737 pounds from S1 during the June through September period. Hence, the model estimates that an additional 161 pounds of phosphorus was loaded to S1 from sediment during September. The model was unable to detect internal loading at S5 during September and estimated a negligible load from S2 (0.1 pound). In the remaining 3 basins, the model estimated September internal loads of 862 pounds at S4, 149 pounds at S6, and 42 pounds at S3.

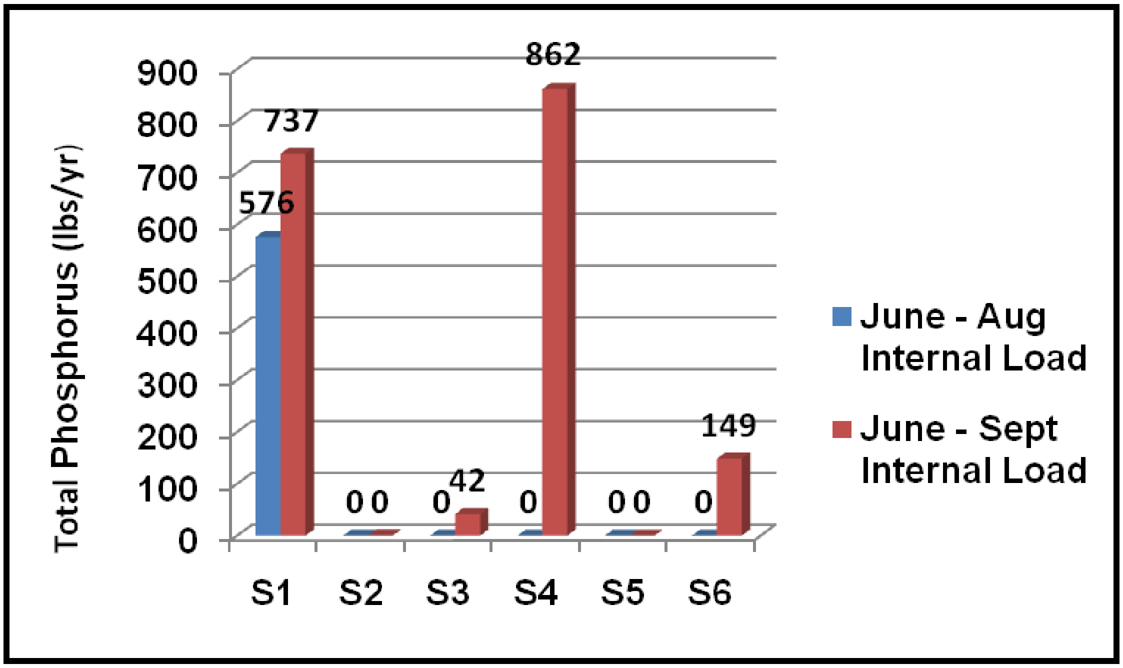


Figure 45 **Comparison of Internal Phosphorus Load to S1 through S6 during June through August and June through September of 2010**

The Balsam Lake internal loads shown in Figure 45 were expressed as daily loading rates. The daily loading rates were computed from the internal loads shown in Figure 45, the sediment area in which anoxic conditions resulted in phosphorus release from sediment (Figures 33 through 38 and Appendices R and S), and the length of time in which anoxic conditions (and phosphorus release) occurred (Figures 33 through 38). The estimated internal loading rates of Balsam Lake basins S1 through S6 are compared with internal loading rates of several Minnesota lakes in Table 15. S1 observed an internal laoding rate of 27.7 mg/m^2/day, which was the second highest internal loading rate shown in Table 15. Neighboring Long Lake in Polk County, WI surpassed S1 with an internal loading rate of 30.3 mg/m^2/day. The third highest internal loading rate in Table 15 is Lake of the Isles, a well known Minneapolis, MN lake, which observed an internal loading rate of 14.1 mg/m^2/day prior to an alum treatment. S6 observed an internal loading rate nearly an order of magnitude lower than S1, a rate of 3.8 mg/m^2/day. The S6 internal loading rate places it number 22 on the list of lakes in Table 15. S4 observed an internal loading rate of 2.9 mg/m^2/day. S3 and S2 observed internal loading rates of 0.3 mg/m^2/day and 0.03 mg/m^2/day. As noted earlier, the Bathtub model did not detect an internal load in S5.

