Lake Redstone Watershed and Lake Modeling Study

Prepared for
Lake Redstone Protection District

August 2009

BARR

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Executive Summary

During the summer of 1996 detailed inflow and in-lake sampling was conducted in an attempt to develop water and nutrient budgets for use in a lake response model. A second detailed inflow and in-lake sampling study was conducted during 2007. This report presents the results of the recent watershed and in-lake modeling effort to evaluate 2007 data and compares these modeling results to 1996 modeling results.

Modeling results indicate phosphorus loading to Lake Redstone in 2007 differed from 1996 both in the size of the load and in its composition. During 1996, watershed loading comprised 66 percent of the lake's phosphorus load compared with 26 percent in 2007. In contrast, internal loading comprised 73 percent of the lake's phosphorus load in 2007 compared with 29 percent in 1996. Watershed loading was higher in 2007 (2,626 kg) than 1996 (1,500 kg), but comprised a lower percent of the total load. East and West Big Creek loading rates increased 35 and 43 percent, respectively, between 1996 and 2007. Internal load increased in 2007 by more than an order of magnitude. In 1996, the lake's total phosphorus load totaled 2,220 kg compared with 9,850 kg in 2007.

The impact of increased phosphorus loading to Lake Redstone was assessed using Carlson's Trophic State Index (TSI). Total phosphorus, chlorophyll *a*, and Secchi disc transparency are key water quality parameters upon which TSI statistics are computed, for the following reasons:

- **Phosphorus** generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is typically the limiting nutrient.

- **Chlorophyll *a*** is the main pigment in algae. Therefore, the amount of chlorophyll *a* in the water indicates the abundance of algae present in the lake.

- **Secchi disc** transparency is a measure of water clarity and is inversely related to the abundance of algae.

The TSI rating system is scaled to place a mesotrophic (medium fertility level) lake on the scale between 40 and 50, and high and low fertility lakes (eutrophic and oligotrophic) toward the high and low ends of the TSI range, respectively. Characteristics of lakes in different trophic status categories are listed below with their respective TSI ranges:

Oligotrophic—[20 ≤ TSI ≤ 38] clear, low productivity lakes, with total phosphorus concentrations less than or equal to 10 µg/L, chlorophyll *a* concentrations less than or equal to 2 µg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet).

Mesotrophic—[38 ≤ TSI ≤ 50] intermediate productivity lakes, with 10 to 25 µg/L total phosphorus, 2 to 8 µg/L chlorophyll *a* concentrations, and Secchi disc measurements of 2 to 4.6 meters (6 to 15 feet).

Eutrophic—[50 ≤ TSI ≤ 62] high productivity lakes, with 25 to 57 µg/L total phosphorus, 8 to 26 µg/L chlorophyll *a* concentrations, and Secchi disc measurements of 0.85 to 2 meters (2.7 to 6 feet).

Hypereutrophic—[62 ≤ TSI] extremely productive lakes, with total phosphorus concentrations greater than 57 µg/L, chlorophyll *a* concentrations greater than 26 µg/L, and Secchi disc measurements less than 0.85 meters (less than 2.7 feet).

Lake Redstone noted water quality problems in 1996, but increased phosphorus loading in 2007 caused the lake's water quality to be poorer than observed during 1996. In 2007, TSI total phosphorus and chlorophyll *a* values were greater than 62 and in the hypereutrophic (very poor water quality) category. In 2007, TSI of observed Secchi disc values were less than 62 and in the eutrophic (poor water quality) category. In 1996, the TSI chlorophyll *a* and Secchi disc transparency values from the northern site and observed chlorophyll *a* value from the middle site were greater than 62 and in the hypereutrophic category. However, the TSI total phosphorus value from the northern site, total phosphorus, and Secchi disc transparency from the middle site, and all TSI values from the southern site were less than 62 and in the eutrophic category.

A trend analysis of Lake Redstone data was completed to identify any significant degradation or improvement during years for which water quality data were available. Although there have been fluctuations in phosphorus levels, chlorophyll *a* levels, and in-lake clarity, it appears that over time the water quality of the lake has remained relatively stable and changes in phosphorus, chlorophyll *a*, and Secchi disc have not been statistically significant.

Modeling scenarios to estimate Lake Redstone water quality following implementation of Best Management Practices indicate addressing the lake's internal and watershed loading would improve the lake's water quality. Control of the lake's internal load (i.e., 90 percent reduction of internal load) would, on average, result in lake water quality that is poorer than 1996 lake water quality by 1 to 2 TSI units. Because both internal and watershed loading were higher in 2007 than 1996, solely controlling internal load would not attain the water quality observed in 1996. Controlling internal load (i.e., 90 percent reduction of internal load) and watershed load from East and West Big Creek (i.e., 65 percent reduction of East and West Big Creek phosphorus load) would, on average, attain a water quality that is the same as 1996 conditions (chlorophyll *a* and Secchi Disc TSI) or better by approximately 2 TSI units (total phosphorus TSI). The northern site would note the largest improvement in water quality and the southern site would realize the least benefit.

The water quality degradation observed in 2007 indicates a need for the following programs recommended herein:

1. **Sediment Study**

2. **Upgraded Lake Monitoring Program**

3. **Additional Monitoring of East and West Big Creek**

4. **Study to Determine Feasibility of Inflow Alum Treatment Facility**

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1.0 Introduction

Lake Redstone is a 612 acre impoundment located in Sauk County, Wisconsin, near the town of LaValle. The lake was created in 1965 by impounding the lower reach of Big Creek, a tributary of the Baraboo River. The project was undertaken by a real estate developer with the intent of making Lake Redstone the recreational focus of a large residential development. Once the project was completed over 1,600 lots were platted around the 16.4 mile shoreline. Approximately half are water front lots. About 700 homes have been constructed, mostly on lake front lots.

The highly fertile, 30 square mile watershed has many steep slopes and lies mostly to the north of the lake. The watershed to lake ratio is 31 to 1.

Lake Redstone's deepest point is approximately 36 feet. It has a mean depth of 14 feet. The flushing rate is approximately 1.8 times during the growing season.

The lake began to experience degraded water quality shortly after its filling in 1966 and still experiences extensive algal blooms during the summer months. During the summer of 1966 detailed inflow and in-lake sampling was conducted in an attempt to develop water and nutrient budgets for use in a lake response model. The modeling results indicated the seasonal watershed water loading to Lake Redstone was about 93 percent of the total and was the largest single source. The seasonal watershed phosphorus loading to Lake Redstone was about 63 percent of the total and was the largest single source. The internal recycling of phosphorus in Lake Redstone comprised about 29 percent of the seasonal total.

Since 1996 many Best Management Practices (BMPs) have been installed at various locations in the watershed. Many BMPs were funded by the District. A second detailed inflow and in-lake sampling was conducted during 2007 to learn the effectiveness of those BMPs. The data were used to develop a watershed and in-lake model to evaluate changes in watershed phosphorus loading to the lake as well as changes in lake water quality. This report presents the results of the recent watershed and in-lake modeling effort to evaluate 2007 data and compares these modeling results to 1996 modeling results.

2.0 Methods

2.1 Tributary Monitoring

Two flow monitoring stations were set up in manholes and sampling was conducted at the two main tributaries coming into Lake Redstone, the east and west branches of Big Creek shown on Figure 1. From the 1996 data, the west branch comprised 48 percent of the surface water coming into Lake Redstone while the east branch of Big Creek contributed 18 percent. A weir was installed on the east branch of Big Creek to provide a defined cross sectional area for flow measurement. The west branch of Big Creek was monitored at a culvert that provided a defined cross sectional area.

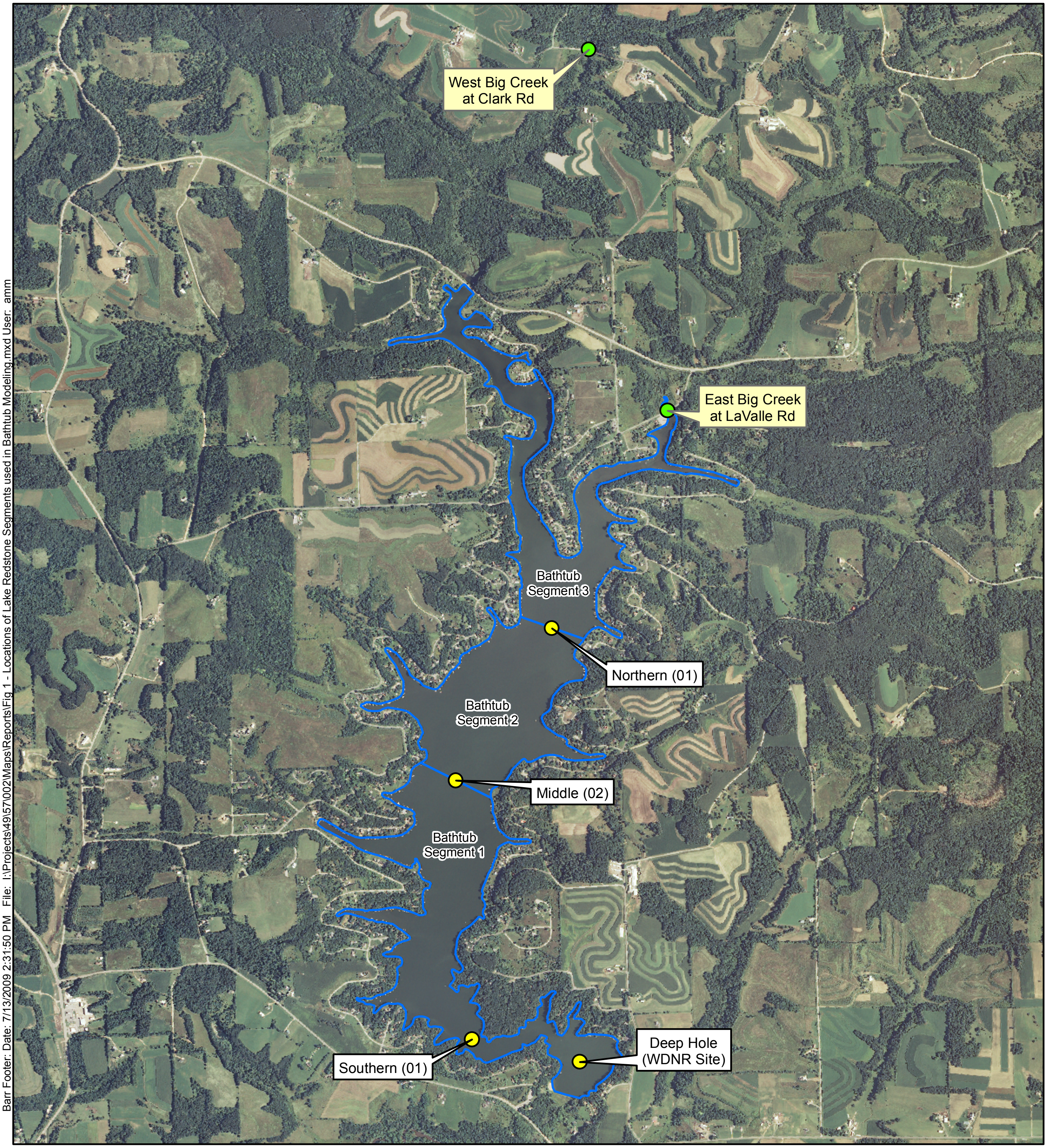
At the east and west branches of Big Creek, data were obtained using an Isco flow monitor and Isco sampler. Every 15 minutes stage data and flow in feet per second were recorded. The sampler was set to take an automatic composite sample during storm events. In addition, non-storm samples were also manually collected at both monitoring stations. Total phosphorus as well as ortho-phosphorus data were obtained from all tributary samples. Storm event samples at a smaller tributary from the northern portion of the Southeast Branch were also taken.

Flow and sample data were collected during 2006 and 2007. Unfortunately, equipment malfunction on both the east and west branch caused all flow data to be lost during 2006. Equipment malfunction on the west branch caused all flow data to be lost during 2007. However, the 2007 stage data appeared reasonable. Ten stage and discharge measurements were taken during June through November of 2008 from the west branch sample site to relate stream stage to stream discharge. A stage discharge curve was developed from these measurements and used to compute discharge from 2007 stage data.

Flow was monitored during the period March 29 through November 1, 2007. Phosphorus samples (total and ortho) were collected during the period April 18 through October 31, 2007.

2.2 In-Lake Monitoring

Monthly in-lake monitoring occurred during 2006 and 2007. Only the 2007 data were used in modeling, however, since all 2006 flow data were lost due to equipment malfunction. Three lake locations, shown on Figure 1, were monitored during each sample event. Samples were collected from two feet below the surface and two feet above the bottom and analyzed for total phosphorus and ortho phosphorus. Samples collected from two feet below the surface were analyzed for chlorophyll *a*. Secchi disc, temperature profiles, and dissolved oxygen profiles were measured monthly.



Stream Sample Locations

Lake Monitoring Locations

Bathtub Segments

N

Miles

0.5 0.25 0 0.5

Figure 1

LOCATIONS OF LAKE REDSTONE SEGMENTS USED IN BATHTUB MODELING AND MONITORING LOCATIONS
Sauk County, WI

2.3 FLUX Modeling

The total growing season (May through September) flow volume and phosphorus loads from the East and West Branches of Big Creek were calculated using the US Army Corps of Engineers (USACE) tributary loading model FLUX (Walker, 1996). The 15 minute flow values monitored at the East and West Branch sites were averaged into daily values and entered into FLUX. Phosphorus concentrations from samples collected at the East and West Branch during the growing season and the mean daily flow value for each sampling date were entered into FLUX. The total growing season (May through September) flow volume and phosphorus loads from the East and West Branches of Big Creek, watershed area, and precipitation were used to compute the 2007 phosphorus loading rates for the East and West Branches of Big Creek during 2007. The same growing season period was used to compute 2007 phosphorus loading rates from Big Creek as was used to compute 1996 phosphorus loading rates. The 2007 phosphorus loading rates from Big Creek were then applied to 1996 precipitation to express the 2007 loading rates in a format that is directly comparable to 1996 Big Creek loading rates.

2.4 BATHTUB Modeling

The USACE BATHTUB model (Walker, 1996) was used to model Lake Redstone’s pool water quality and also its response to changes in phosphorus loading. BATHTUB is comprised of a suite of models and the user chooses the appropriate model for each modeled parameter. The same models used in the 1996 study were used for the 2007 study.

The reservoir was divided into 3 segments, upper, middle, and lower as shown in Figure 1. After inflow and phosphorus loading sources were entered into BATHTUB, the model was calibrated to the observed 2007 in-lake conditions.

Internal loading was much higher during 2007 than 1996 and the internal loading component of the 2007 model was adjusted to:

- 15 $mg/m^2/day$ for the northern (03) segment
- 11.5 $mg/m^2/day$ for the middle (02) segment and
- 0.5 $mg/m^2/day$ for the southern (03) segment.

In 1996, internal loading was modeled in only one segment (northern) at a rate of 2.5 $mg/m^2/day$. The increased internal loading in 2007 was consistent with the reduced precipitation and increased residence time observed in 2007 as compared with 1996 conditions.

Although the 1996 BATHTUB models were used in 2007, changes in model calibration coefficients were necessary due to changes in the lake between the two years. The non- algal turbidity in 2007 (0.08 1/m) was much lower than 1996 (0.26 to 0.65 1/m) and corresponding changes in relationship between phosphorus, chlorophyll, and Secchi disc resulted from this change. In addition, internal loading of phosphorus increased by an order of magnitude in 2007 as compared with 1996. The phosphorus loaded by internal loading is soluble phosphorus readily available to algae. Increased loading of soluble phosphorus in 2007 changed the relationship between phosphorus, chlorophyll, and Secchi disc. Hence, calibration coefficients for chlorophyll and Secchi depth were adjusted in 2007. Table 1 summarizes the phosphorus, chlorophyll *a*, Secchi depth, and dispersion models and calibration values used within BATHTUB during 1996 and 2007.

Table 1 Summary of models

Parameter	1996 and 2007 Model	2007 Calibration Coefficient	1996 Calibration Coefficient
Phosphorus Retention	No. 3; 2^{nd} Order Fixed	Global Coefficient of 1.0	Global Coefficient of 1.0
Chlorophyll *a*	No. 5; Jones & Bachmann	Southern (01) of 1.05, Middle (02) of 0.85, and Northern (03) of 0.95	Global Coefficient of 1.25
Secchi Depth	01 vs Chl *a* & Turbidity	Southern (01) of 1.5, Middle (02) and Northern (03) of 2.0	Global Coefficient of 1.0
Dispersion	01 Fischer-Numeric	Global Coefficient of 1.0	Global Coefficient of 1.0

After model calibration, a model run was completed using 2007 phosphorus loading rates and 1996 precipitation conditions. The 2007 model calibration coefficients for chlorophyll and Secchi depth were was used as well as 2007 phosphorus loading rates from East and West Big Creek and 2007 internal loading rates. 1996 precipitation and flows were used. The results were then compared with 1996 BATHTUB results to determine changes in lake water quality resulting from changes in watershed and internal phosphorus loading.

Three best management practice (BMP) scenarios were then modeled to assess opportunities for water quality improvement. The first scenario modeled a 90 percent reduction in current internal loading rate. The second scenario modeled a 90 percent reduction in current internal loading rate as well as a 65 percent reduction in current watershed loading rate from West Big Creek. The third scenario modeled a 90 percent reduction in current internal loading rate, a 65 percent reduction in current watershed loading rate from West Big Creek, and a 65 percent reduction in current watershed loading rate from East Big Creek. The three models used 1996 precipitation and flows as well as the 2007 model calibration coefficients.

3.0 Results and Discussion

3.1 1996 and 2007 Precipitation

Although 1996 and 2007 noted similarities in climate, the differences between the two climatic years are significant. Both years were dry and both years noted a significant rain event. In 1996, nearly two thirds of the seasonal precipitation occurred during June. A 4-inch storm occurred on June 17, 1996 resulting in a monthly rainfall total of 9.56 inches which is 5.6 inches above normal (Table 1). In 2007, nearly 60 percent of the seasonal precipitation occurred during August. A 5.25-inch storm occurred on August 19, 2007, resulting in a monthly rainfall total of 13.42 inches which is 9.05 inches above normal (Table 1). The National Oceanic and Atmospheric Administration describes the summer of 2007 as follows:

> *"During June and July much of the state saw 2 to 4 inch precipitation deficits. The effect of this dryness was amplified by unusually warm temperatures (1 to 3 degrees above normal). This caused the drought to spread across almost all (85.85%) of Wisconsin. With the exception of the southern two tiers of counties, the state was either in moderate or severe drought. Record August rains across the southern half of the state quickly alleviated the drought across this area"* (NOAA, 2007).

Table 2 Seasonal Rainfall in Inches for Lake Redstone During 1996 and 2007

Month	30 Year Normal Precipitation*	1996 Observed Precipitation	2007 Observed Precipitation
May	3.4	0.35	1.81
June	3.96	9.56	2.65
July	3.75	2.75	1.96
August	4.37	1.32	13.42
September	3.89	1.38	3.06
Total	**19.37**	**15.36**	**22.9**

*From Leverance et al. 1997. Hence, 2007 precipitation is compared with the 30 Year Normal Precipitation for 1996.

Drought conditions during much of the summer of 2007 provided ideal conditions for internal phosphorus loads to remain in the lake and become available for algal growth during the summer season. The unusually warm temperatures in 2007 provided additional impetus for algal growth within the lake since the rate of algal cell division increases with temperature. The June 1996 storm added particulate material to Lake Redstone that reduced light availability to algae. In contrast, the drought conditions of 2007 reduced the addition of non-algal turbidity to the lake. The clearer waters resulting from this reduction aided algal growth within the lake during 2007. Modeling results indicate non-algal turbidity during 1996 ranged from 0.26 to 0.65 1/m compared with 0.08 1/m during 2007. The combination drought conditions during June and July, warmer temperatures, and better light conditions due to less sediment in the water resulted in increased algal growth and poorer lake water quality in 2007 than was observed during 1996.

3.2 1996 and 2007 Runoff

Watershed runoff comprised 93 percent of the seasonal water input to Lake Redstone during 1996 and 89 percent during 2007. Groundwater comprised 8 percent of the lake's seasonal water input during 1996 and 5 percent during 2007. In 1996, a net loss of about 1 percent from evaporation off the lake's surface occurred, while precipitation added an additional 6 percent of the seasonal water input during 2007 (Figures 2 and 3).

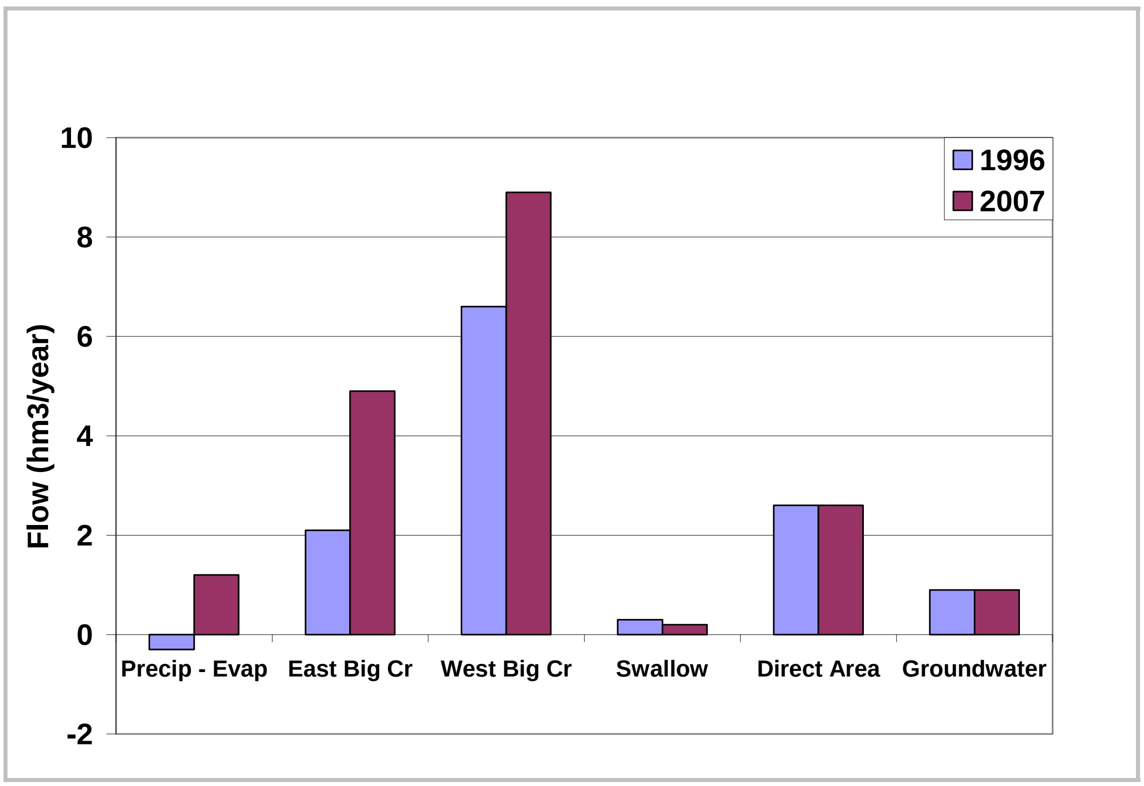


Figure 2 Lake Redstone Water Loading: Flow

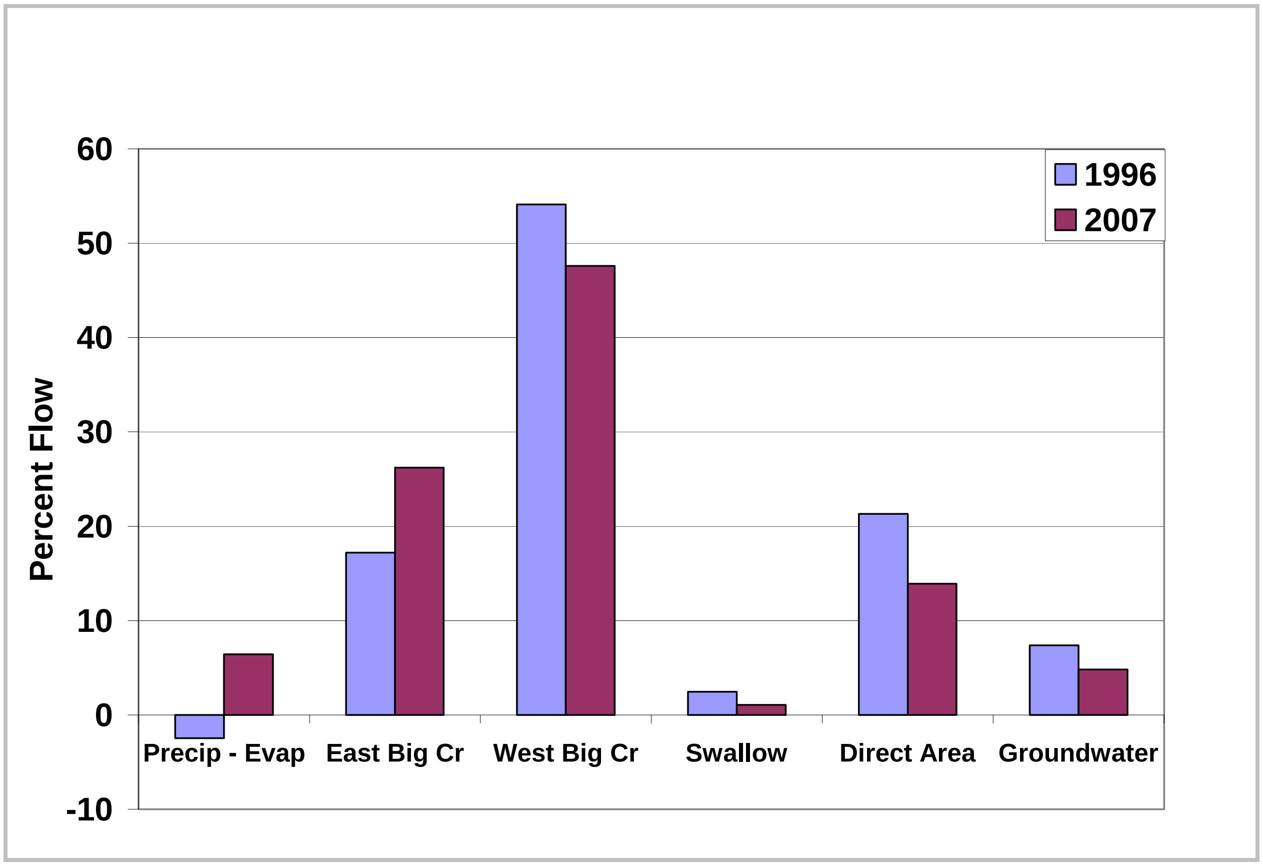


Figure 3 Lake Redstone Water Loading: Percent Flow

2007 mean daily discharge data were consistent with 1996 data and indicated the west branch is slower to respond to precipitation events than the flashier east branch. For example, a 5.25-inch precipitation event on August 19 resulted in a mean daily flow of 84.8 cubic feet per second on East Big Creek while the comparable West Big Creek mean daily flow was 1.5 cfs. Stage and discharge data from West Big Creek were not available for August 20 and 21 and, hence, the peak flow observed at West Big Creek following this rainstorm is not available. Nonetheless, the data on the day of the rainstorm indicate the East branch is quicker to respond to precipitation than the West Branch of Big Creek.

In 2007, West Big Creek generally observed higher mean daily flows than East Big Creek. Mean daily flows at West Big Creek (Clark Road) were generally less than 15 cubic feet per second while mean daily flows at East Big Creek were generally less than 10 cubic feet per second (Figures 4 and 5).

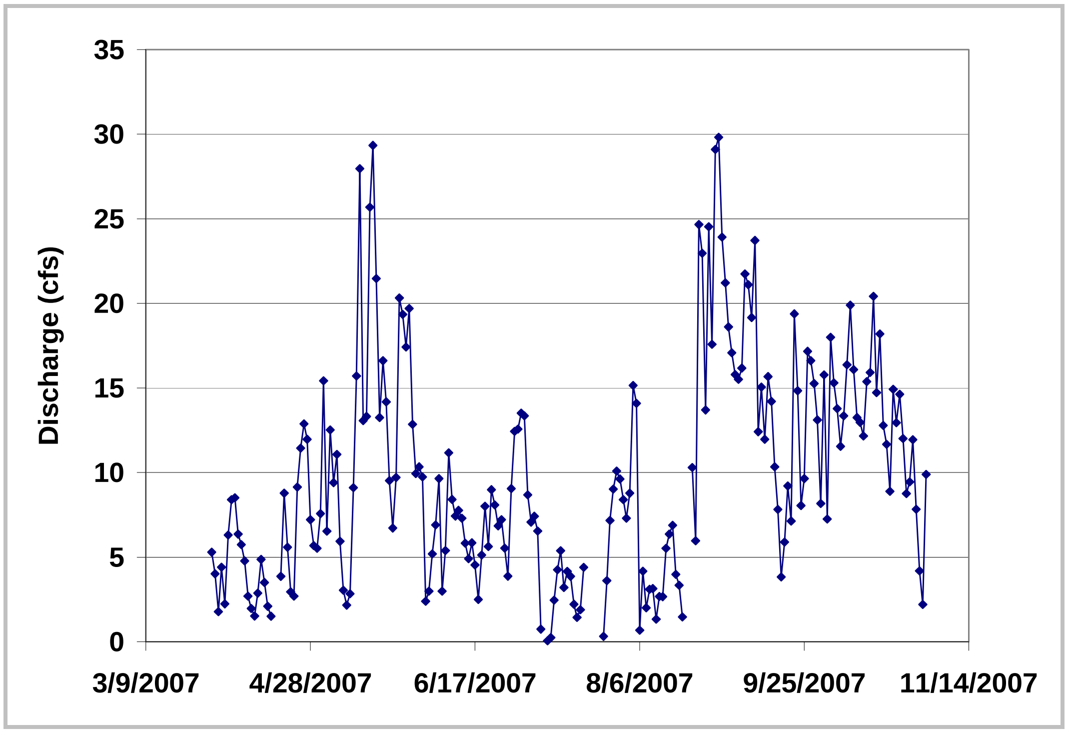


Figure 4 2007 West Big Creek (Clark Rd.) Mean Daily Flows

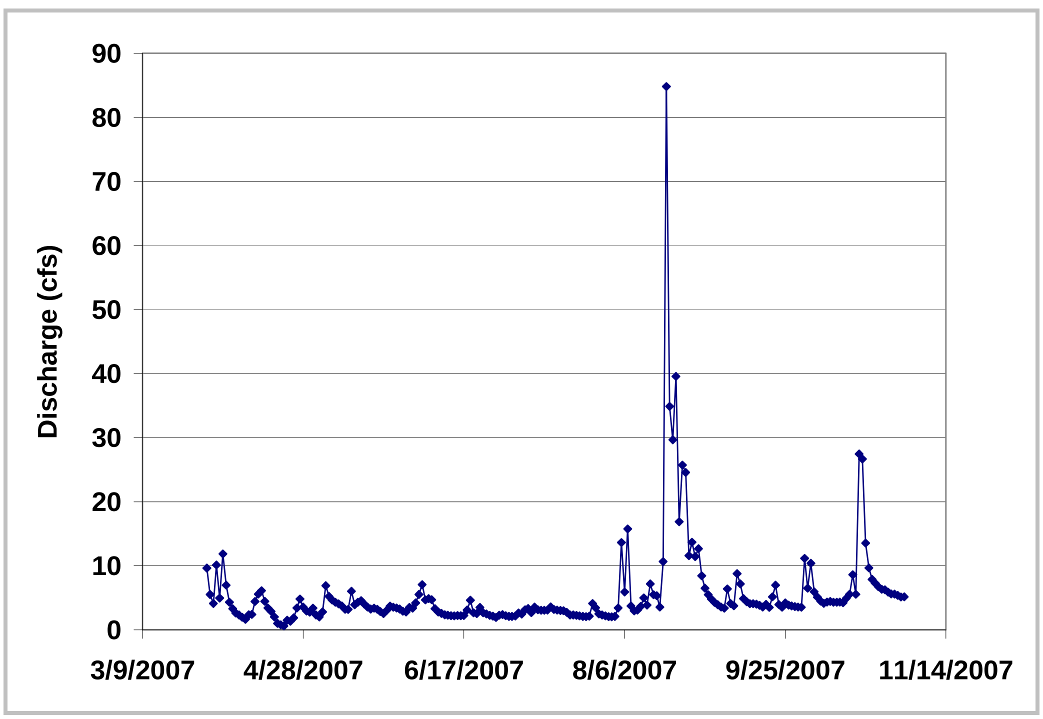


Figure 5 2007 East Big Creek (Lavalle Rd.) Mean Daily Flows

Watershed water yield is a measure of the amount of input precipitation that eventually exits the watershed. West Big Creek and East Big Creek convey the water yielded from their respective watersheds to Lake Redstone. The 2007 data indicate a higher water yield from the East Branch than the West Branch of Big Creek during the March 29 through November 1, 2007 monitoring period. The East Branch of Big Creek observed a 2007 cumulative water yield of 8.85 inches compared with a cumulative water yield of 5.37 inches from the West Branch (Figure 6). Precipitation input to the respective watersheds for this period was 31.56 inches. As shown in Figure 6, the flashier East Branch of Big Creek yielded more water than the West Branch following the record setting August storms.

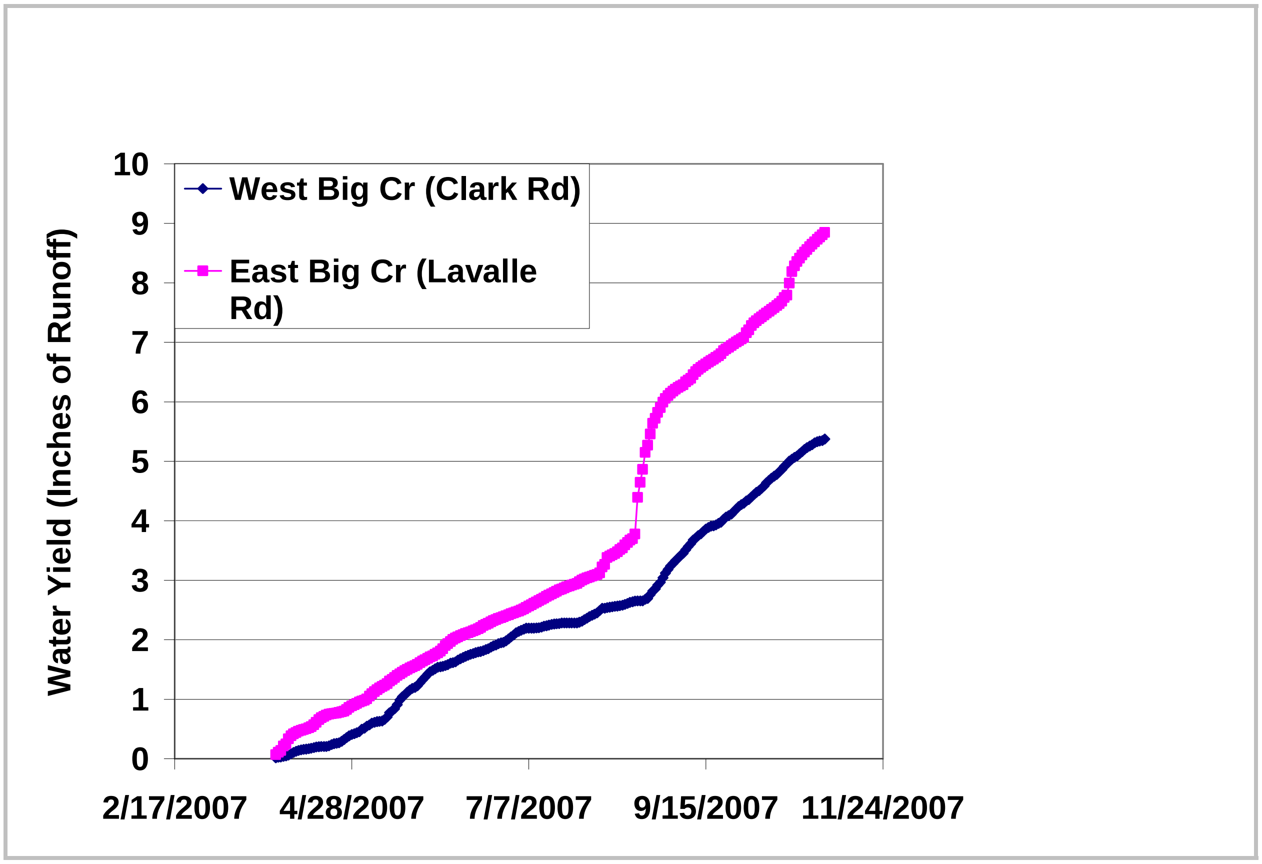


Figure 6 2007 Lake Redstone Watershed Water Yield

3.3 1996 and 2007 Phosphorus Loading

Flux modeling results indicate the cumulative total phosphorus mass conveyed from West Big Creek to Lake Redstone during March 29 through November 1, 2007 totaled 679 kilograms (kg). The dissolved fraction of phosphorus, ortho phosphorus, totaled 327 kg or 48 percent of the total phosphorus mass conveyed from West Big Creek to Lake Redstone (Figure 7). During this same period, the total phosphorus mass conveyed from East Big Creek to Lake Redstone totaled 471 kg. The dissolved fraction of phosphorus, ortho phosphorus, totaled 171 kg or 36 percent of the total phosphorus mass conveyed from East Big Creek to Lake Redstone (Figure 8). In 1996, ratio of total phosphorus to ortho phosphorus for West Big Creek and East Big Creek were 40 percent and 30 percent, respectively.

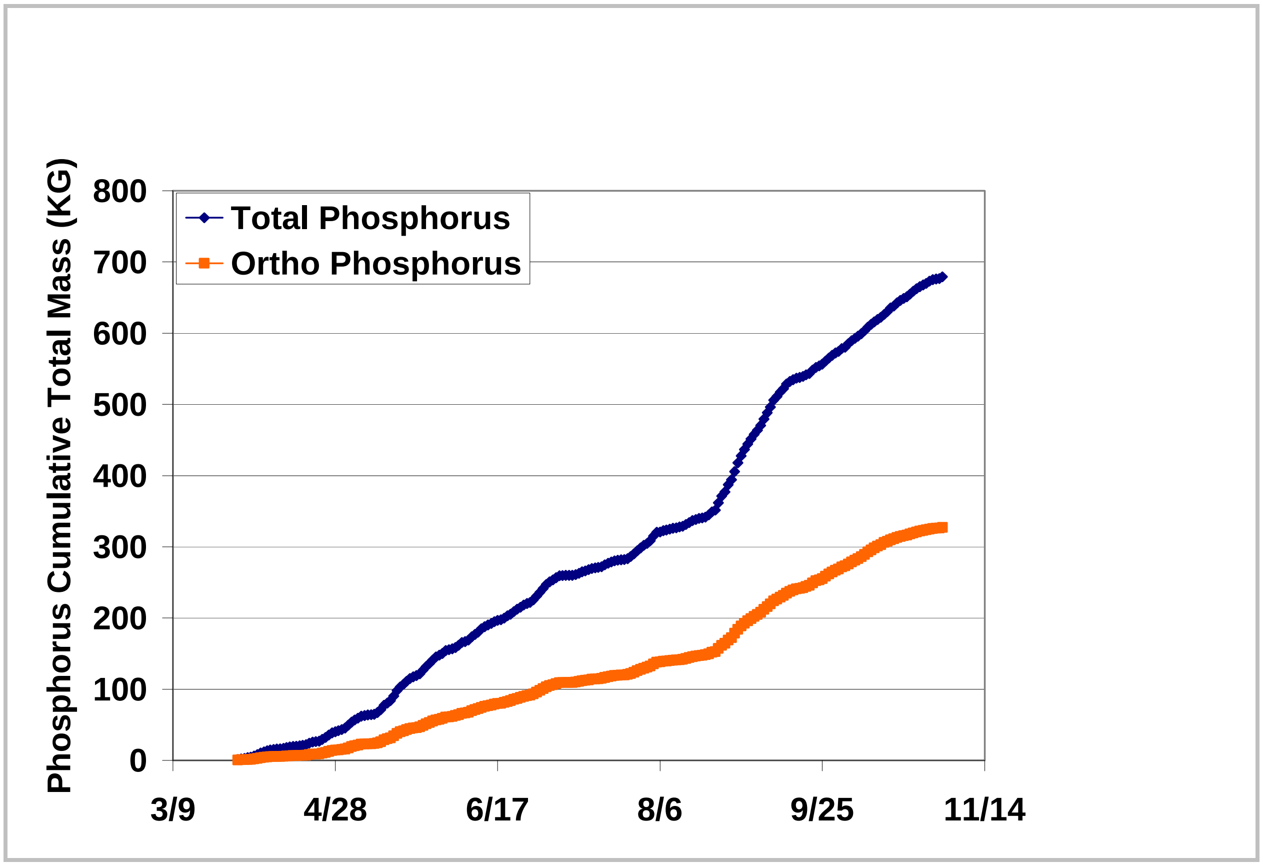


Figure 7 2007 West Big Creek at Clark Road: Modeled Ortho and Total Phosphorus Cumulative Total Mass During March 29 Through November 1, 2007

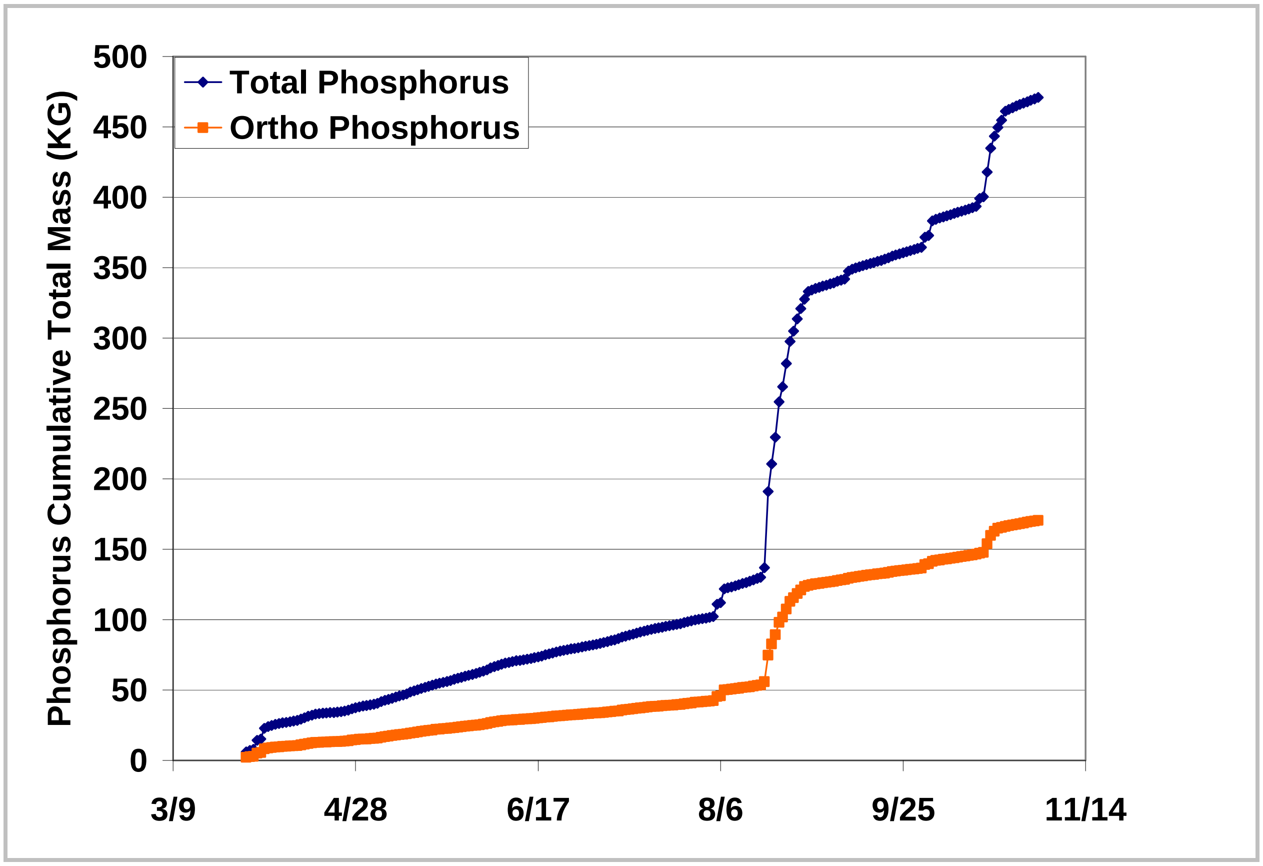


Figure 8 **2007 East Big Creek at Lavalle Road: Modeled Ortho and Total Phosphorus Cumulative Total Mass During March 29 Through November 1, 2007**

FLUX and BATHTUB modeling results indicate the primary source of phosphorus to Lake Redstone during the May through September period of 2007 was internal loading rather than watershed loading. Internal loading comprised 73 percent of the seasonal phosphorus load in 2007. Watershed loading comprised 26 percent of the seasonal load and precipitation 1 percent during 2007 (Figure 9).

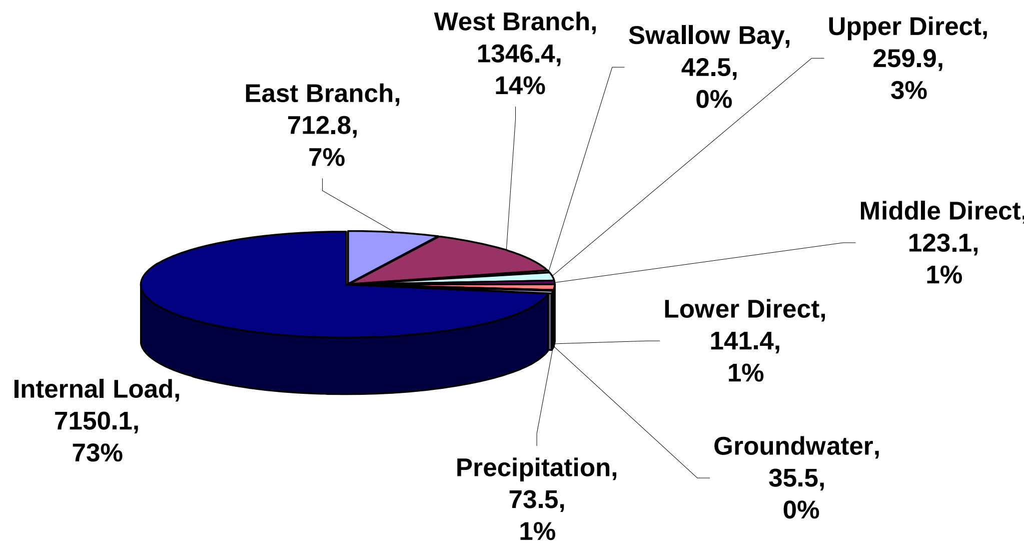


Figure 9 2007 Lake Redstone Total Phosphorus Sources (Source, Load in Kg/Yr, and Percent of Total)

Phosphorus loading in 2007 differed from 1996 both in the size of the load and its composition. During 1996, watershed loading comprised 66 percent of the lake's phosphorus load compared with 26 percent in 2007 (Figures 10 and 11). In contrast, internal loading comprised 73 percent of the lake's phosphorus load in 2007 compared with 29 percent in 1996 (Figures 10 and 11). In 1996, the lake's phosphorus load totaled 2,220 kg compared with 9,850 kg in 2007 (Figure 10). Watershed loading in 2007 (2,626 kg) was higher than 1996 (1,500 kg), but comprised a lower percent of the total load (Figures 10 and 11). The data indicate the climatic conditions discussed previously resulted in higher watershed and internal phosphorus loading to Lake Redstone in 2007 compared with 1996 levels. In 1996, East and West Big Creek noted phosphorus loading rates of 0.026 and 0.023 pounds of phosphorus per inch of runoff per acre of watershed. In 2007, East and Big Creek noted phosphorus loading rates of 0.035 and 0.033 pounds of phosphorus per inch of runoff per acre of watershed, respectively. Hence, East and West Big Creek watershed loading rates increased 35 and 43 percent, respectively, between 1996 and 2007.