Table 15 Comparison of 2010 Balsam Lake Internal Loading Rates with Internal Loading Rates in Some Selected MN lakes.
***(Huser et al. 2011), **(Pilgrim et al. 2007), ***(Barr 2003)**

Lake	**Internal P Load ($mg/m^2/d$)**
Long Lake (Polk County, WI)	30.3
Balsam Lake S1	**27.7**
Isles (pre-alum, deep hole)*	14.1
Fountain-Dane Bay	13.6
Twin Lake (Golden Valley)	13.1
Harriet (pre-alum, deep hole)*	11.1
Calhoun (pre-alum, deep hole)*	10.8
Fish E**	10.5
Cedar (pre-alum)*	9.3
Fountain-Edgewater Bay	9.0
Fountain-Bancroft Bay	8.1
Fish W**	8.1
Como**	7.6
Harriet**	6.9
Fountain-Main Bay	6.8
North Twin	6.0
South Twin	9.2
Como-littoral**	5.7
Calhoun (pre-alum, shallow)**	5.6
Pickerel Lake	3.9
White Lake	3.8
Balsam Lake S6	**3.8**
Albert Lea Lake	3.6
Parkers**	3.5
Earley Lake	2.9
Balsam Lake S4	**2.9**
Phalen**	2.3
McCarrons**	2.0
Bryant**	1.5
Nokomis**	1.0
Balsam Lake S3	**0.3**
Minnewashta	0.2
Balsam Lake S2	**0.03**
Balsam Lake S5	**0.0**
Christmas**	0.0

The lake's summer average phosphorus concentration discussed in Section 4.2.1 of this report did not include the additional phosphorus loaded to the lake in September. The summer average is based on June through August data because this average is used to determine whether the lake fully supports recreational use during the summer period when the majority of lake use occurs. The 2010 average summer total phosphorus concentration for Balsam Lake (average of S1 through S6) was 26 µg/L.

As discussed previously, this concentration meets the Wisconsin State Standard for Balsam Lake, indicating the lake fully supports recreational use during the summer period. The Wisconsin State Standard is based upon the summer average because this is the period when the majority of lake use occurs. The Balsam Lake September average total phosphorus concentration in 2010 was 40 µg/L. The data indicate the addition of the lake's internal load to the lake's surface waters during September helped to increase the lake's average phosphorus concentration so that it was 50 percent higher than the average summer concentration. Although the September internal load did not impact the summer water quality of the lake, this internal load increased the lake's fertility during September.

The 2010 Balsam Lake average summer phosphorus concentration fully met the State Standard, indicating the lake fully supports recreational use, such as skiing pictured above, during the summer period.

8.0 Recommendations

8.1 S1 Sediment Study

2010 Balsam Lake water quality data indicated that S1 (Figure 21), also known as East Balsam Lake, noted severe water quality problems during the summer period. Other portions of Balsam Lake (S2 through S6, Figure 21) did not exhibit water quality problems during the summer of 2010. Hence, S1 is the only area of Balsam Lake in need of management for improved summer water quality.

BATHTUB modeling results indicate half of the 2010 S1 annual phosphorus load was from summer internal loading. As shown in Figure 46, removal of the summer internal phosphorus load from S1 is expected to reduce the basin’s summer average total phosphorus concentration by 35 percent, from 48 µg/L (observed in 2010) to 31 µg/L. Because S1 flows into S3 and influences its water quality, the phosphorus reduction in S1 is expected to reduce the S3 summer average total phosphorus concentration by 13 percent, from 23 µg/L to 20 µg/L. In addition, since S2 and S5, frequently mix with S3, the water quality of S2 and S5 are influenced by the water quality of S3. The phosphorus reduction in S3 is expected to reduce average summer phosphorus concentrations in S5 by 5 percent (from 21 µg/L to 20 µg/L) and in S2 by 3 percent (from 21.2 µg/L to 20.5 µg/L). Hence, solving the water quality problem of S1 would have a beneficial effect on the summer water quality of 3 additional basins.