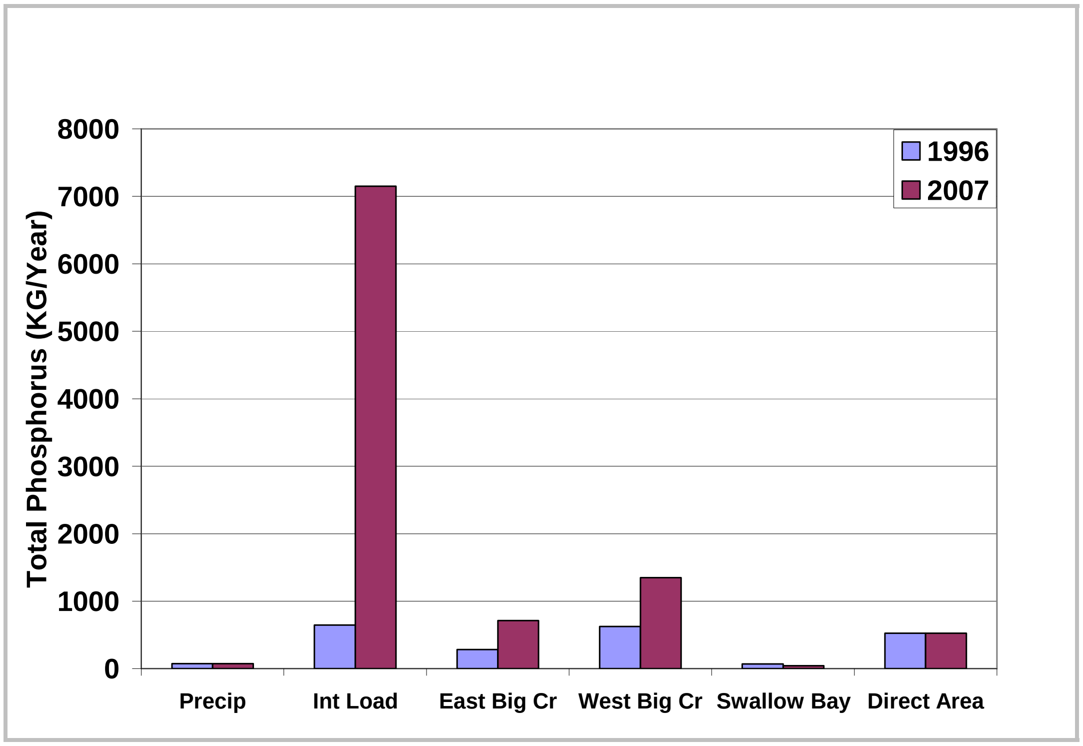


Figure 10 1996 and 2007 Lake Redstone Phosphorus Loading

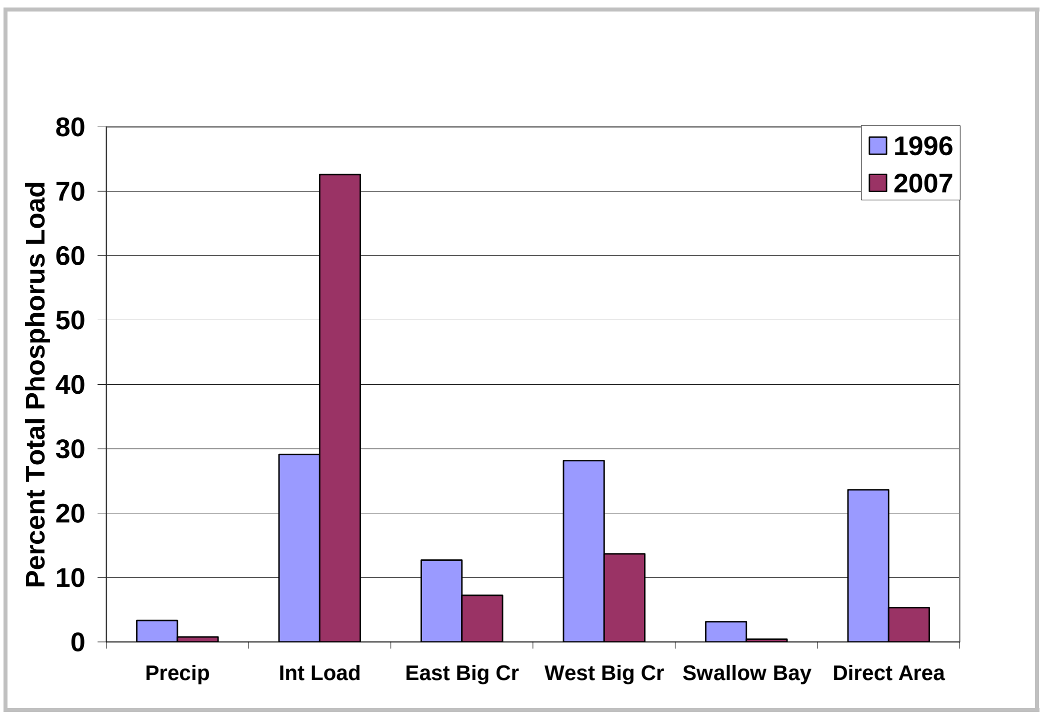


Figure 11 1996 and 2007 Lake Redstone Phosphorus Loading: Percent of Total Load

3.4 Comparison of 2007 Phosphorus Loading Rates Applied to 1996 Precipitation With 1996 and 2007 Phosphorus Loads

Modeled phosphorus loading to Lake Redstone using 2007 phosphorus loading rates applied to 1996 precipitation was directly compared with 1996 and 2007 phosphorus loading (Figure 12). The phosphorus load to Lake Redstone resulting from 2007 phosphorus loading rates and 1996 precipitation is only slightly less than the modeled 2007 load and substantially greater than the modeled 1996 load. The similarity to 2007 is due to internal loading which increased by an order of magnitude from 1996 to 2007.

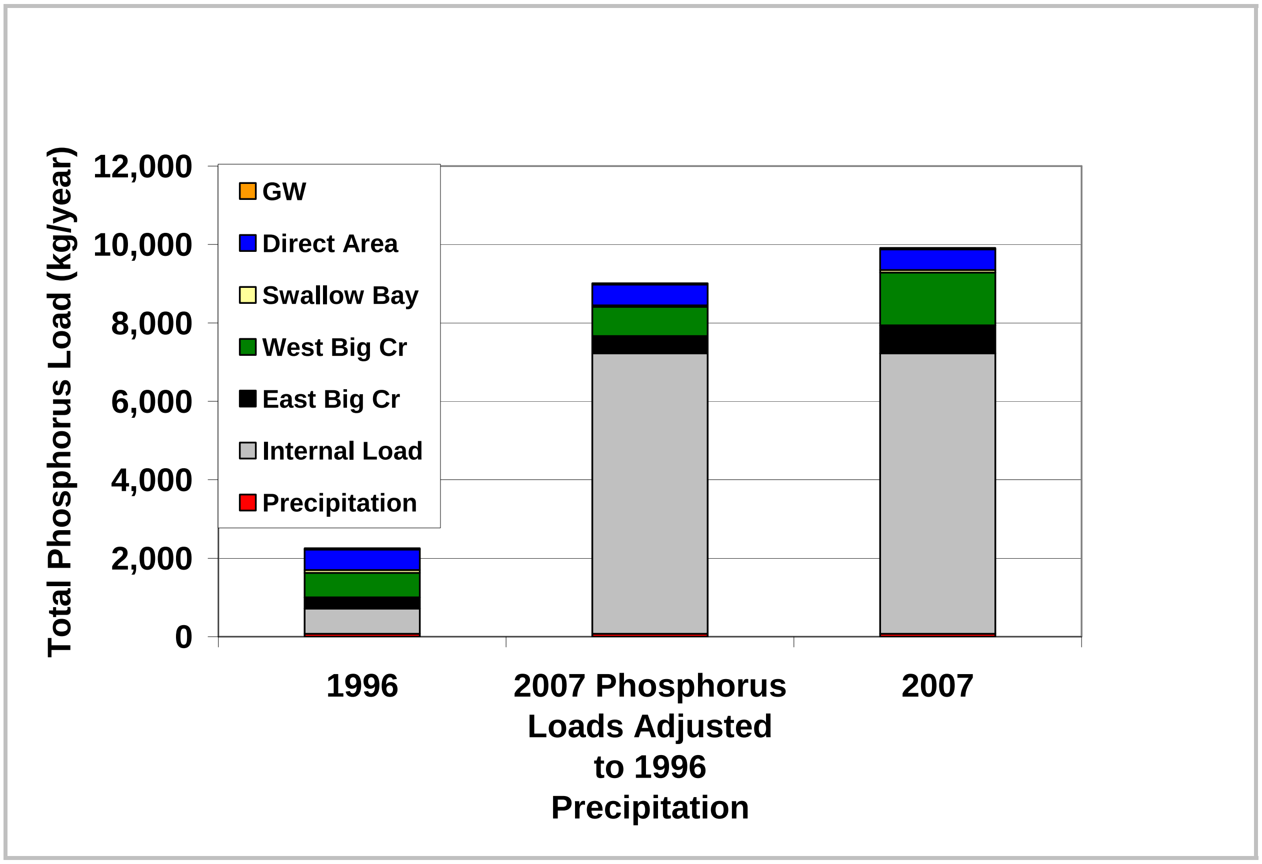


Figure 12 Lake Redstone Seasonal Total Phosphorus Loads: Compare 1996 and 2007 With Modeled Scenario of 1996 Precipitation With 2007 Loading Rate

3.5 Load Duration Curves

Watershed phosphorus loading by East and West Big Creek was evaluated under varying precipitation conditions using load duration curves. To create a load duration curve for each site, all flows from 1996 and 2007 were sorted from highest to lowest flow. Flow duration intervals (FDI), or the percent of the time that a flow interval occurred during the period of flow measurement, was then determined. After determining FDI, phosphorus loads for the period of record were computed by multiplying the phosphorus concentration of each sample collected during the period of record by the corresponding flow value. Phosphorus loads were graphed by placing each phosphorus load value within the flow duration interval, which corresponds to the flow occurring at the time of sample collection. Load duration curves for West and East Big Creek are presented in Figures 13 and 14. The curves indicate phosphorus loading is flow related. Highest loads are associated with highest flows and lowest loads are associated with lowest flows. The distribution of loads relative to flows was similar during 1996 and 2007 with a couple of exceptions. Higher phosphorus loads were generally observed under dry conditions during 2007 than were observed in 1996 at West Big Creek. Higher phosphorus loads were generally observed under high and moist flow conditions during 2007 than were observed in 1996 at East Big Creek.

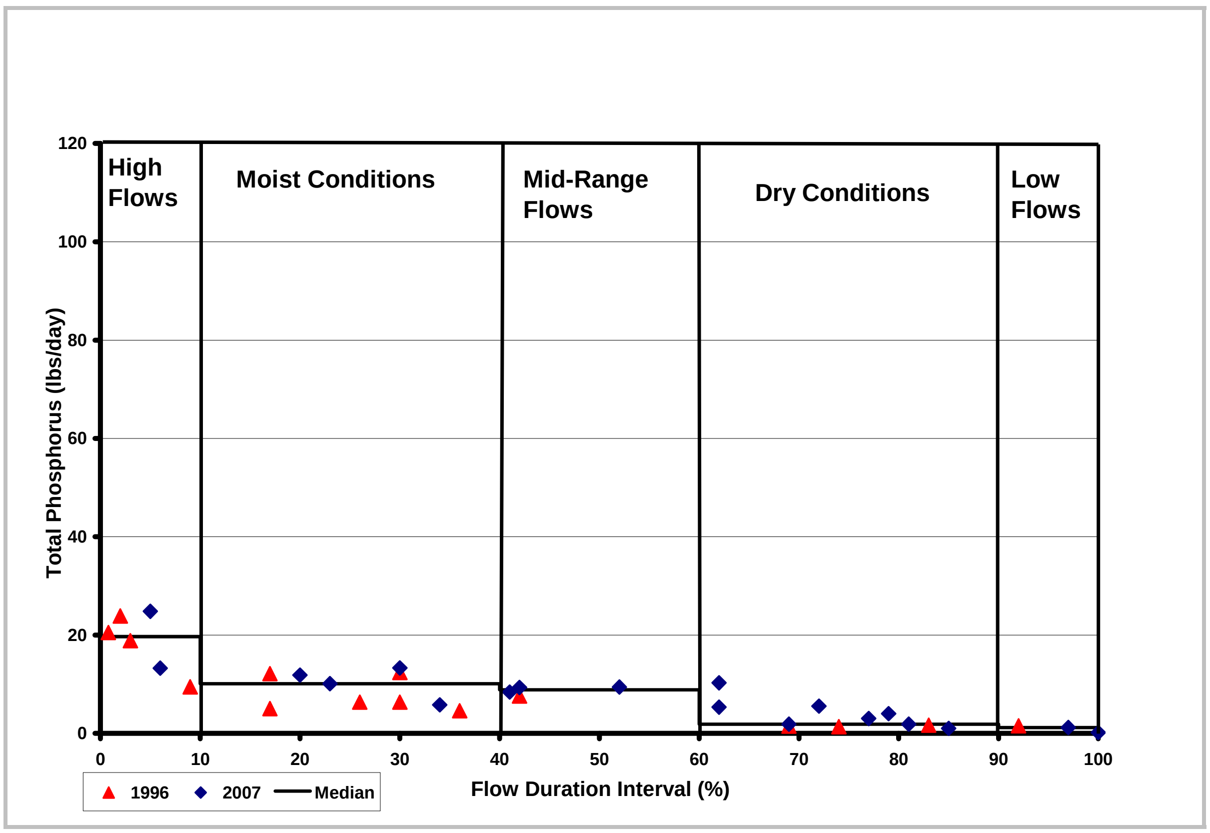


Figure 13 West Big Creek (Clark Rd) Total Phosphorus Load Duration Curve (1996 and 2007 Monitoring Data)

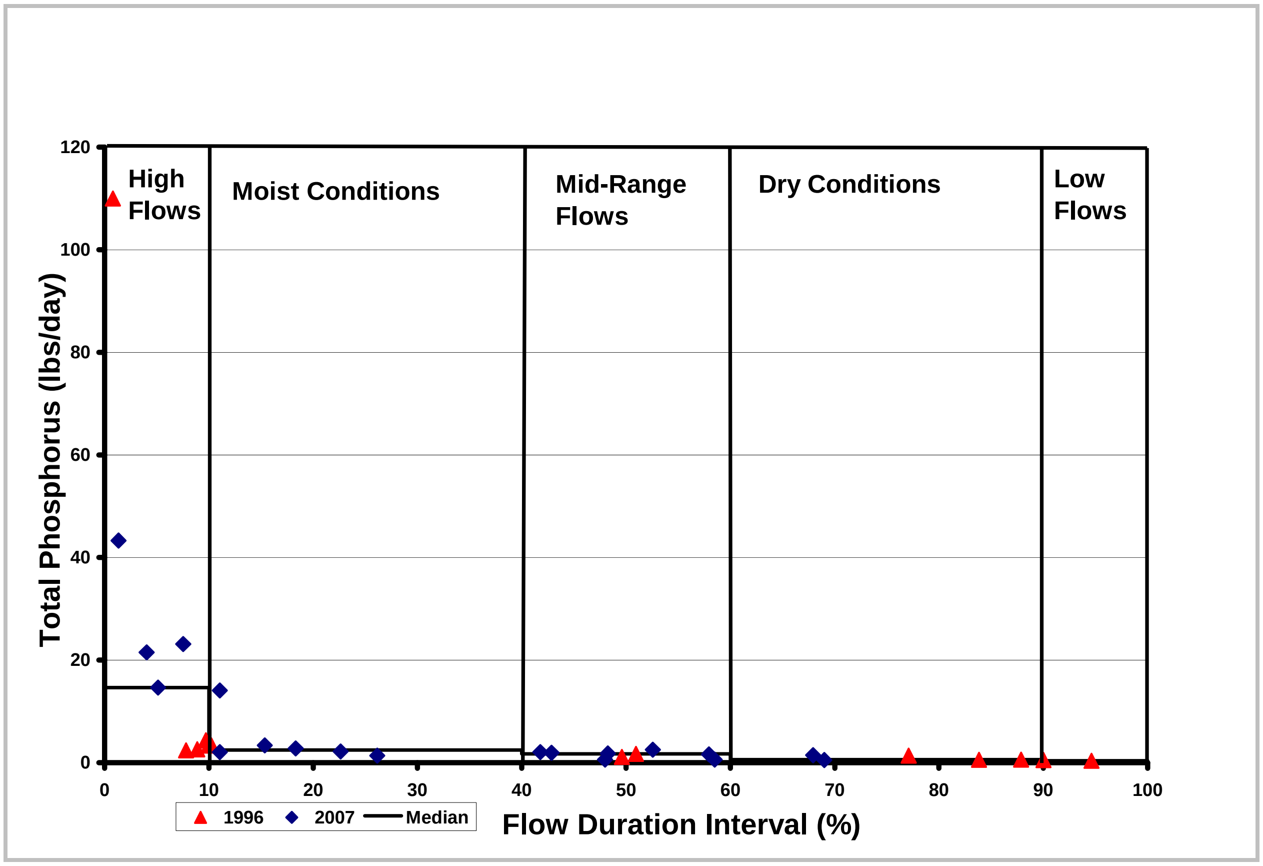


Figure 14 East Big Creek (Lavalle Rd) Total Phosphorus Load Duration Curve (1996 and 2007 Monitoring Data)

3.6 Lake Redstone Water Quality

3.6.1 Dissolved Oxygen and Temperature

Temperature and dissolved oxygen profiles of Lake Redstone are presented in Figures 15 through 20. Temperature profiles indicate frequent mixing occurred in the upper segment and some mixing occurred in the middle segment during the growing season. Despite the mixing, low oxygen levels were generally observed near the lake's bottom at these locations during the summer. The southern segment was thermally stratified and did not appear to mix during the summer. Low oxygen levels were also observed in the bottom waters of the southern segment.

Lake Redstone has the capacity to recycle phosphorus from its sediment back into the lake's water column. This capacity occurs because much of the phosphorus added to Lake Redstone since its creation has been stored in its sediments. When the lake's bottom waters become stagnant and lose oxygen, the sediment changes from a phosphorus storage unit to a massive phosphorus pumping system. The lake's sediment pumps phosphorus back into the lake where it can once again fuel algal blooms and degrade the lake's water quality. This cycle continues until oxygen is added to the water which breaks this cycle. The stagnant bottom waters of Lake Redstone annually load phosphorus into the lake each summer, but a much higher loading rate was observed in 2007 than was observed in 1996. In 2007, mixing in the northern and middle segments brought the phosphorus rich bottom waters to the surface where it degraded the lake's water quality and fueled algal blooms. Modeling results indicate the northern segment loaded 54 percent of the lake's internal phosphorus load and the middle segment loaded 43 percent of the lake's internal load. Although mixing did not occur in the southern segment during the growing season, diffusion brought some of the phosphorus from the lake's bottom to the surface. Hence, the southern segment loaded approximately 3 percent of the lake's internal load in 2007.

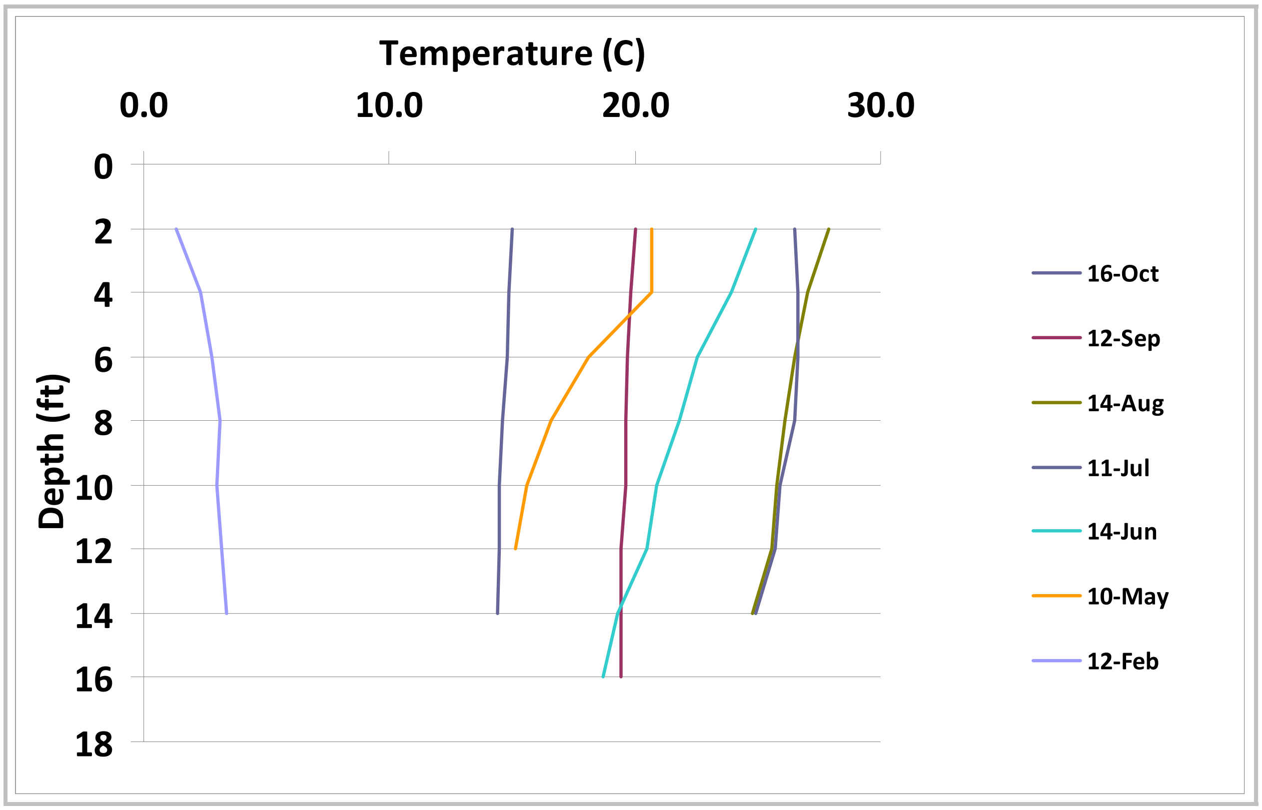


Figure 15 2007 Lake Redstone Temperature Profiles: Northern Site (03)