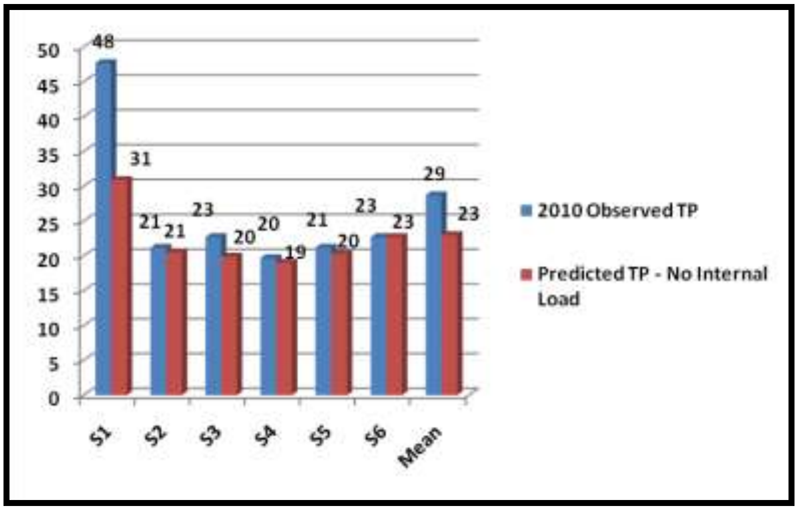


Figure 46 Predicted Reductions in Balsam Lake Total Phosphorus Concentration with Removal of Internal Load from S1

As shown in Figure 47, removal of the S1 summer internal load would increase the summer water transparency of S1 to a similar Secchi disc depth as the other basins. Removal of the summer internal load is expected to increase the summer average Secchi disc depth at S1 by about 3 and one half feet. The improved summer water quality in S1 is also expected to result in small increases in summer Secchi disc depth in S2 through S5.

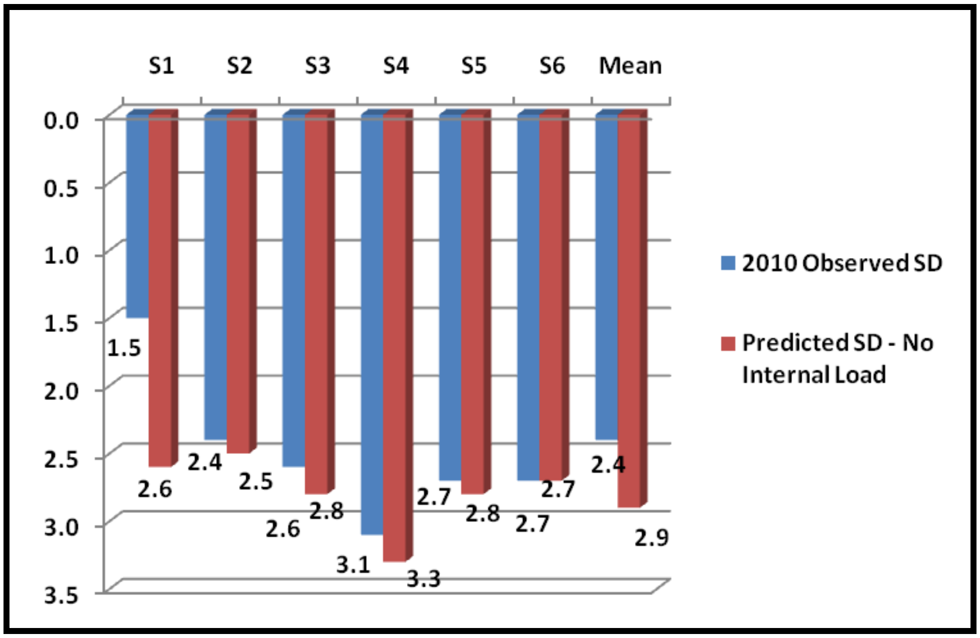


Figure 47 Predicted Increase in Balsam Lake Secchi Disc Transparency with Removal of S1 Internal Load