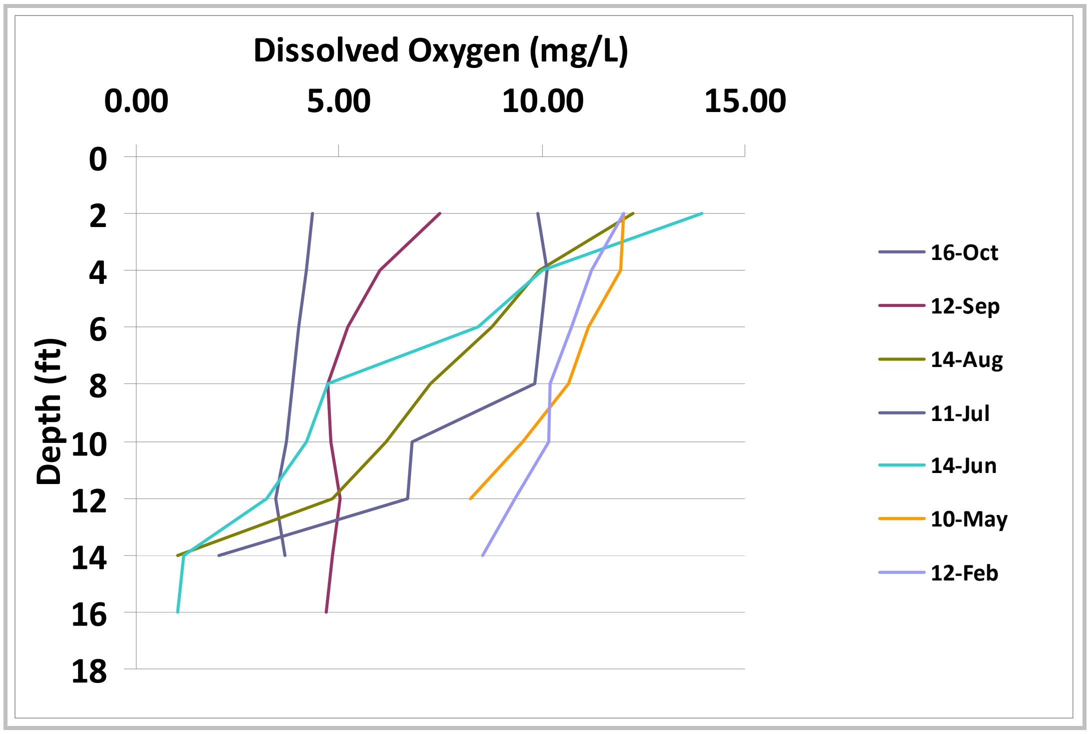


Figure 16   2007 Lake Redstone Dissolved Oxygen Profiles: Northern Site (03)

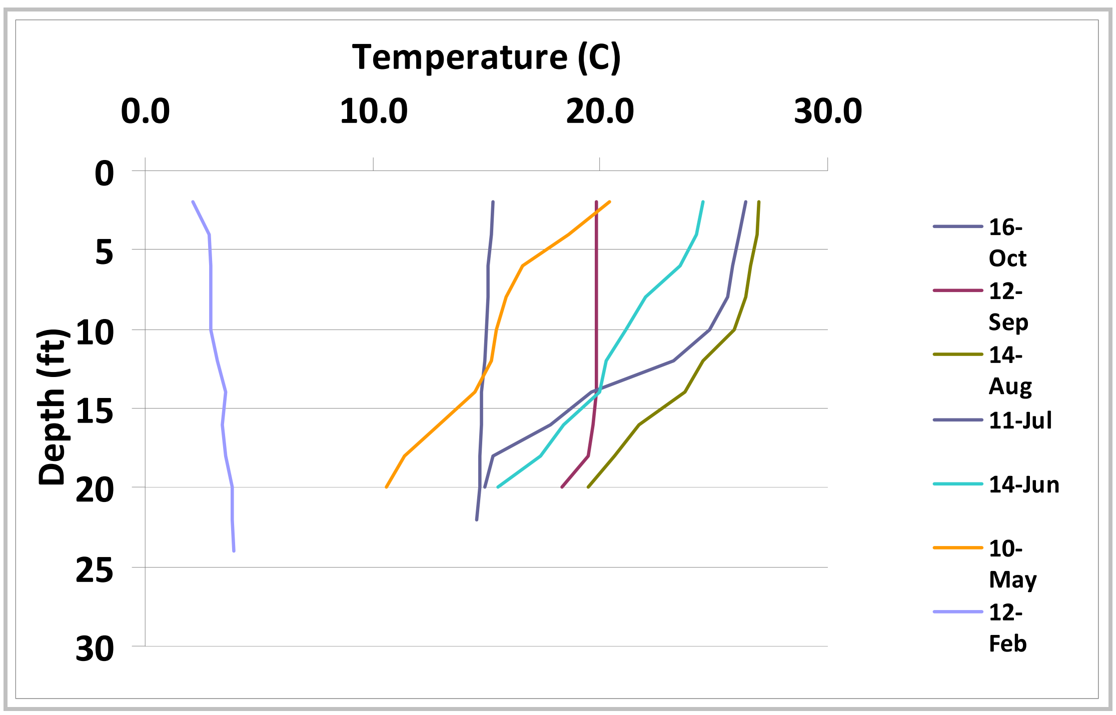


Figure 17   2007 Lake Redstone Temperature Profiles: Middle Site (02)

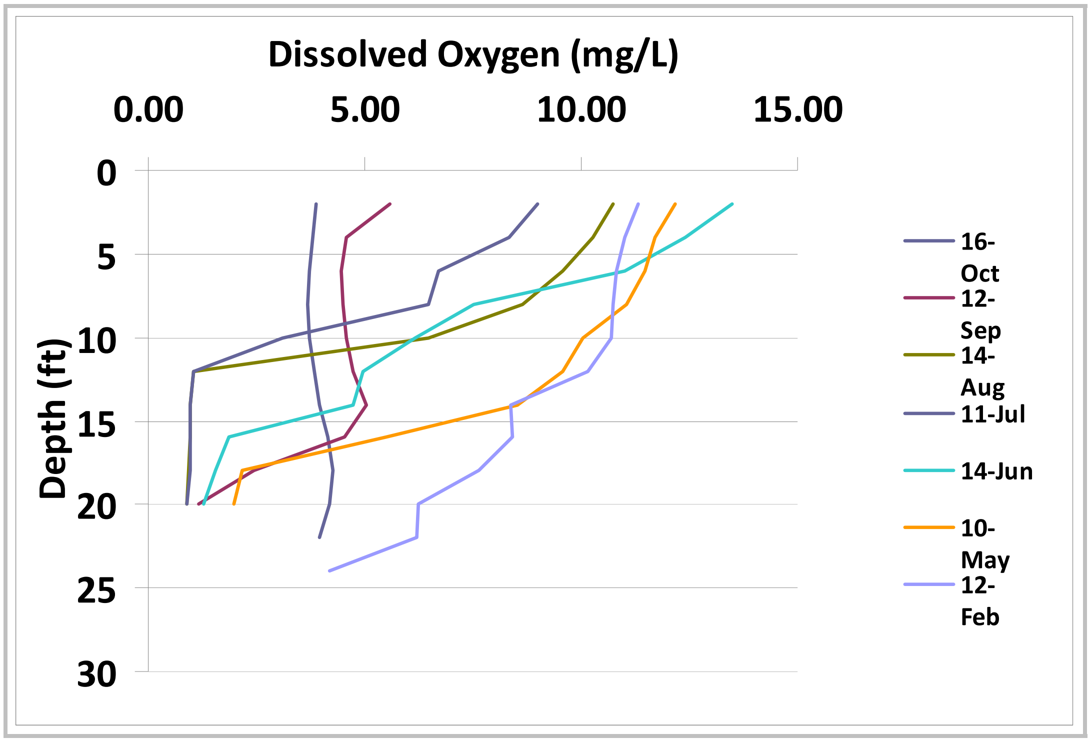


Figure 18 2007 Lake Redstone Dissolved Oxygen Profiles: Middle Site (02)

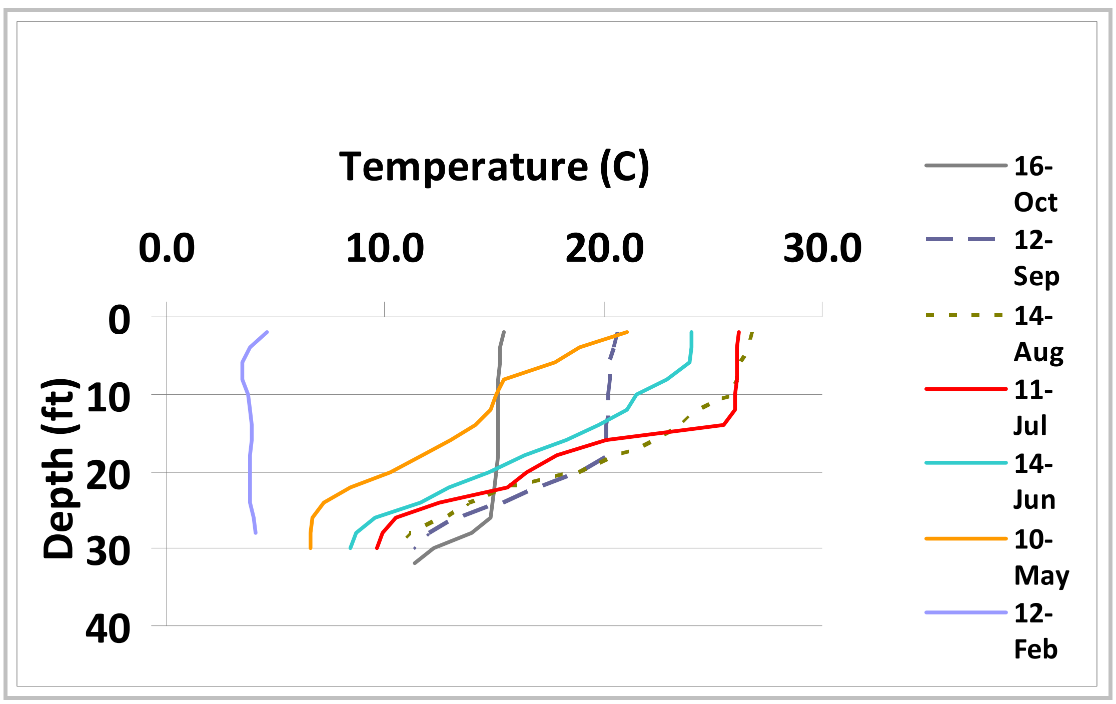


Figure 19 2007 Lake Redstone Temperature Profiles: Southern Site (01)

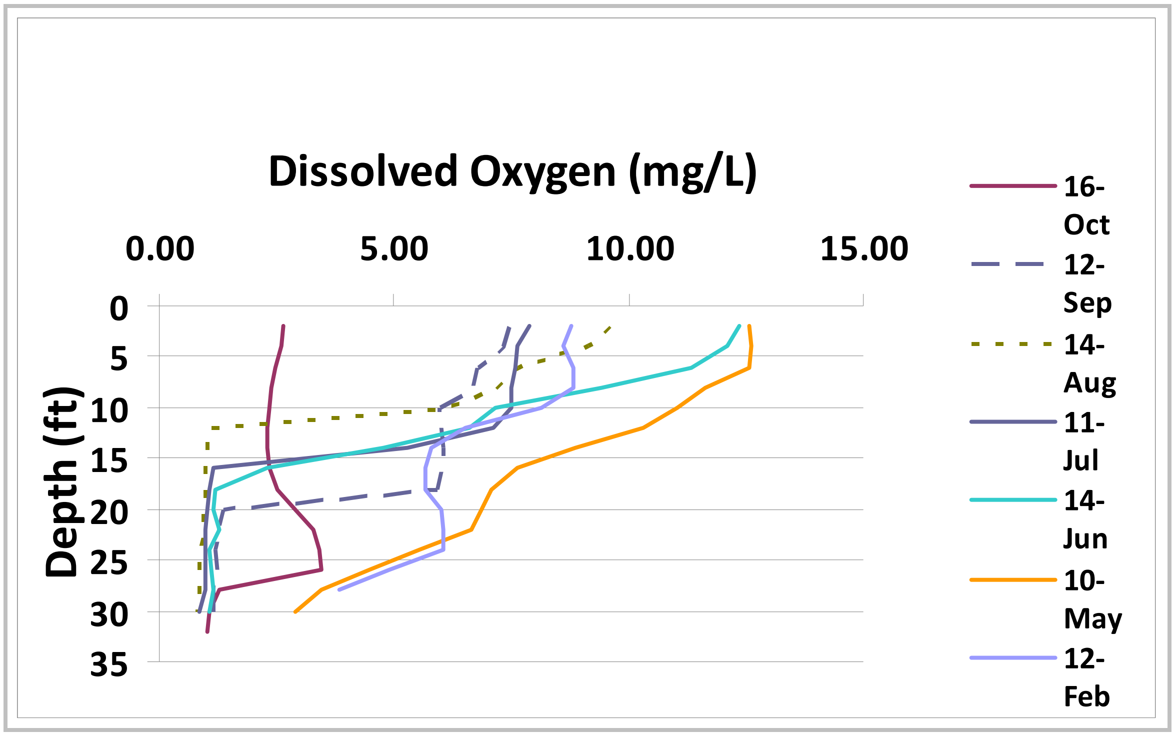


Figure 20 2007 Lake Redstone Dissolved Oxygen Profiles: Southern Site (01)

3.6.2 2007 Total Phosphorus, Chlorophyll, and Secchi Disc Transparency

In 2007, Lake Redstone total phosphorus concentrations were generally within the hypereutrophic or very poor water quality category. Surface concentrations were generally highest at the northern site and lowest at the southern site. In contrast, bottom concentrations were generally highest at the southern site and lowest at the northern site. Frequent mixing at the northern site resulted in very similar surface and bottom phosphorus concentrations throughout the growing season. Lack of mixing at the southern site allowed phosphorus released from the sediments to accumulate in the lake's bottom waters until the lake was mixed during the fall.

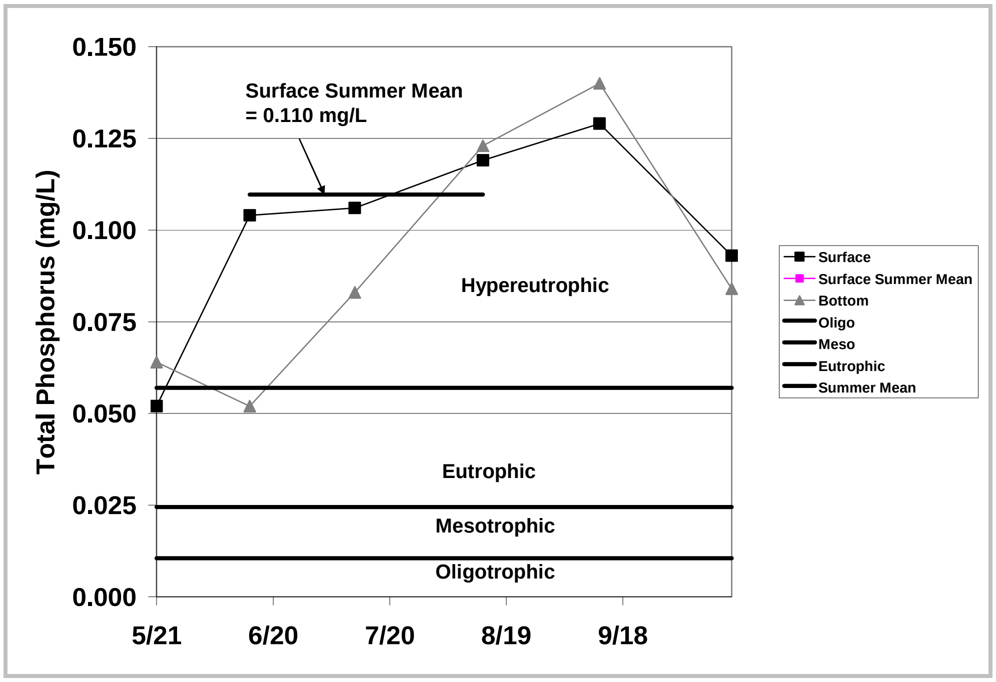


Figure 21 Lake Redstone 2007 Total Phosphorus Concentrations: Northern Site (03)

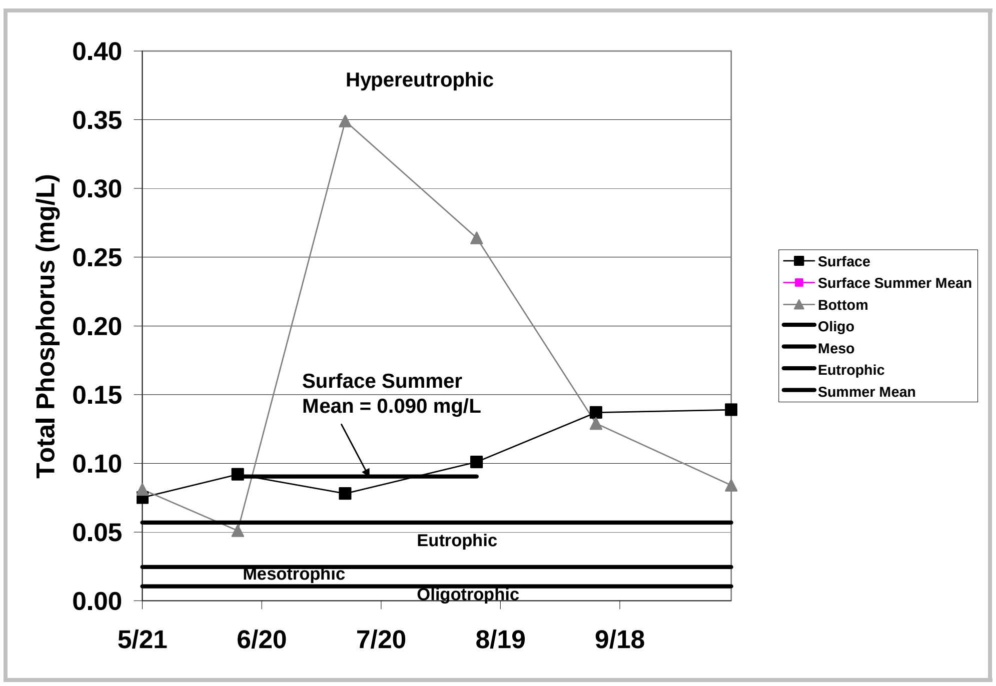


Figure 22 Lake Redstone 2007 Total Phosphorus Concentrations: Middle Site (02)

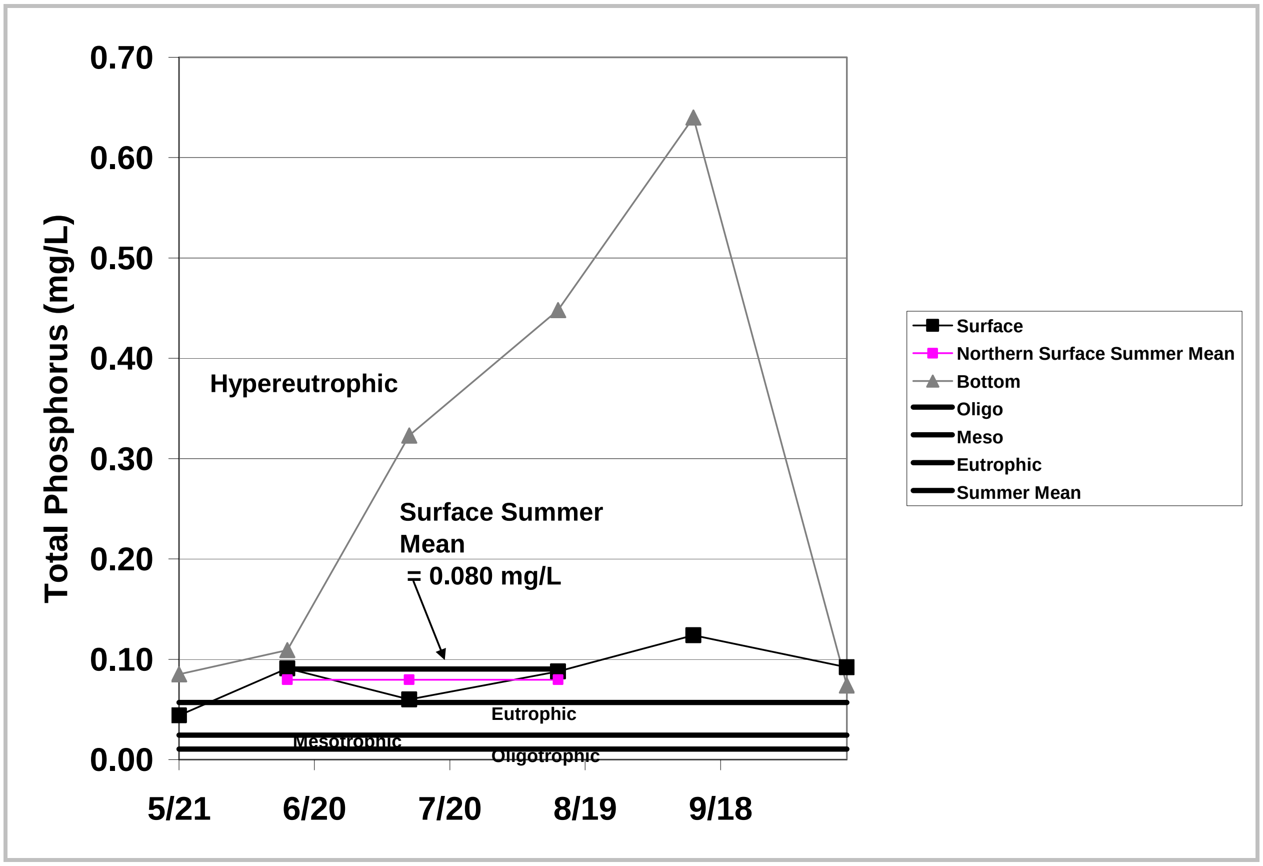


Figure 23 Lake Redstone 2007 Total Phosphorus Concentrations: Southern Site (01)

2007 Lake Redstone chlorophyll *a c*oncentrations were in the hypereutrophic category during the summer period. Concentrations were highest during June at all locations. The high chlorophyll concentrations indicate problematic algal blooms occurred throughout the summer.