A sediment study completed by an experienced engineer is recommended to detail the problem and design a solution to the problem. Sediment samples would be collected from several locations within S1 that are representative of varying water column depths and spatial locations. On average, one sample would be collected every 50 to 100 acres. Hence, from 6 to 11 samples would be collected from S1. This sample frequency is necessary to accurately determine the spatial variation of phosphorus within Balsam Lake at varying water column depths and the corresponding potential for internal phosphorus loading from sediments. The specific number of samples for the monitoring program would be determined from a review of basin shape and bathymetry.

Sediment cores (see above) would be collected from S1

The sediment of each core would be sliced into 2-cm depth intervals from 0 to 10 centimeters (5 samples) and each sample would be analyzed to determine phosphorus content. Two background samples would be analyzed, one from 15 to 20 centimeters and one from 25 to 30 centimeters, to determine phosphorus content of lake sediment prior to settlement by man. All samples (surficial and background) would be analyzed for water content (percent H_2O), loss on ignition (LOI), mobile phosphorus (loosely bound phosphorus that is readily added to the water column by sediments), and organic phosphorus (a type of phosphorus added to lake sediments by decaying plants).

The results from the study would be used to:

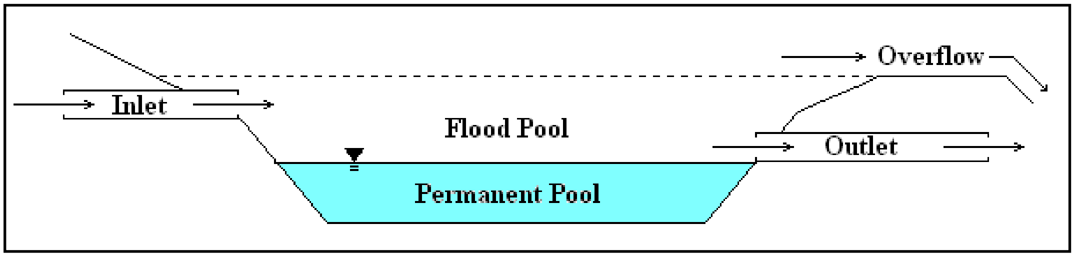
- Determine internal phosphorus loading rates from S1 sediment (Pilgrim et al. 2007);
- Determine the quantity of alum needed for an alum treatment of S1;
- Determine cost of an S1 alum treatment; and
- Determine expected water quality improvement in S1 following alum treatment.

Results from the sediment study would be summarized and presented in a report. The results of the mobile and organic phosphorus analyses would be mapped. The map would show the spatial variability of phosphorus (i.e., areas with highest phosphorus content and areas with lowest phosphorus content will be shown on the map). The report would summarize study methods, findings, and recommendations. The report would be the basis for the design of an alum treatment to solve the internal loading problems of S1. It is recommended that the report be written by the same engineer who designs and completes the alum treatment of the lake to insure that all needed components of the treatment design are contained in the report.

Each sediment core would be sliced (see above) and analyzed to determine phosphorus content.

8.2 Periodic Inspection and Maintenance of Rice Creek Sedimentation Basin

The Rice Creek sedimentation basin should be inspected periodically by an experienced engineer to determine maintenance needs. The sedimentation basin located on Rice Creek plays an important role in treating stormwater runoff and protecting the water quality of S6, also known as Little Balsam Lake. BATHTUB modeling results indicate Rice Creek contributes 71 percent of the annual phosphorus load to S6 and S6 contributes approximately 75 percent of the annual phosphorus load to S5. S5 flows into S3 which flows into S4. Hence, Rice Creek influences the water quality of S3 through S6. For this reason, maintenance of the Rice Creek sedimentation basin is important to insure that the water quality of Balsam Lake is protected. A periodic inspection of the basin is recommended to determine maintenance needs. Maintenance should occur whenever the basin is about half full of sediment.



Within the next year, an inspection of the Rice Creek sedimentation basin by an experienced engineer is recommended to determine the pond's current permanent pool storage volume and to evaluate maintenance needs. Recommended pond inspection methods follow. The permanent pool (i.e., dead storage volume) is the volume below the outlet elevation (See above illustration).

The inspection of the Rice Creek sedimentation pond would begin by recording the perimeter of the pond at its water edge using a Global Positioning System (GPS) data logger that tracks latitude and longitude. The depth from the water surface to the pond bottom at a regular grid of inspection points within the pond would be physically measured and then added as a field note to a specific GPS location. The outlet elevation would be measured. The outlet, pond bottom, and pond surface water elevations would be referenced to a bench mark using an auto-level and survey rod. At a later date, field elevations (outlet, water surface, and pond bottom) would be converted to NGVD 1929 datum. The current permanent pool storage volume would be calculated and compared with the design storage volume to determine the portion of the pond that has filled with sediment. Maintenance needs for the pond would then be determined. If the inspection determined the pond is already at least half full of sediment, a recommendation would be made that the pond should be cleaned out as soon as possible to attain design treatment capability. If the pond the inspection determined the pond was less than half full of sediment, the rate of sediment accumulation would be computed and an estimated maintenance period identified. Another pond inspection would then be scheduled to coincide with the expected maintenance period. This subsequent pond inspection would either confirm the need for maintenance or determine a future estimated maintenance period if the pond inspection indicated the pond was not yet at least half full of sediment.

8.3 Annual Secchi Disc Monitoring Program

It is recommended that Secchi disc depth be monitored annually from S1 (East Balsam Lake), S2 (Stumps Bay), S4 (Main Lake), and S6 (Little Balsam Lake). The current Secchi disc monitoring program includes S1, S4, and S6. The addition of S2 to the annual Secchi disc monitoring program is recommended. BATHTUB modeling results indicate Harder Creek contributed 74 percent of the 2010 annual phosphorus load to S2. Annual monitoring of S2 Secchi disc transparency would detect changes in water clarity, which could be an indication of changes in phosphorus loading from Harder Creek. Measurement of Secchi disc by volunteers is a cost effective means of detecting changes in Harder Creek water quality which will determine whether additional Harder Creek monitoring and a study of possible watershed phosphorus loading changes is warranted.

The recommended Secchi disc monitoring program does not include S3 and S5 because the water quality of these basins is primarily determined by contributions from adjacent basins. BATHTUB modeling results indicate adjacent basins contributed 87 and 83 percent of the annual phosphorus load to S3 and S5, respectively. Hence, the watershed phosphorus loading in these basins is overwhelmed by phosphorus loading from upstream basins. Management of the water quality of upstream basins is the key to management of S3 and S5 water quality.

The annual Secchi disc monitoring program should include biweekly measurements during June through August. The regular monitoring schedule is recommended to consistently measure Secchi disc throughout the summer period. Consistent data are needed for trend analyses which identify significant changes in water quality should it occur.

8.4 Periodic Trend Analysis

A trend analysis of summer Secchi disc data should be performed by an experienced professional on a regular basis to identify significant changes in water quality, should it occur. A frequency of once every 3 years is recommended for locations in which at least 5 years of data are available. Hence, a trend analysis of Secchi disc data collected from S1, S4, and S6 is recommended for 2013 and once every three years thereafter. Trend analysis of Secchi disc data collected from S2 should begin when at least 5 years of data become available. Data used for trend analysis should only include years in which at least 4 Secchi disc measurements occur during the period June through August. The recommended trend analysis method is the nonparametric Mann-Kendall trend analysis. The WQ Stat Plus software should be used and the Sen's slope should be used to determine the slope of the trend line. The 95 percent confidence interval should be used to determine whether significant changes have occurred.