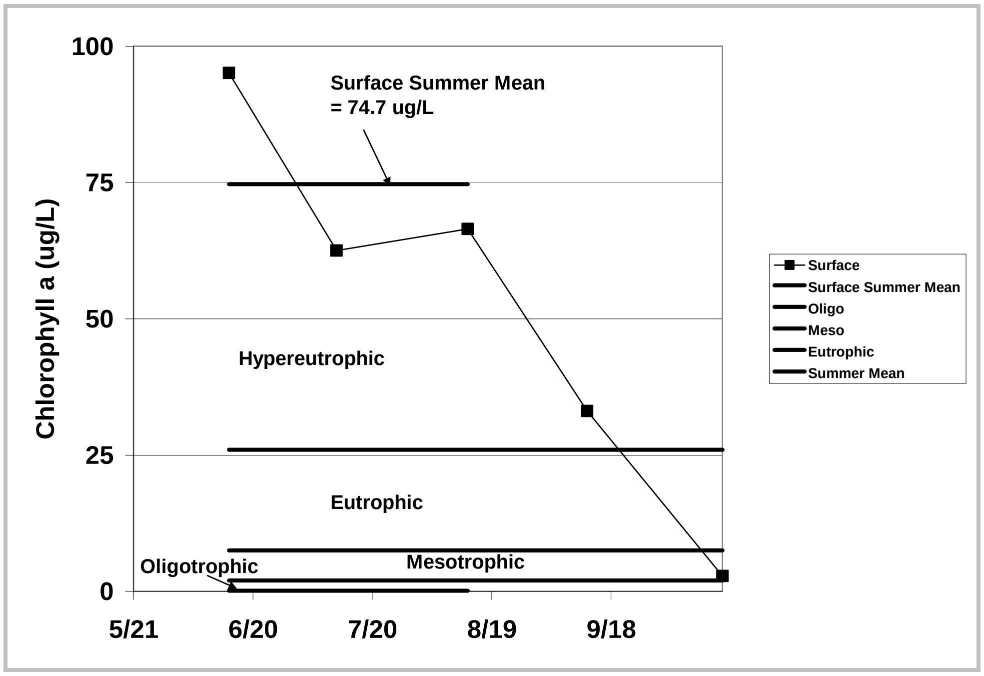


Figure 24 2007 Lake Redstone Chlorophyll *a* Concentrations: Northern Site (03)

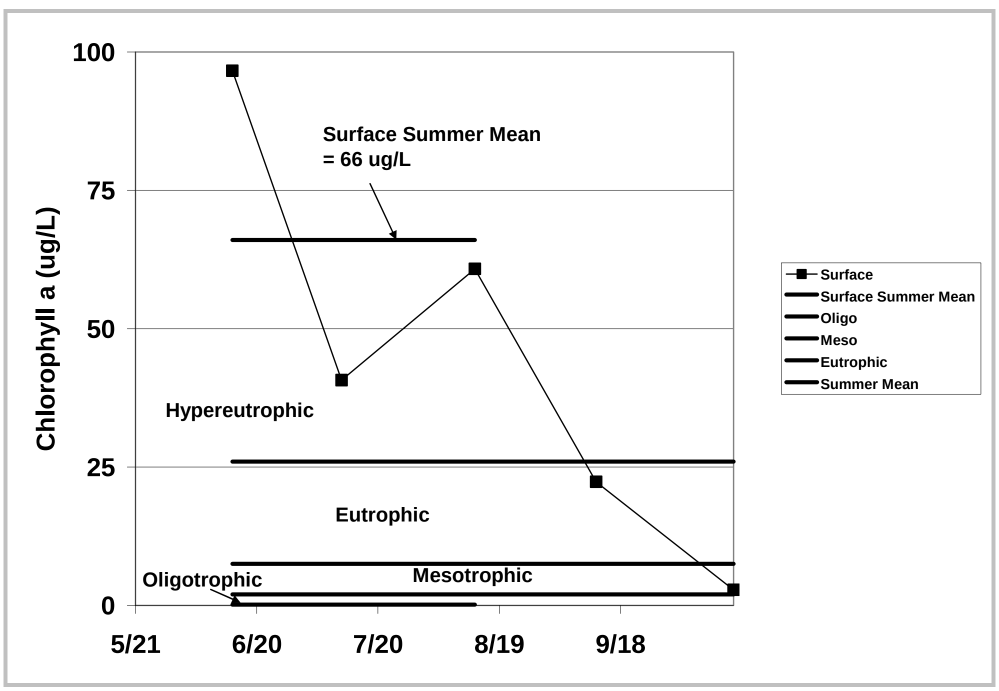


Figure 25 2007 Lake Redstone Chlorophyll *a* Concentrations: Middle Site (02)

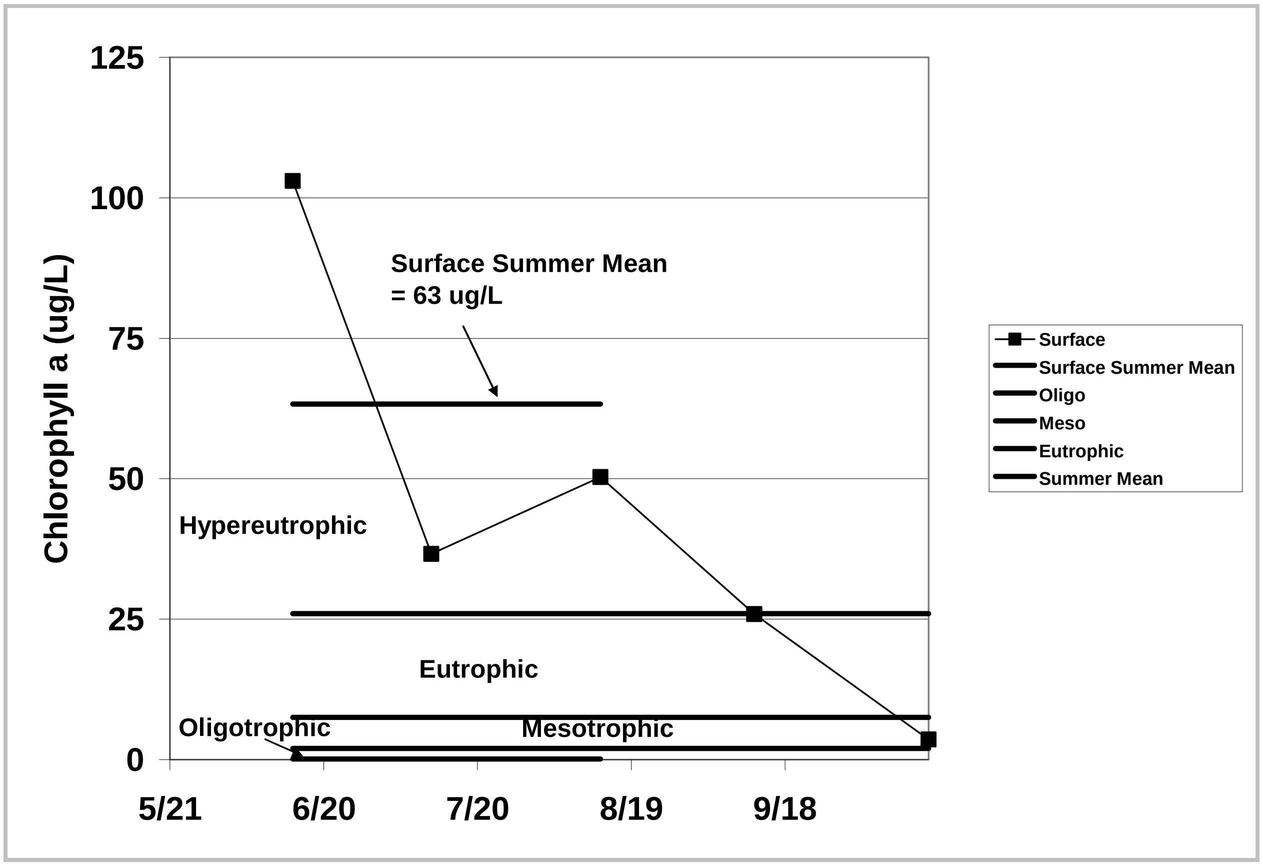


Figure 26 2007 Lake Redstone Chlorophyll *a* Concentrations: Southern Site (01)

Secchi disc measurements were within the hypereutrophic or poor water quality category at all locations during the summer period. Better water transparency was observed in the southern segment than the northern or middle segment.

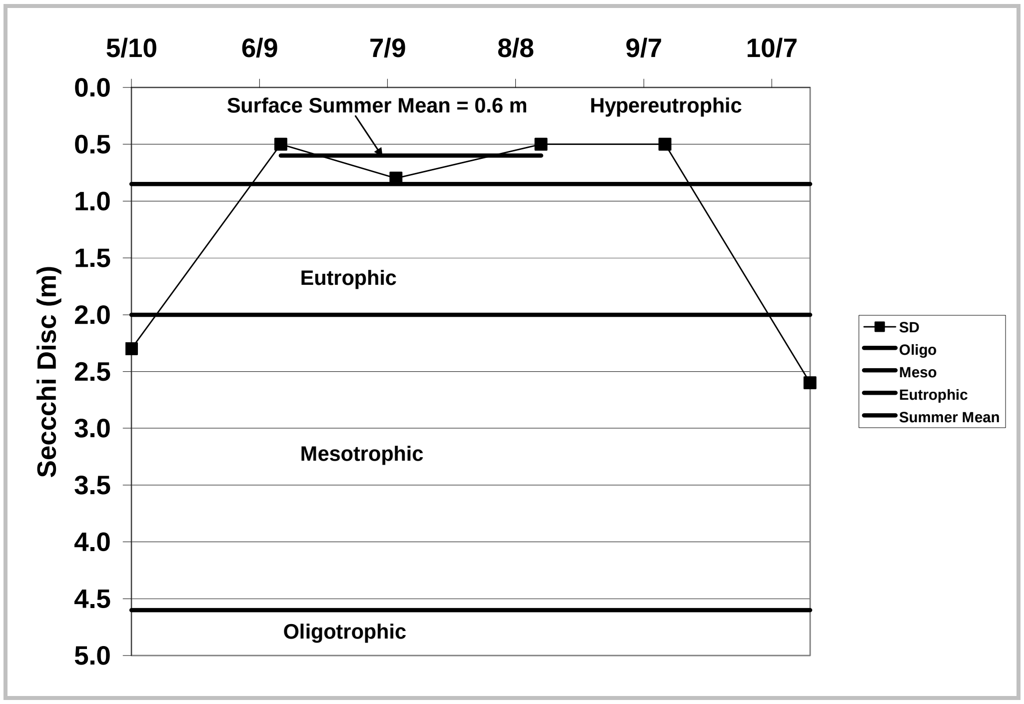


Figure 27 2007 Lake Redstone Secchi Disc Transparency: Northern Site (03)

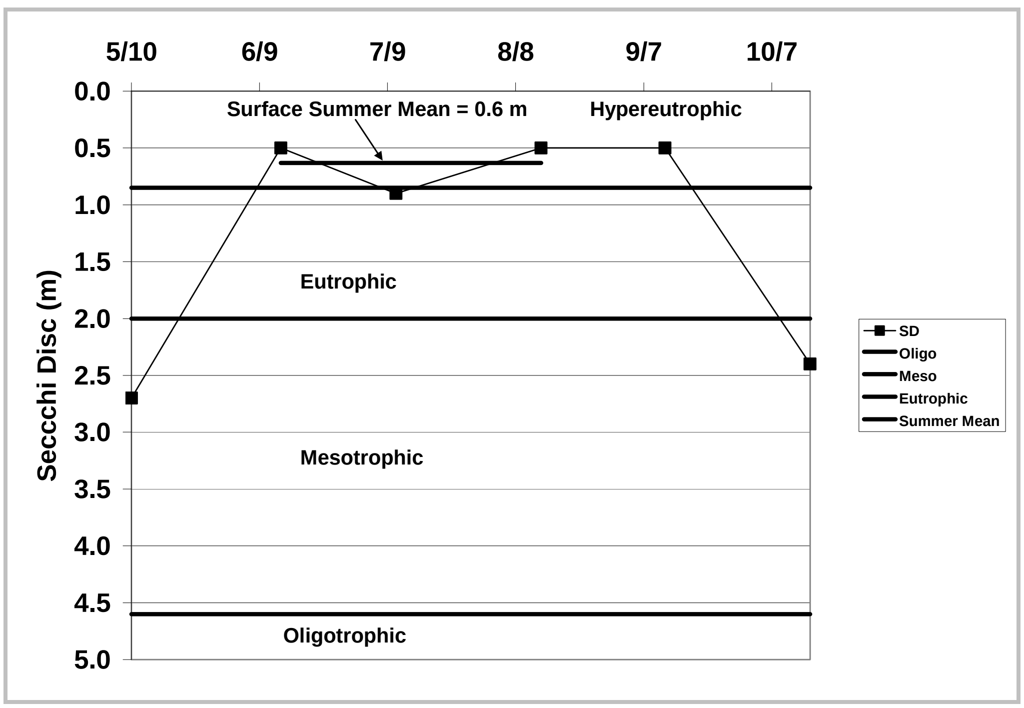


Figure 28 2007 Lake Redstone Secchi Disc Transparency: Middle Site (02

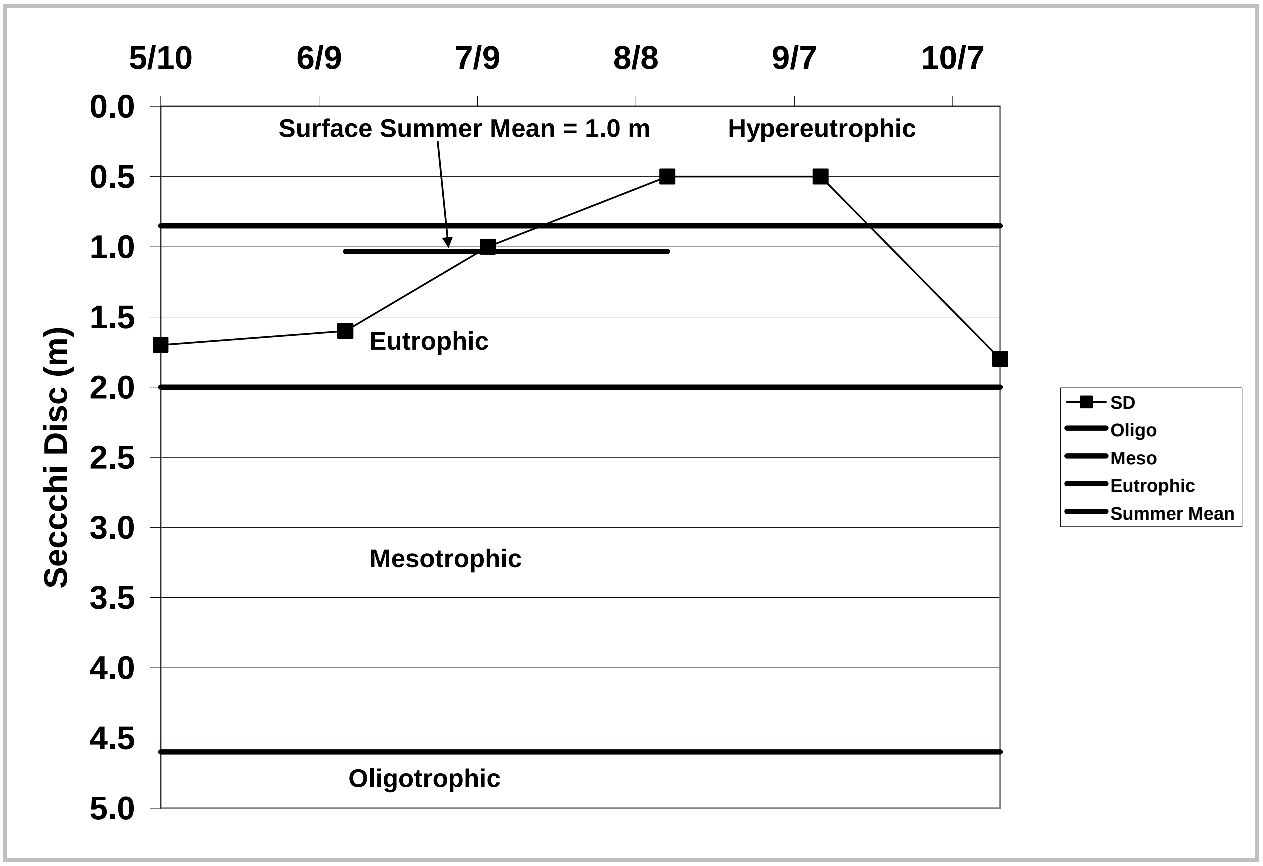


Figure 29 2007 Lake Redstone Secchi Disc Transparency: Southern Site (01

3.6.3 Historical Total Phosphorus, Chlorophyll, and Secchi Disc Transparency

The Lake Redstone Protection District measured Secchi disc transparency from the Northern (03), Middle (02) and Southern (01) sites during 1998 through 2008. Site locations are shown in Figure 1. An assessment of the data indicates Secchi disc water transparency data from Lake Redstone was poorer during 2007 than either 2006 or 2008. 2007 noted the second poorest water transparency of the period of record. In general, poorest water transparency was observed at the north end of the lake, nearest the inflow of West and East Big Creek. Best water transparency occurred at the south end of the lake (Figure 30).

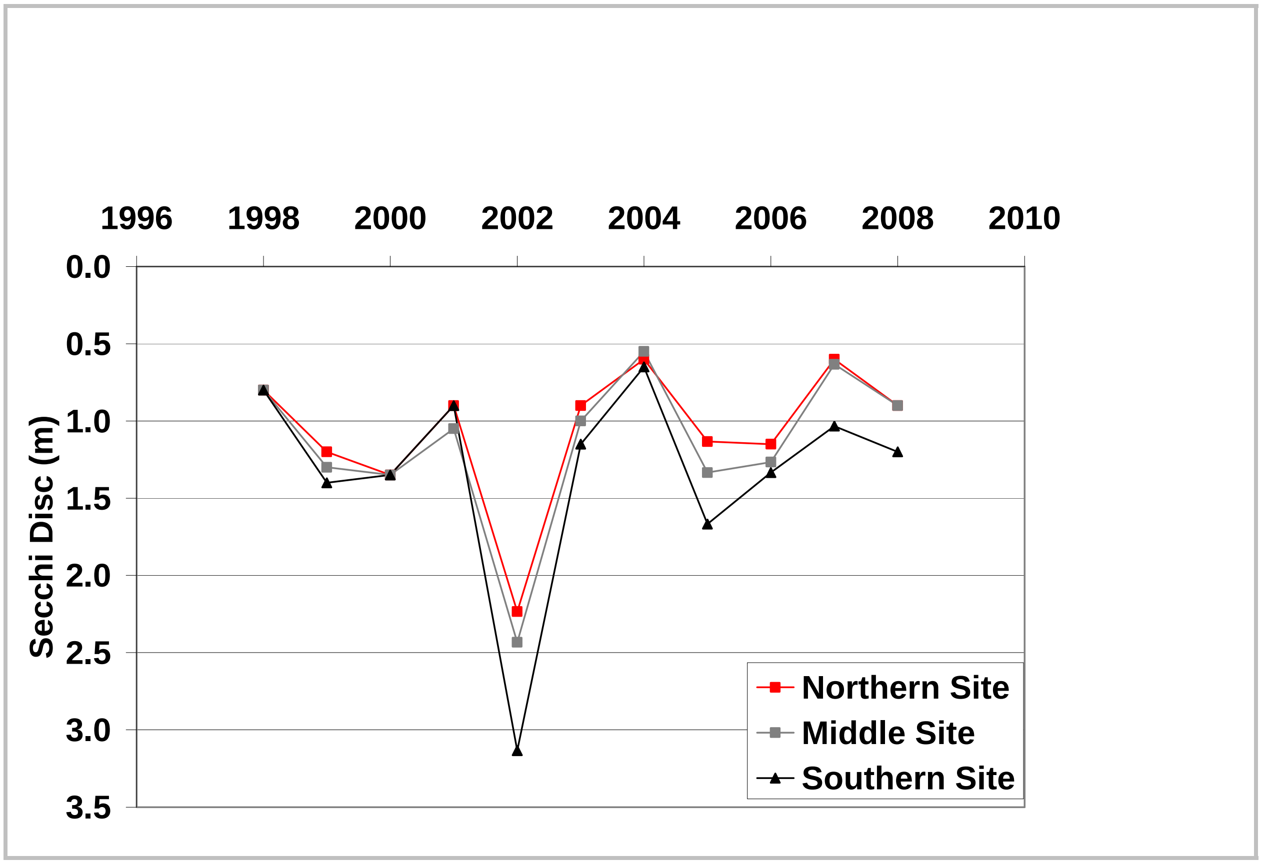


Figure 30 1998-2008 Lake Redstone Summer Mean Secchi Disc Transparency

The Wisconsin Department of Natural Resources (WDNR) monitored total phosphorus, chlorophyll *a*, and Secchi disc transparency at a location near the dam, south of the southern site (01), during the period 1988 through 2007. The site is called deep hole and its location is shown on Figure 1. Summer mean total phosphorus and chlorophyll concentrations and Secchi disc transparency from the deep hole are presented in Figures 31 through 33. The 2007 mean summer total phosphorus concentration in Lake Redstone was the highest concentration observed during the 1988 through 2007 period of record (Figure 31). The data indicate the unusual climatic conditions of 2007 resulted in unusually high total phosphorus concentrations in the lake. The 2007 summer mean chlorophyll concentration was better than the concentration observed in 1996, but poorer than concentrations observed during 1997 through 2000 (Figure 32). The 2007 summer mean Secchi disc transparency was similar to 1996 (Figure 33).

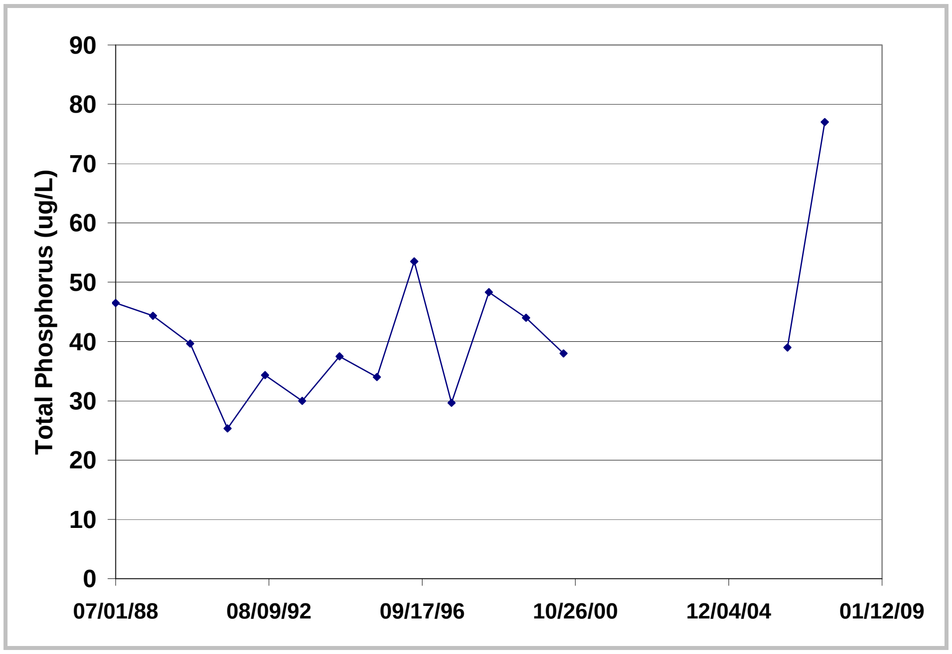


Figure 31 1988-2007 Lake Redstone Summer Mean Total Phosphorus Concentrations (Deep Hole)

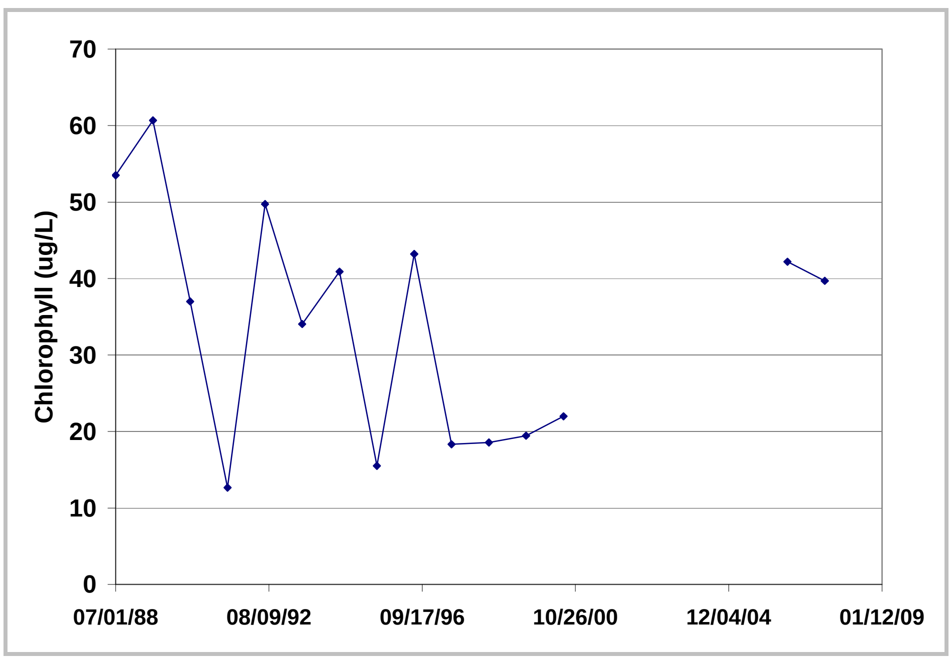


Figure 32 1988-2007 Lake Redstone Summer Mean Chlorophyll Concentrations (Deep Hole)

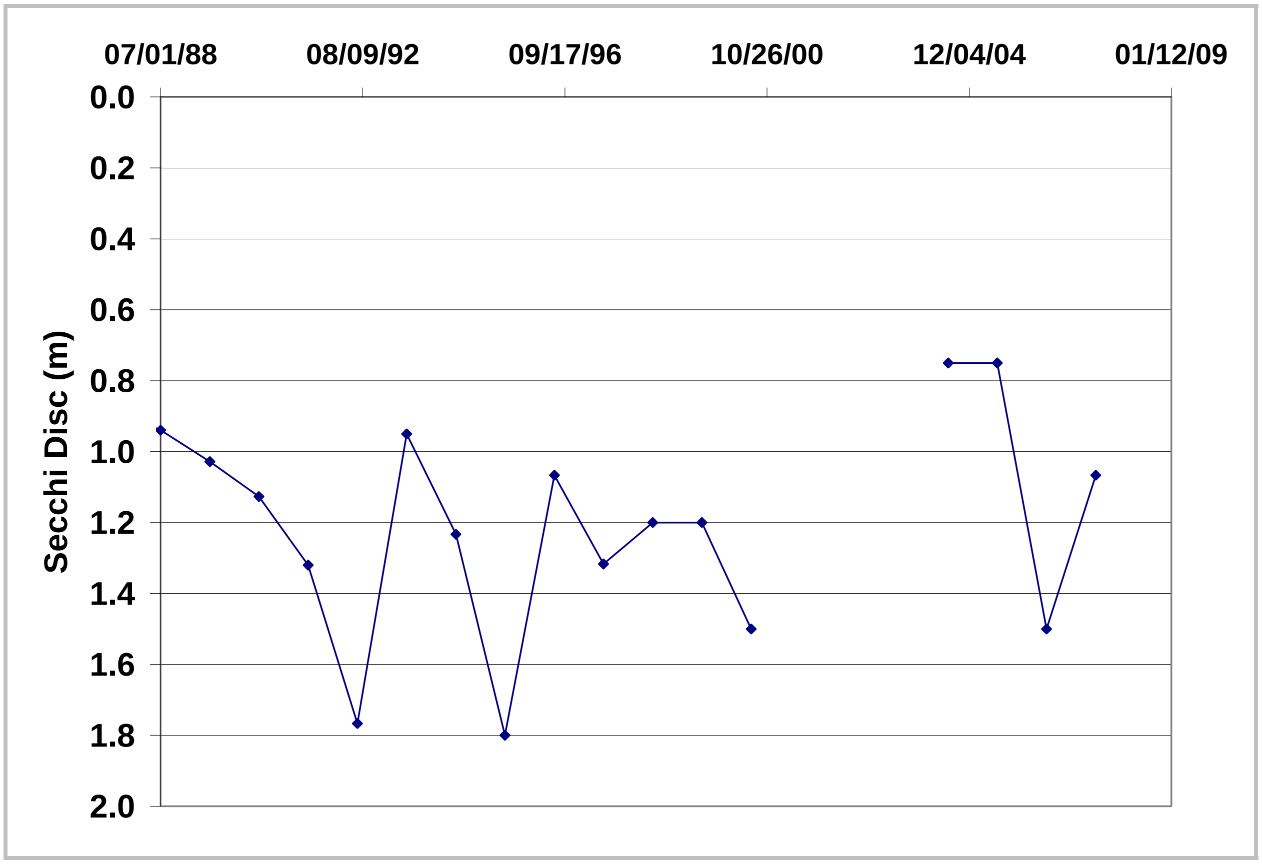


Figure 33 1988-2007 Summer Mean Secchi Disc Transparency (Deep Hole)

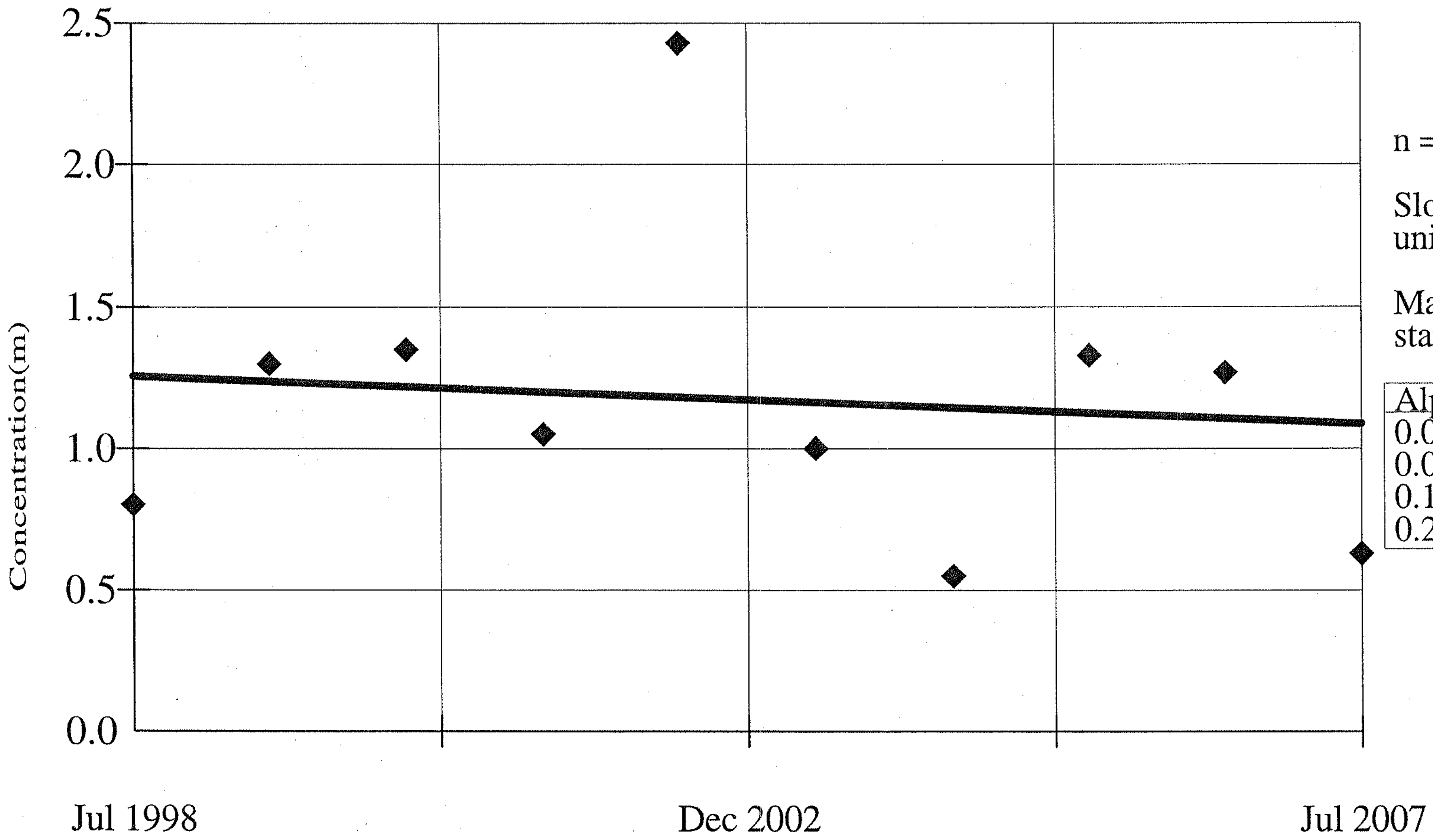
3.7 Trend Analyses

A trend analysis of Lake Redstone data was completed to identify any significant degradation or improvement during years for which water quality data were available. Figures 34 through 36 present the results of trend analyses of Secchi disc data collected from the northern site (Figure 34), middle site (Figure 35), and southern site (Figure 36) during 1998 through 2008. Figures 37 through 39 present the results of trend analyses of total phosphorus, chlorophyll *a*, and Secchi disc data from the deep hole location (WDNR site) during 1996 through 2007. Figures 40 through 42 present the results of trend analyses of total phosphorus, chlorophyll *a*, and Secchi disc data from the deep hole location (WDNR site) during 1988 through 2007.

Although there have been fluctuations in phosphorus levels, chlorophyll *a* levels, and in-lake clarity, it appears that over time the water quality of the lake has remained relatively stable and changes in phosphorus, chlorophyll *a*, and Secchi disc have not been statistically significant (see statistical analysis below in Figures 34 through 42).

Figure 34. Mann-Kendall Trend Analysis of Secchi Disc Transparency Since 1998 for Lake Redstone Northern Site (03)

SEN'S SLOPE ESTIMATOR
Redstone



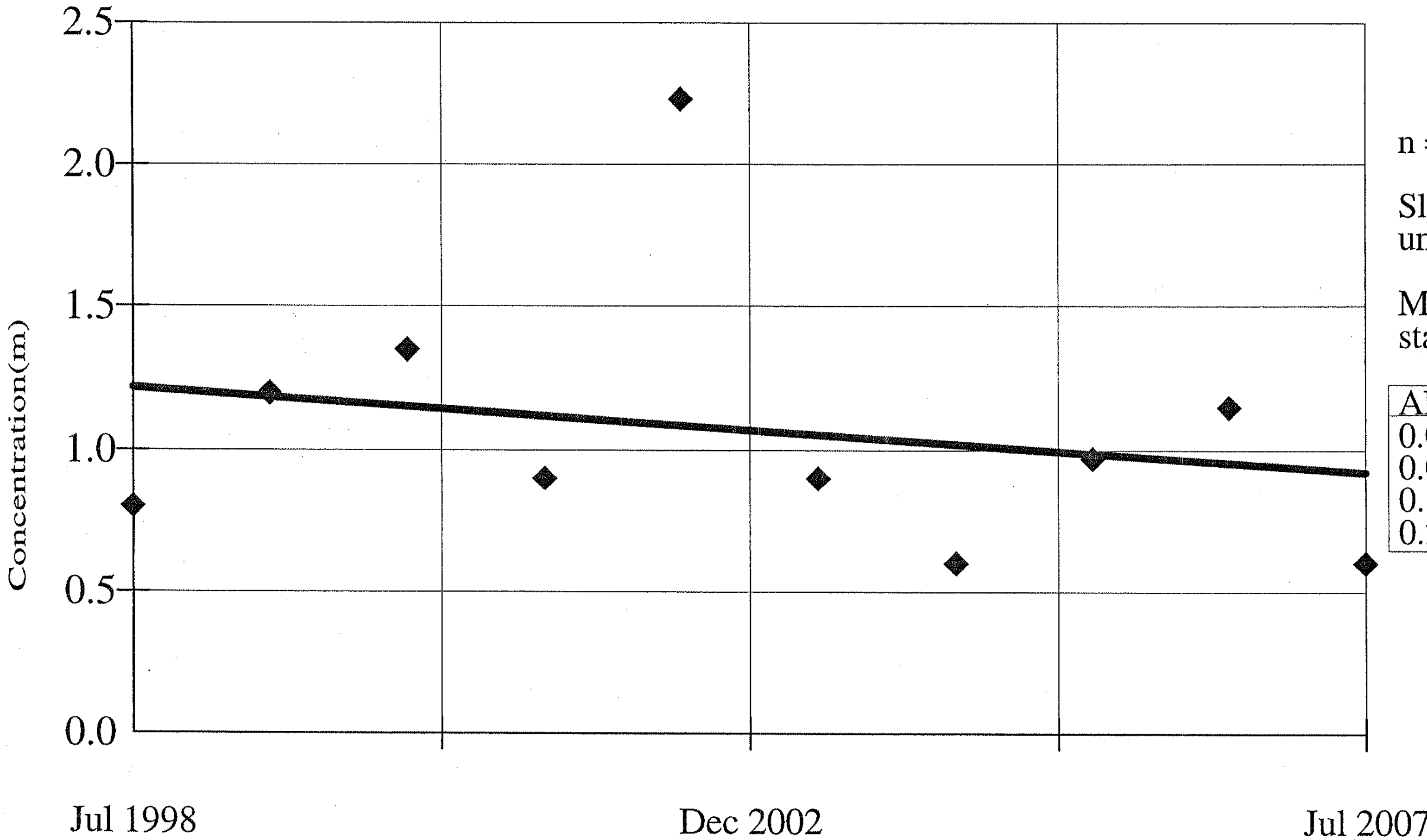
Alpha	Critical	Signif.
0.01	-30	No
0.05	-23	No
0.1	-20	No
0.2	-16	No

Constituent: SD (m)
Facility: Lake Trend Analysis
Data File: REDSTO~2

Date: 6/30/09
Time: 4:17 PM
View: Red2

Figure 35. Mann-Kendall Trend Analysis of Secchi Disc Transparency Since 1998 for Lake Redstone Middle Site (02)

SEN'S SLOPE ESTIMATOR
Redstone



n = 10

Slope = -0.033
units per year.

Mann Kendall
statistic = -7

Alpha	Critical	Signif.
0.01	-30	No
0.05	-23	No
0.1	-20	No
0.2	-16	No

Constituent: SD (m)

Date: 6/30/09

Facility: Lake Trend Analysis

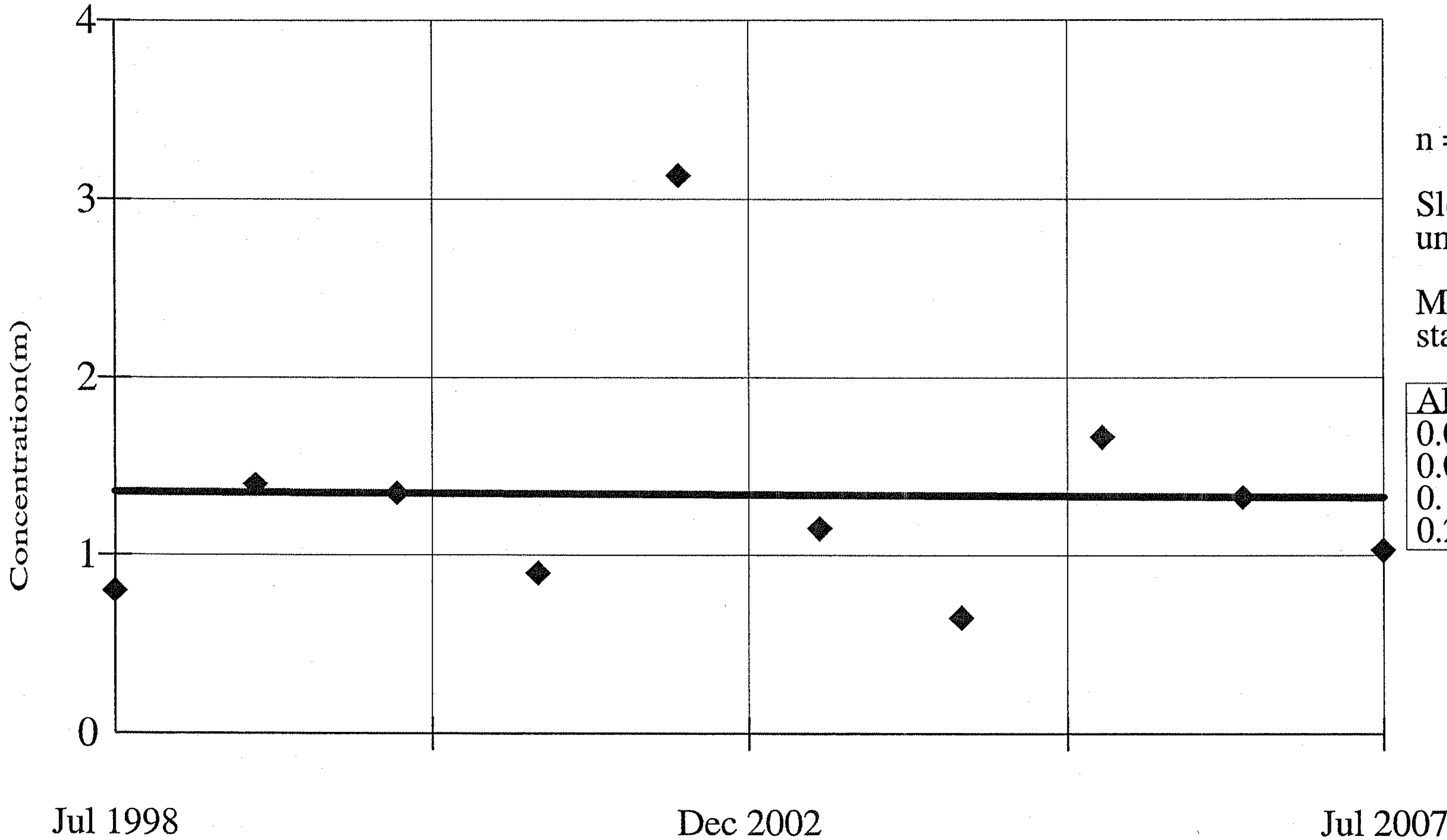
Time: 4:44 PM

Data File: REDSTO~3

View: Red3

Figure 36. Mann-Kendall Trend Analysis of Secchi Disc Transparency Since 1998 for Lake Redstone Southern Site (01)

SEN'S SLOPE ESTIMATOR
Redstone



n = 10

Slope = -0.003 units per year.

Mann Kendall statistic = -1

Alpha	Critical	Signif.
0.01	-30	No
0.05	-23	No
0.1	-20	No
0.2	-16	No

Constituent: SD (m)

Facility: Lake Trend Analysis

Data File: REDSTO~4

Date: 6/30/09

Time: 4:26 PM

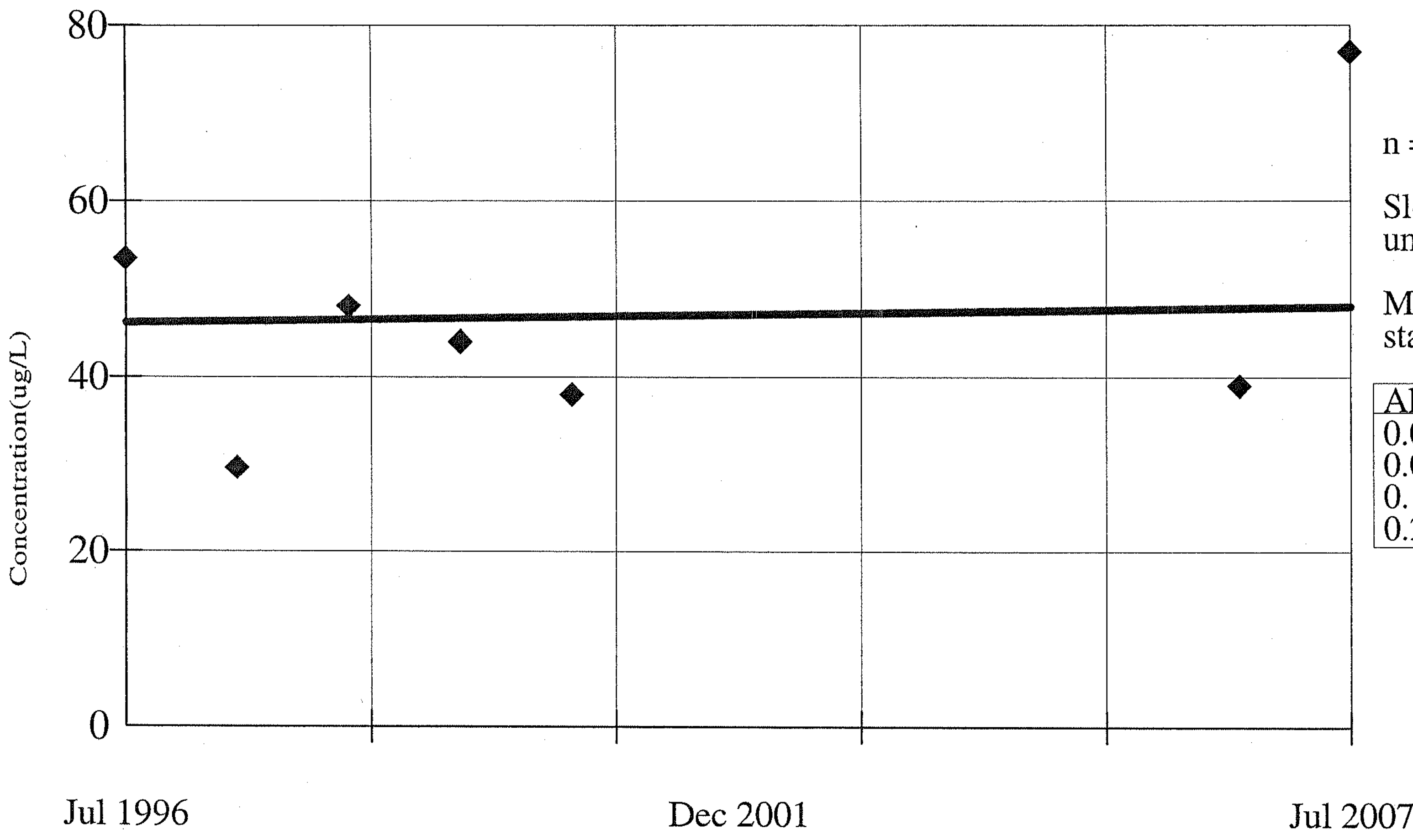
View: red4

v.1.56. CAS# n/a

Figure 37. Mann-Kendall Trend Analysis of Total Phosphorus Concentration Since 1996 for Lake Redstone Deep Hole Site (WDNR)

WQStat Plus™

SEN'S SLOPE ESTIMATOR
Redstone



n = 7

Slope = 0.167 units per year.