8.5 Work with Polk County Land and Water to Periodically Review Cropland Management Practices in S1 and S4 Watersheds

The Balsam Lake Protection and Rehabilitation District should work with Polk County Land and Water to periodically review cropland management practices in S1 and S4.

The Balsam Lake Protection and Rehabilitation District should work with Polk County Land and Water to periodically review cropland management practices in S1 and S4 watersheds. WILMS modeling results indicate cropland comprised 48 percent of the 2010 watershed phosphorus load to S1 (Figure 29) and 71 percent of the watershed phosphorus load to S4 (Figure 30). Changes in cropland management practices within these watersheds could impact the quantity of phosphorus entering the basins from stormwater runoff. Changes in phosphorus loading to the basins could impact water quality. Hence, a periodic review of cropland management practices within these watersheds is recommended to determine changes that could impact lake water quality. It is recommended that the Balsam Lake Protection and Rehabilitation District (BLPRD) work with Polk County Land and Water to perform a periodic review of cropland management practices in the S1 and S4 watersheds. If changes in cropland management that could adversely impact the lake's water quality are identified in the review, it is recommended that the BLPRD work with Polk County Land and Water to address the adverse changes through both the identification of and implementation of cropland management practices that protect Balsam Lake water quality.

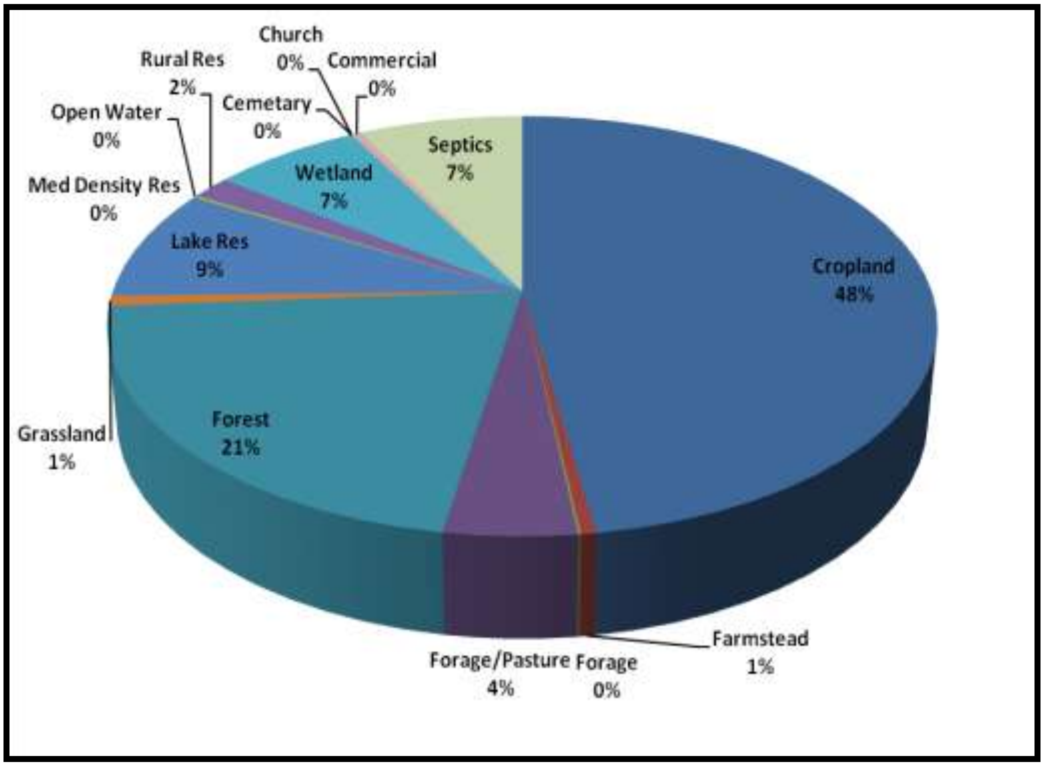


Figure 48   S1 Watershed Phosphorus Sources (Percent of Total)