Mann Kendall statistic = 1

Alpha	Critical	Signif.
0.01	18	No
0.05	15	No
0.1	13	No
0.2	10	No

Constituent: TP (ug/L)

Date: 6/18/08

Facility: Lake Trend Analysis

Time: 10:54 AM

Data File: REDSTO~1

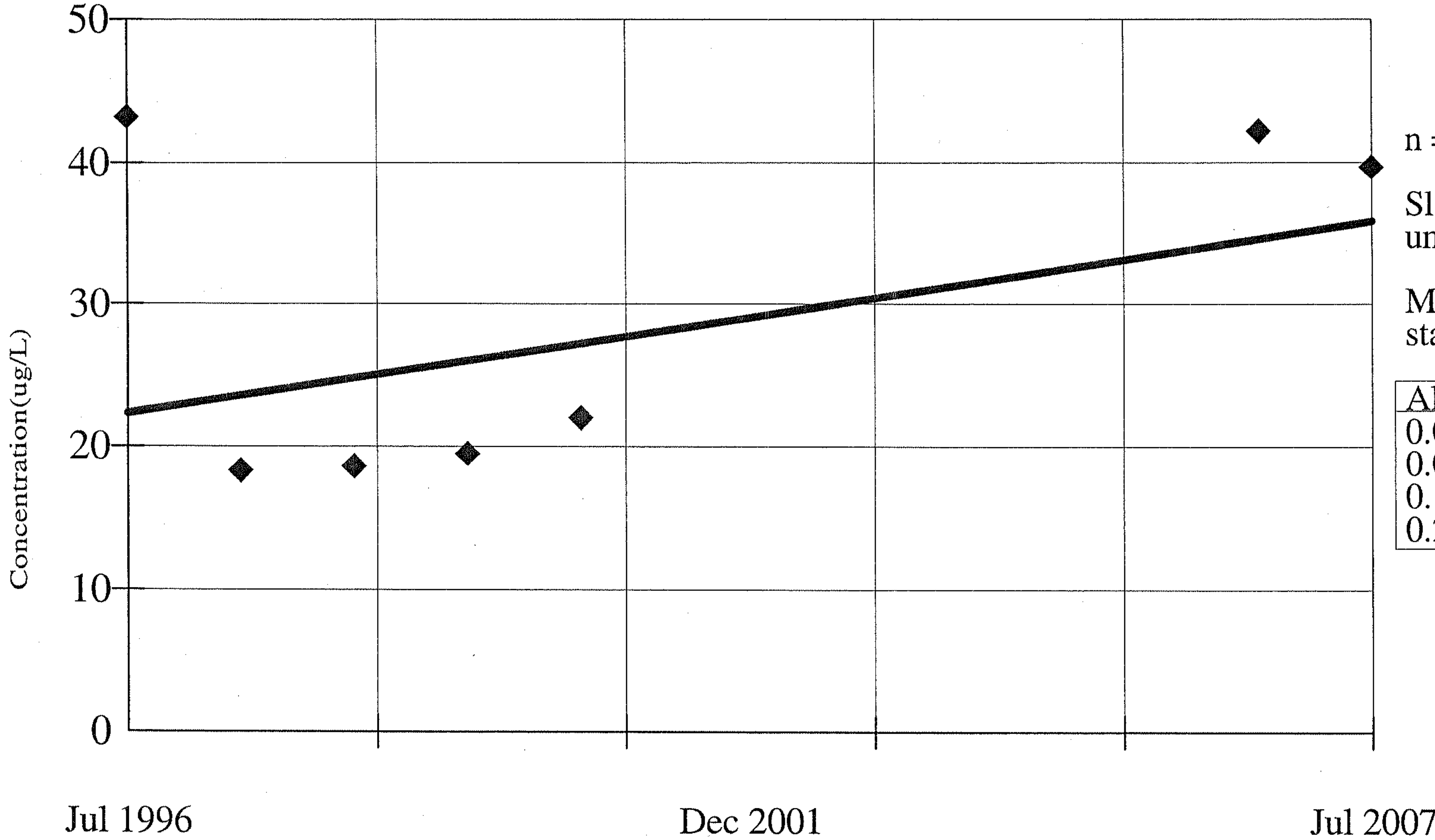
View: TP2

v.1.56. CAS# n/a

Figure 38. Mann-Kendall Trend Analysis of Chlorophyll a Concentration Since 1996 for Lake Redstone Deep Hole Site (WDNR)

WQStat Plus™

SEN'S SLOPE ESTIMATOR
Redstone



n = 7

Slope = 1.232 units per year.

Mann Kendall statistic = 7

Alpha	Critical	Signif.
0.01	18	No
0.05	15	No
0.1	13	No
0.2	10	No

Constituent: Chl a (ug/L)

Date: 6/18/08

Facility: Lake Trend Analysis

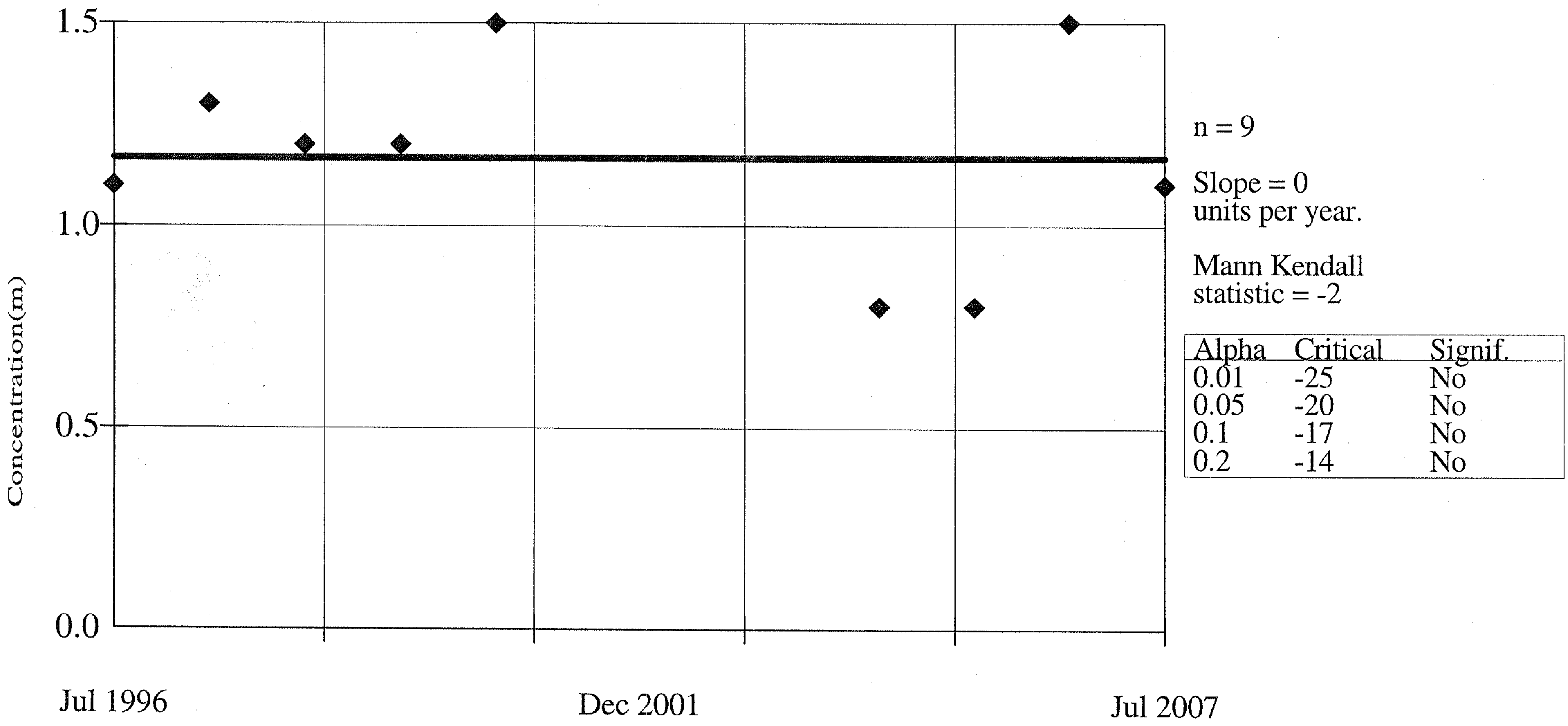
Time: 11:03 AM

Data File: REDSTO~1

View: CHL1

Figure 39. Mann-Kendall Trend Analysis of Secchi Disc Transparency Since 1996 for Lake Redstone Deep Hole Site (WDNR)

SEN'S SLOPE ESTIMATOR
Redstone



Constituent: SD (m)

Date: 6/18/08

Facility: Lake Trend Analysis

Time: 11:04 AM

Data File: REDSTO~1

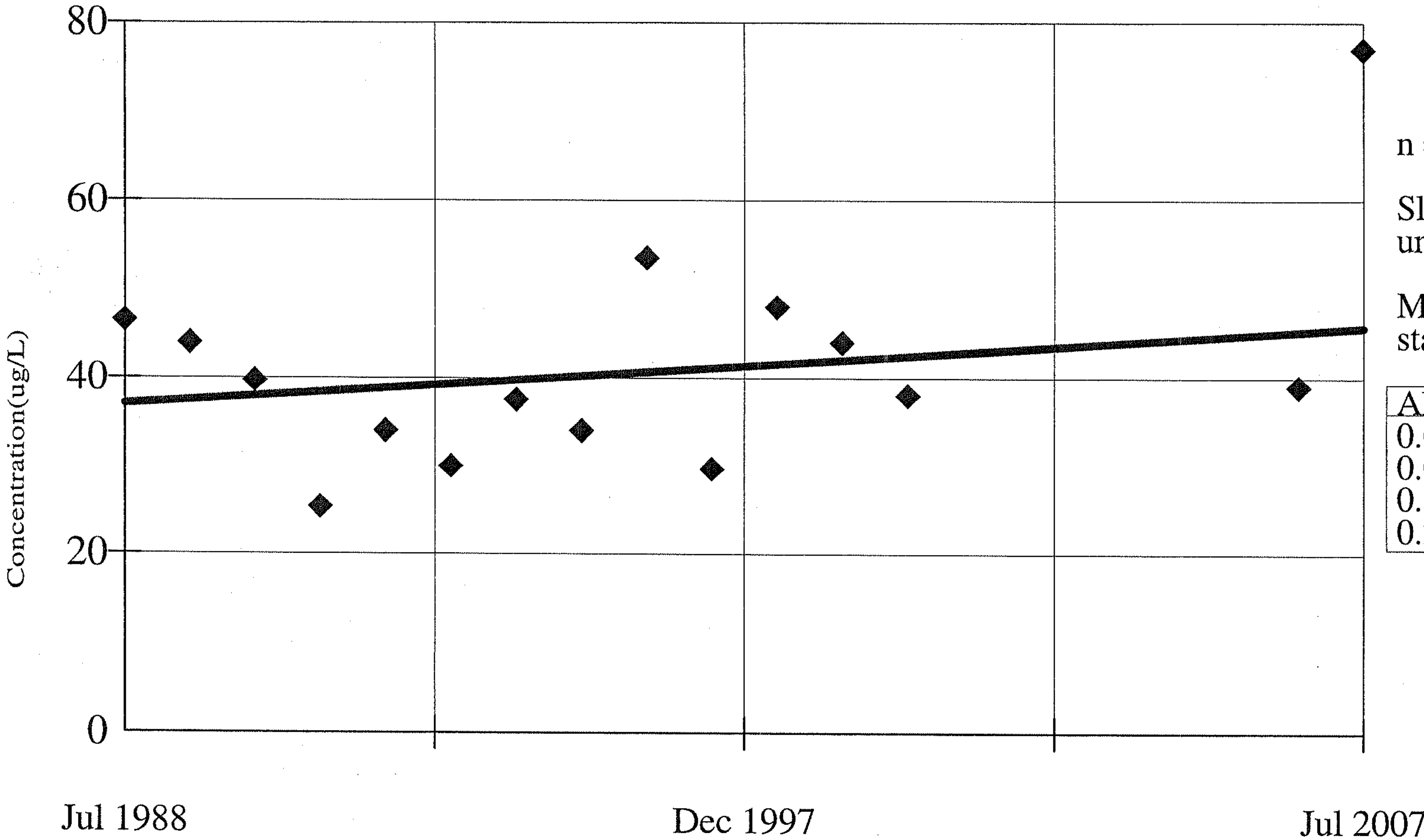
View: SD1

v.1.56. CAS# n/a

Figure 40. Mann-Kendall Trend Analysis of Total Phosphorus Concentration Since 1988 for Lake Redstone Deep Hole Site (WDNR)

WQStat Plus™

SEN'S SLOPE ESTIMATOR
Redstone



n = 15

Slope = 0.454 units per year.

Mann Kendall statistic = 15

Alpha	Critical	Signif.
0.01	53	No
0.05	41	No
0.1	35	No
0.2	28	No

Constituent: TP (ug/L)

Date: 6/18/08

Facility: Lake Trend Analysis

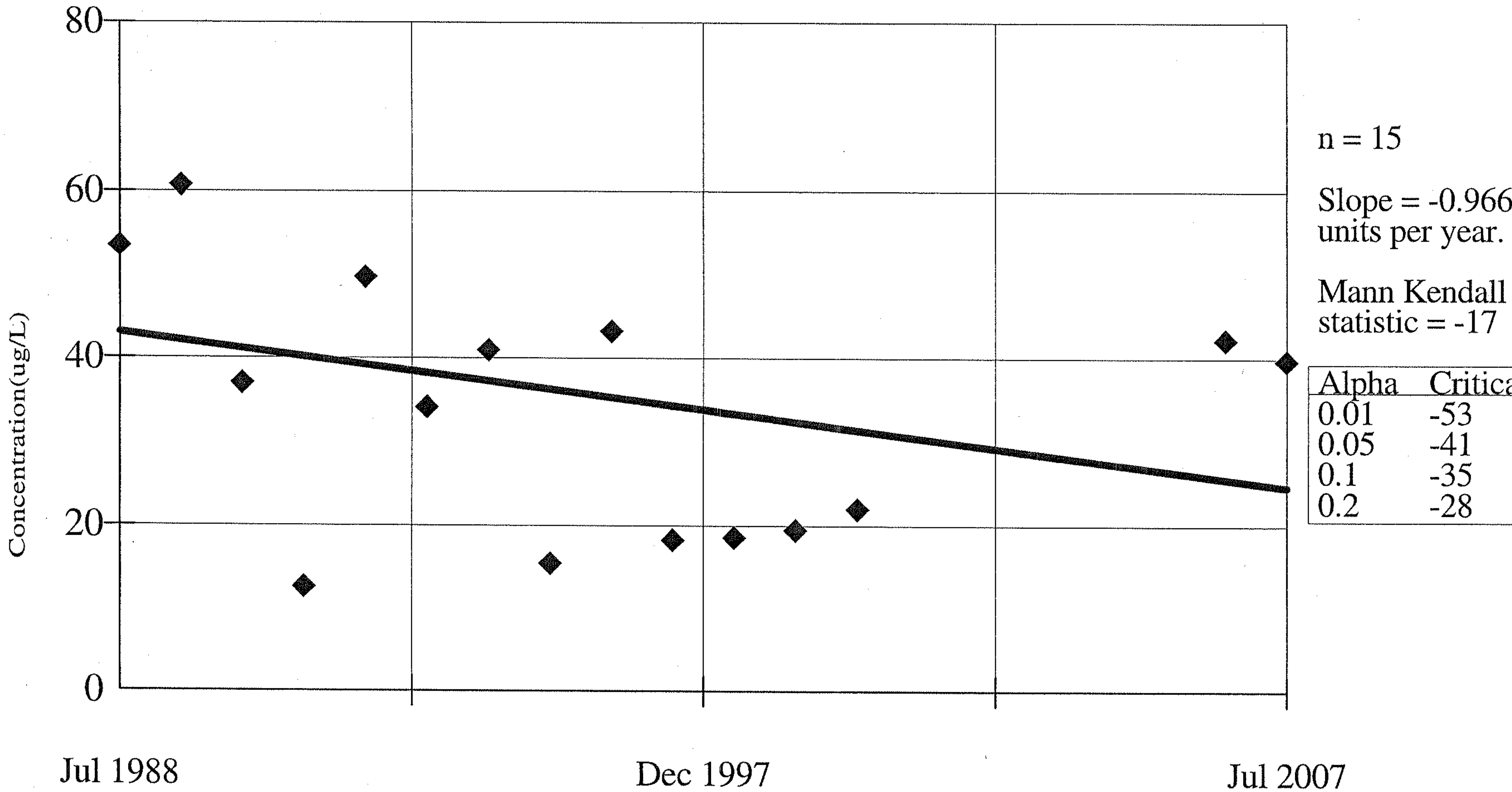
Time: 10:43 AM

Data File: REDSTO~1

View: TP

Figure 41. Mann-Kendall Trend Analysis of Chlorophyll a Concentration Since 1988 for Lake Redstone Deep Hole Site (WDNR)

SEN'S SLOPE ESTIMATOR
Redstone



Alpha	Critical	Signif.
0.01	-53	No
0.05	-41	No
0.1	-35	No
0.2	-28	No

Constituent: Chl a (ug/L)

Date: 6/18/08

Facility: Lake Trend Analysis

Time: 10:52 AM

Data File: REDSTO~1

View: CHL

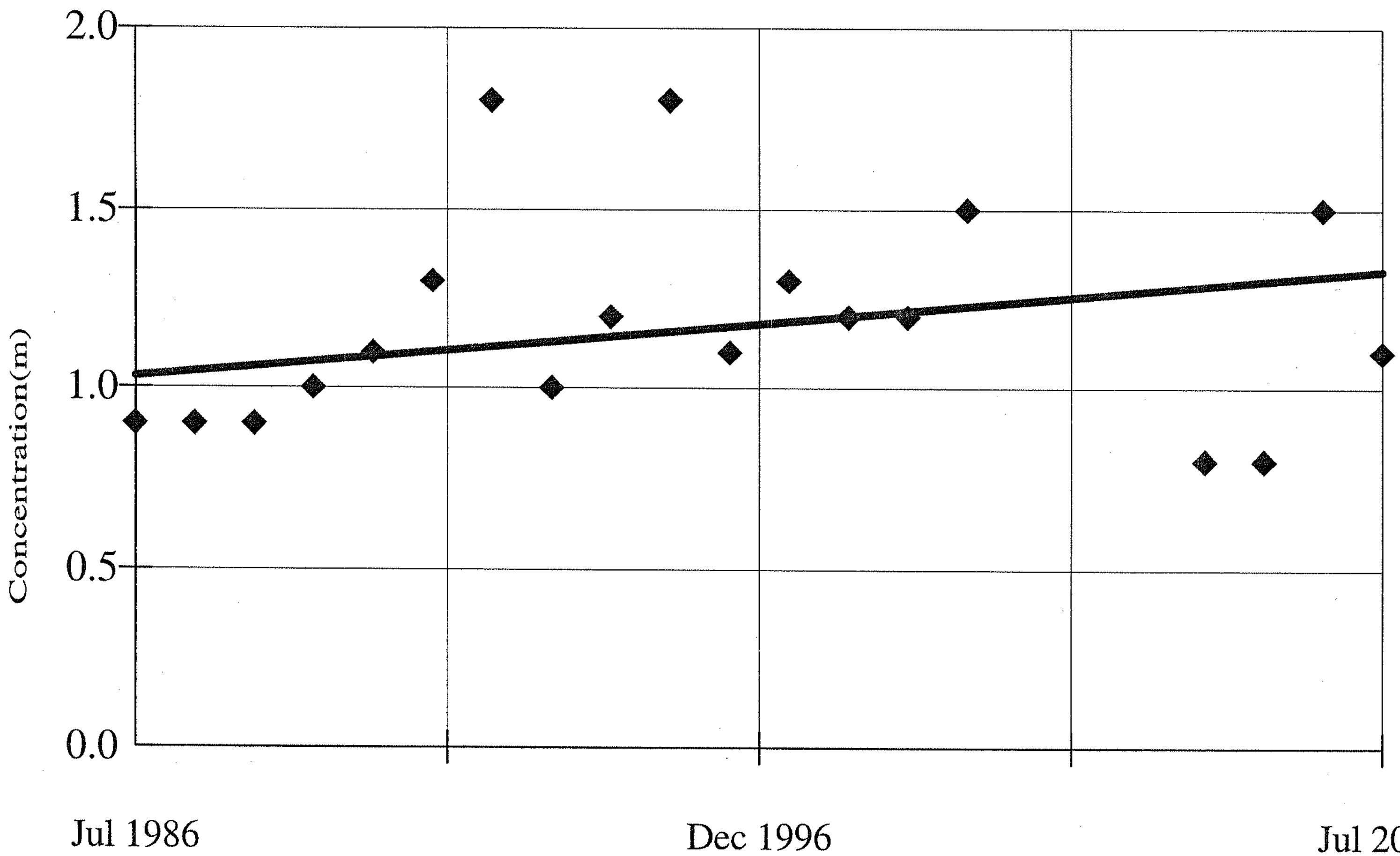
Figure 42. Mann-Kendall Trend Analysis of Secchi Disc Transparency Since 1988 for Lake Redstone Deep Hole Site (WDNR)

v.1.56. CAS# n/a

WQStat Plus™

SEN'S SLOPE ESTIMATOR

Redstone



Alpha	Critical	Signif.
0.01	74	No
0.05	58	No
0.1	49	No
0.2	38	No

Constituent: SD (m)

Facility: Lake Trend Analysis

Data File: REDSTO~1

Date: 6/18/08

Time: 10:53 AM

View: SD

3.8 1996 and 2007 TSI

Total phosphorus, chlorophyll *a*, and Secchi disc transparency are key water quality parameters upon which Carlson's Trophic State Index (TSI) statistics are computed, for the following reasons:

- **Phosphorus** generally controls the growth of algae in lake systems. Of all the substances needed for biological growth, phosphorus is typically the limiting nutrient.

- **Chlorophyll *a*** is the main pigment in algae. Therefore, the amount of chlorophyll *a* in the water indicates the abundance of algae present in the lake.

- **Secchi disc** transparency is a measure of water clarity and is inversely related to the abundance of algae.

The TSI rating system is scaled to place a mesotrophic (medium fertility level) lake on the scale between 40 and 50, and high and low fertility lakes (eutrophic and oligotrophic) toward the high and low ends of the TSI range, respectively. Characteristics of lakes in different trophic status categories are listed below with their respective TSI ranges:

Oligotrophic—[20 ≤ TSI ≤ 38] clear, low productivity lakes, with total phosphorus concentrations less than or equal to 10 µg/L, chlorophyll *a* concentrations less than or equal to 2 µg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet).

Mesotrophic—[38 ≤ TSI ≤ 50] intermediate productivity lakes, with 10 to 25 µg/L total phosphorus, 2 to 8 µg/L chlorophyll *a* concentrations, and Secchi disc measurements of 2 to 4.6 meters (6 to 15 feet).

Eutrophic—[50 ≤ TSI ≤ 62] high productivity lakes, with 25 to 57 µg/L total phosphorus, 8 to 26 µg/L chlorophyll *a* concentrations, and Secchi disc measurements of 0.85 to 2 meters (2.7 to 6 feet).

Hypereutrophic—[62 ≤ TSI] extremely productive lakes, with total phosphorus concentrations greater than 57 µg/L, chlorophyll *a* concentrations greater than 26 µg/L, and Secchi disc measurements less than 0.85 meters (less than 2.7 feet).

In 2007, Lake Redstone mean summer TSI values for total phosphorus and chlorophyll *a* were greater than 62 and in the hypereutrophic category. Mean summer Secchi disc transparency TSI values at the northern and middle sites were greater than 62 and in the hypereutrophic category while values of 60 and 59 at the southern and deep hole sites, respectively, were within the eutrophic category (See Table 3).

Table 3 Lake Redstone 2007 Mean Summer (June Through August) TSI Values

Site	Total Phosphorus (TSI)	Chlorophyll *a* (TSI)	Secchi Disc (TSI)
Northern Site (3)	72	73	67
Middle Site (2)	69	72	67
Southern Site (1)	67	71	60
Deep Hole (0)	67	67	59

2007 Lake Redstone growing season (May through September) observed and modeled (BATHTUB) TSI values are presented in Figures 43 through 45. TSI total phosphorus and chlorophyll *a* values were greater than 62 and in the hypereutrophic category in 2007 while TSI of observed Secchi disc values were less than or equal to 62 and in the eutrophic category.

A comparison of 2007 and 1996 seasonal TSI values indicates poorer water quality occurred in 2007 than 1996. 1996 growing season (May through September) observed and modeled (BATHTUB) TSI values are presented in Figures 46 through 48. TSI chlorophyll *a* and Secchi disc transparency values from the northern site and observed chlorophyll *a* value from the middle site were greater than 62 and in the hypereutrophic category during 1996. However, the TSI total phosphorus value from the northern site, total phosphorus and Secchi disc transparency from the middle site, and all TSI values from the southern site in 1996 were less than 62 and in the eutrophic category.