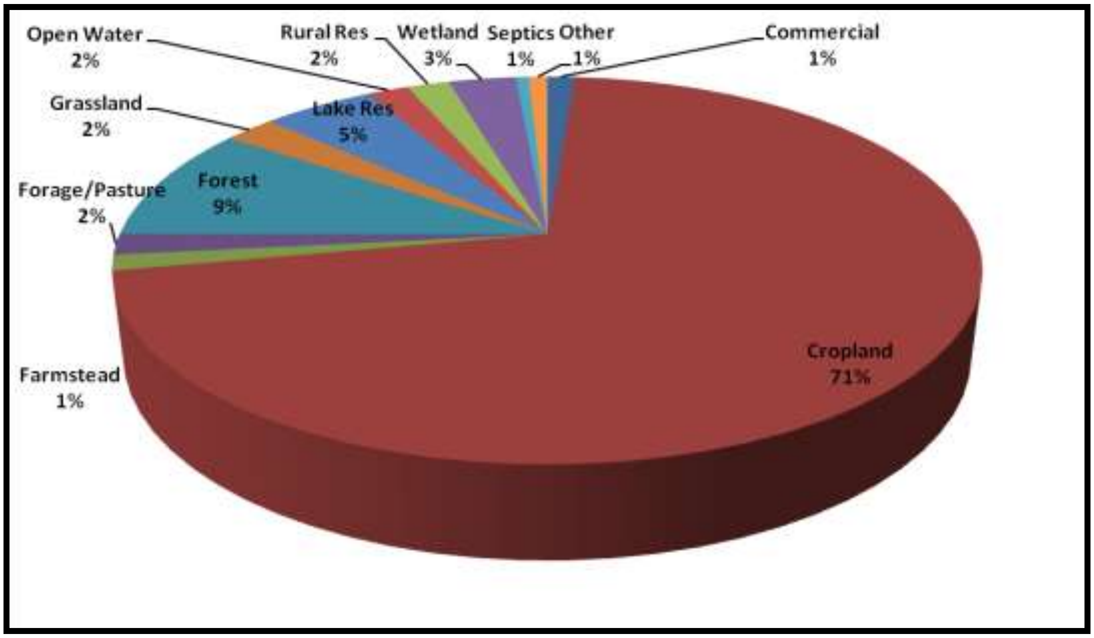


Figure 49   S4 Watershed Phosphorus Sources (Percent of Total)

8.6 Periodic Water Quality Monitoring of Balsam Lake

The lake monitoring program completed in 2010 should be repeated periodically to detect water quality changes and to determine management needs. A frequency of once every 3 to 5 years is recommended. The periodic water quality monitoring of Balsam Lake would (1) track changes in internal loading in S4 and S6 (2) track the results of an S1 alum treatment should it occur (3) determine management needs for the lake, (4) provide a sound scientific basis for management decisions (5) collect total phosphorus and chlorophyll *a* data so that a trend analysis to identify significant changes in phosphorus and chlorophyll *a* concentrations can occur when at least 5 years of data have been collected. Trend analysis of phosphorus and chlorophyll *a* concentrations in addition to Secchi disc transparency will help BLPRD detect significant water quality changes that require management. Past management efforts have successfully protected the water quality of Balsam Lake. Periodic water quality monitoring and trend analyses will provide the information needed by BLPRD to protect Balsam Lake water quality in the future so that lake users can continue to enjoy recreational activities, such as skiing, pictured below.

Annual monitoring of Secchi disc, periodic water quality monitoring of Balsam Lake, and periodic trend analysis are recommended to provide the information needed by BLPRD to protect Balsam lake water quality in the future so that lake users can continue to enjoy recreational activities such as skiing, pictured above.

9.0 References

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