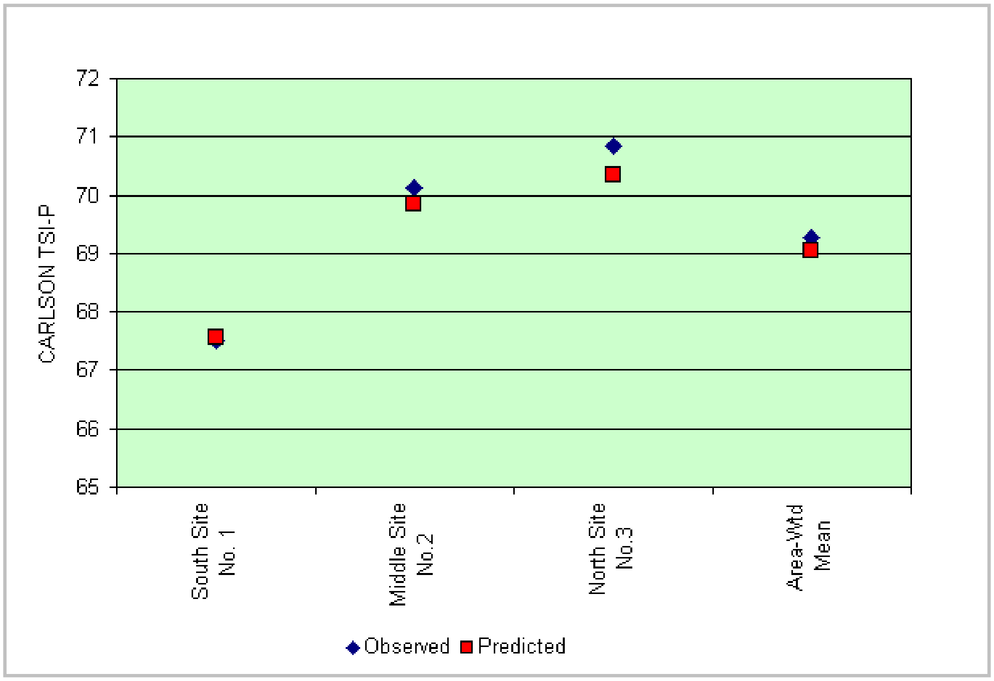


Figure 43 2007 Lake Redstone Seasonal Total Phosphorus TSI

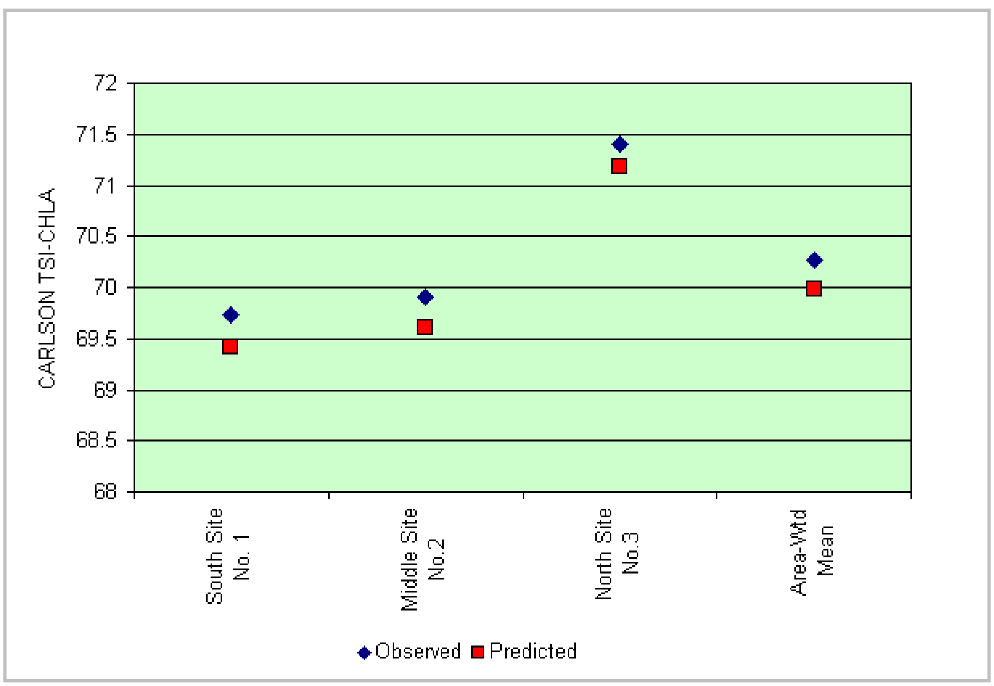


Figure 44 2007 Lake Redstone Seasonal Chlorophyll *a* TSI

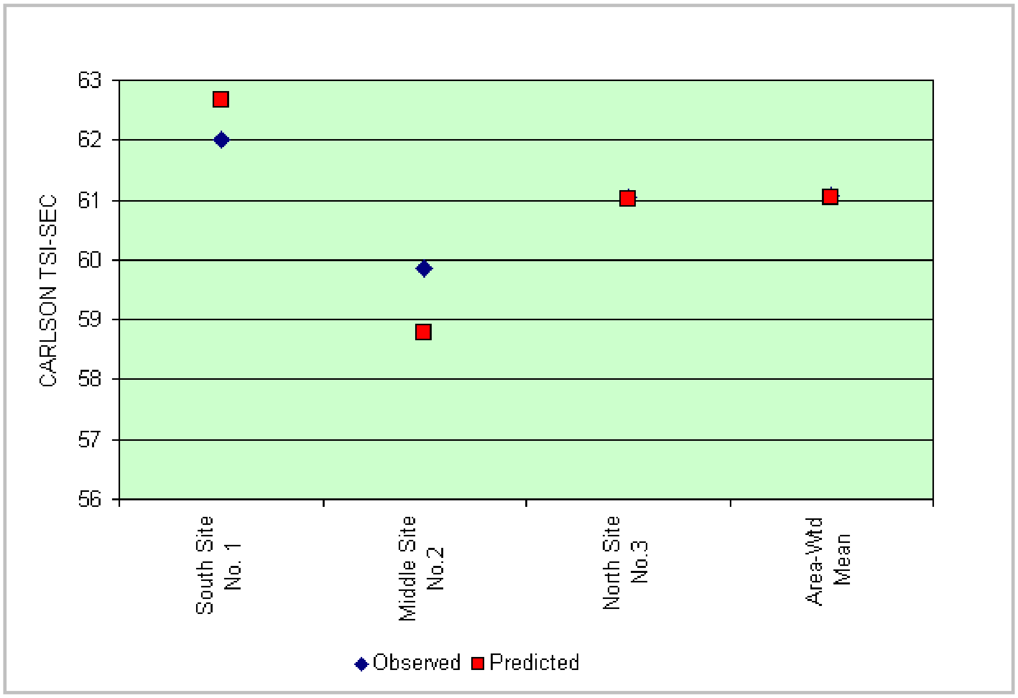


Figure 45 2007 Lake Redstone Seasonal Secchi Disc Transparency TSI

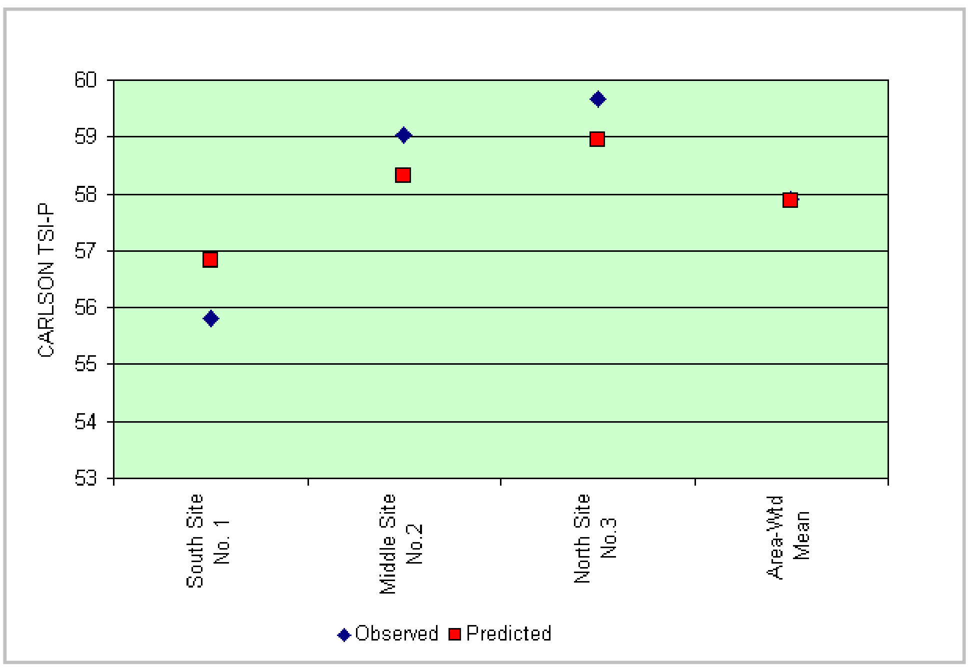


Figure 46 1996 Lake Redstone Seasonal Total Phosphorus TSI

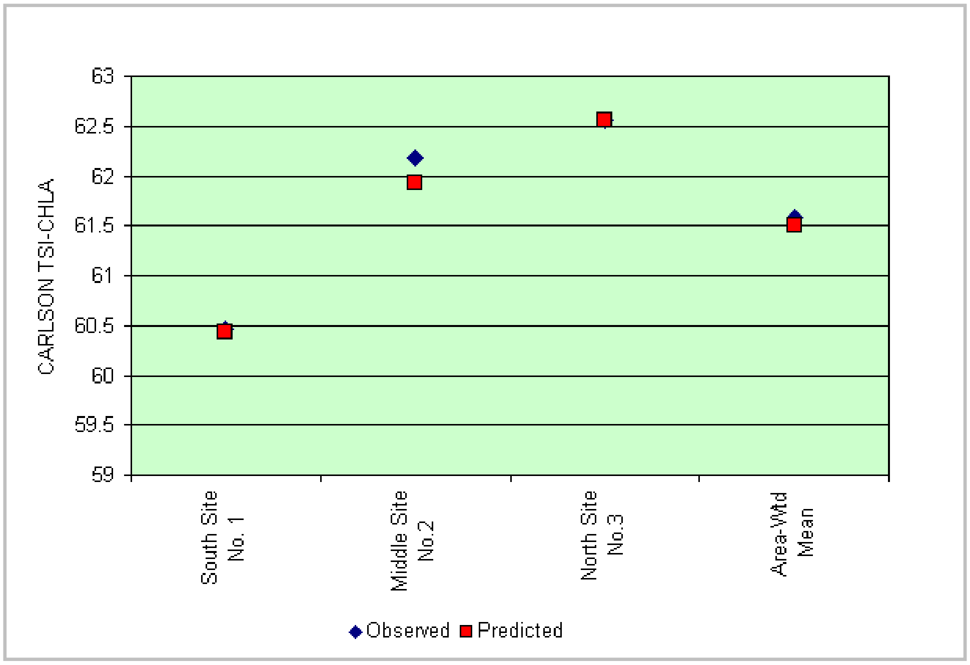


Figure 47 1996 Lake Redstone Seasonal Chlorophyll a TSI

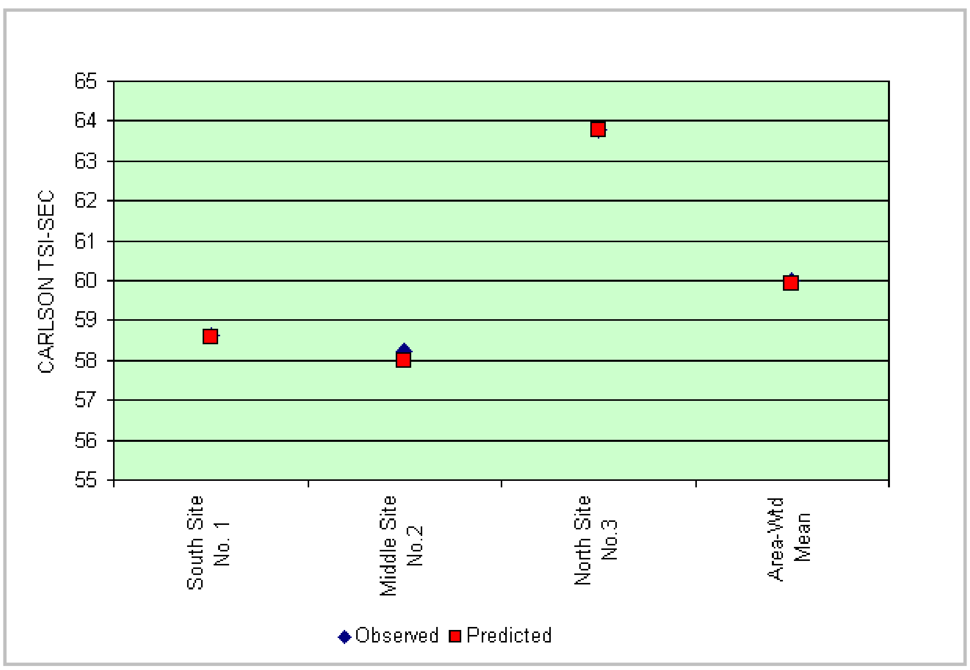


Figure 48 1996 Lake Redstone Seasonal Secchi Disc Transparency TSI

4.0 Model Results: Best Management Practices

4.1 Control Internal Load

In 2007, internal phosphorus loading in Lake Redstone was more than an order of magnitude higher than 1996 and comprised 73 percent of the lake's phosphorus load. Using BATHTUB, a modeling scenario estimated the lake's water quality if 90 percent of the 2007 internal phosphorus load were controlled by an alum treatment. The modeling scenario assumed 2007 watershed and internal phosphorus loading rates applied to 1996 precipitation. The modeled water quality was compared with the 1996 observed water quality. Figures 49 through 51 present the modeled and 1996 observed total phosphorus, chlorophyll *a*, and Secchi disc TSI values. Because both watershed and internal loading were higher in 2007 than 1996, solely controlling internal load would not attain the water quality observed in 1996. Consistent with this expectation, the data indicate the lake's water quality following control of 90 percent of the internal phosphorus load (i.e., 2007 internal load) would, on average, be poorer than 1996 conditions by 1 to 2 TSI units. The northern site would note the largest improvement in water quality following internal load control, consistent with its current status as the site with the highest internal phosphorus load. The southern site would realize the least benefit of internal load control, consistent with its current status of noting very little internal load.

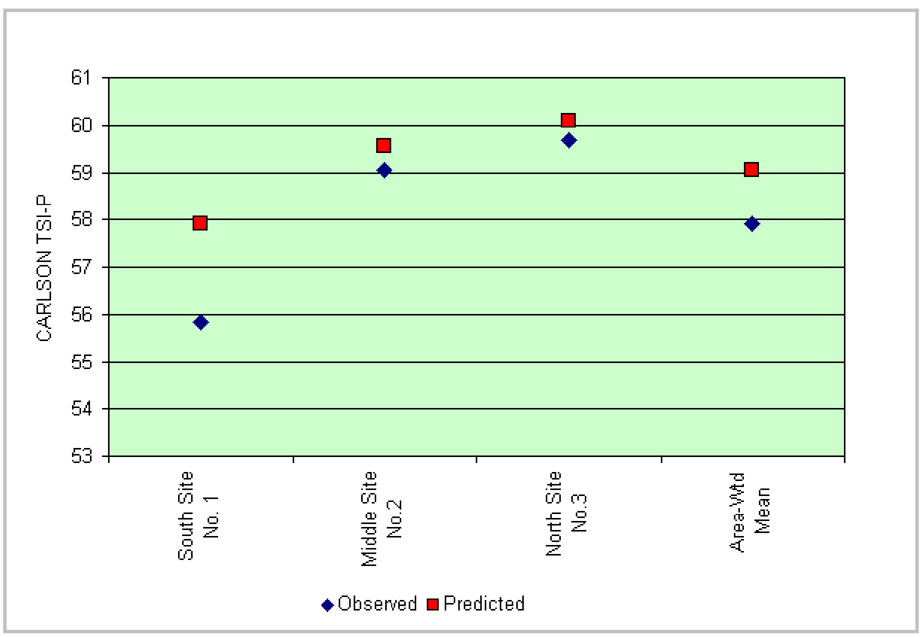


Figure 49 Lake Redstone Seasonal Total Phosphorus TSI: Control Internal Load Scenario

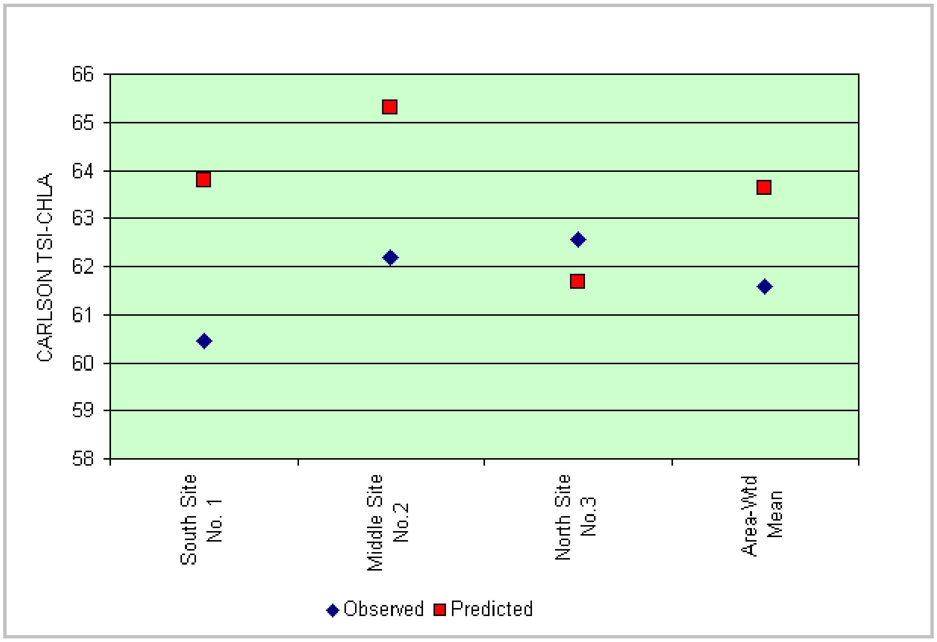


Figure 50   Lake Redstone Seasonal Chlorophyll *a* TSI: Control Internal Load Scenario

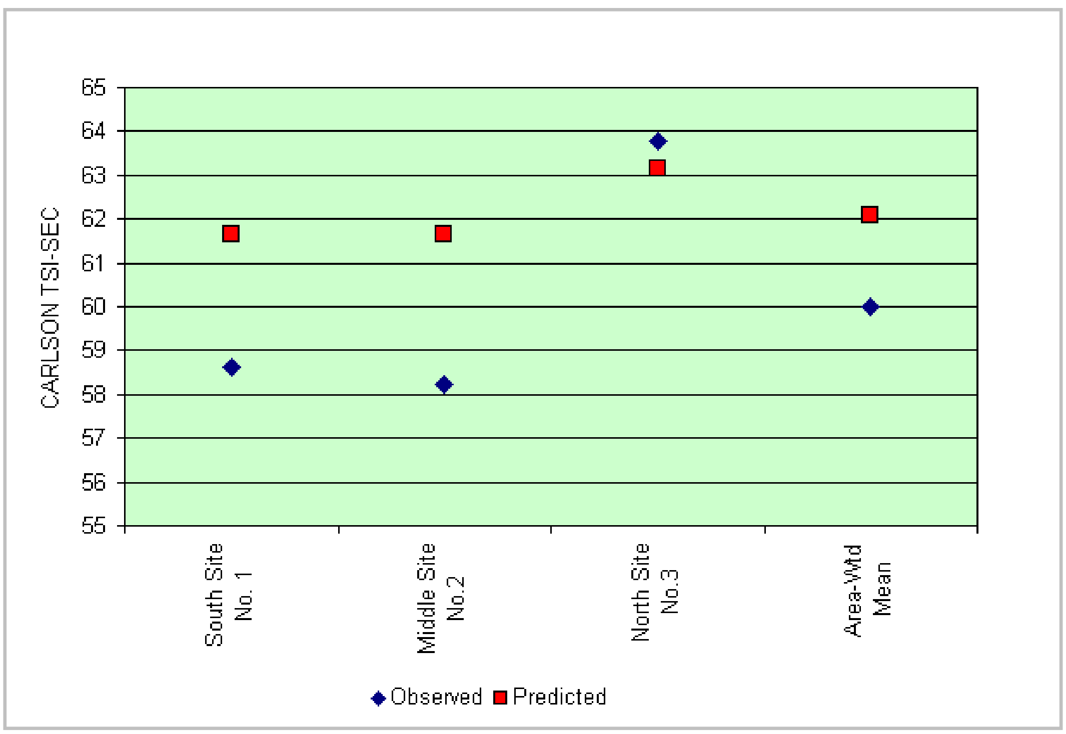


Figure 51   Lake Redstone Seasonal Secchi Disc Transparency TSI: Control Internal Load Scenario

4.2 Control Internal Load and Reduce Loading From West Big Creek Watershed by 65 Percent

In 2007, watershed loading from West Big Creek increased by about 43 percent from 1996 loading rates. As discussed previously, internal phosphorus loading increased by more than an order of magnitude in 2007 from 1996 loading rates. Using BATHTUB, a modeling scenario estimated the lake's water quality if 90 percent of the 2007 internal phosphorus load and 65 percent of the watershed phosphorus load from West Big Creek were controlled. The modeling scenario assumed 2007 watershed and internal phosphorus loading rates applied to 1996 precipitation. The modeled water quality was compared with the 1996 observed water quality. Figures 52 through 54 present the modeled and 1996 observed total phosphorus, chlorophyll *a*, and Secchi disc TSI values. The data indicate the lake's water quality following control of 90 percent of the internal phosphorus load and 65 percent of the watershed phosphorus load from West Big Creek (i.e., 2007 loads) would, on average, be better than 1996 conditions by approximately 1 TSI unit for total phosphorus and poorer by approximately 1 TSI unit for chlorophyll *a* and Secchi disc transparency. The northern site would note the largest improvement in water quality and the southern site would realize the least benefit.

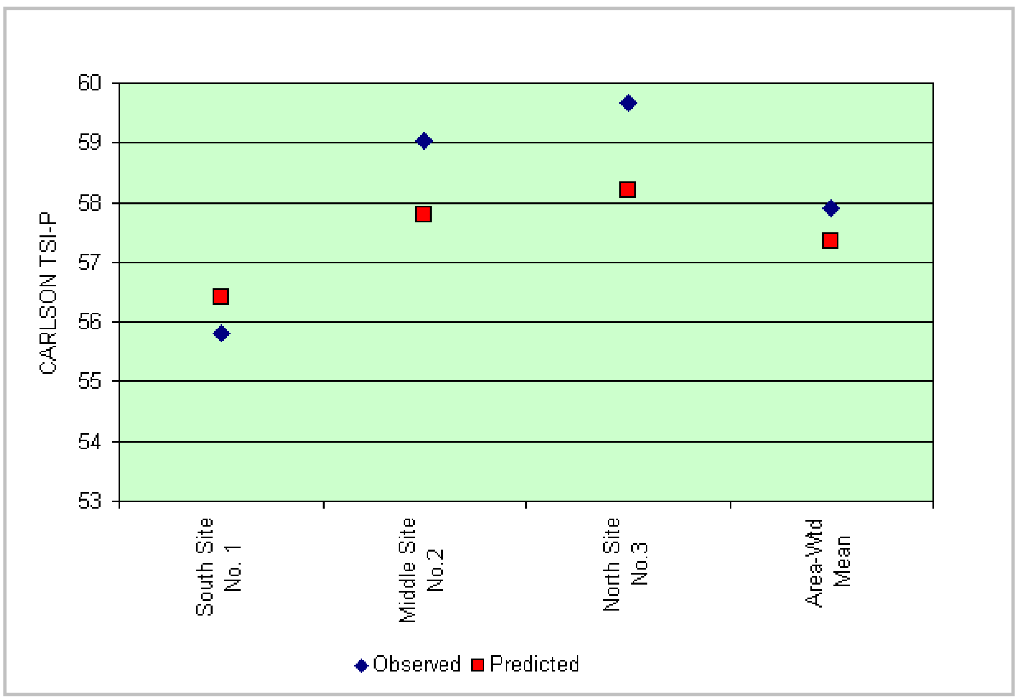


Figure 52 Lake Redstone Seasonal Total Phosphorus TSI: Control Internal Load and Reduce Load From West Big Creek Watershed by 65 Percent

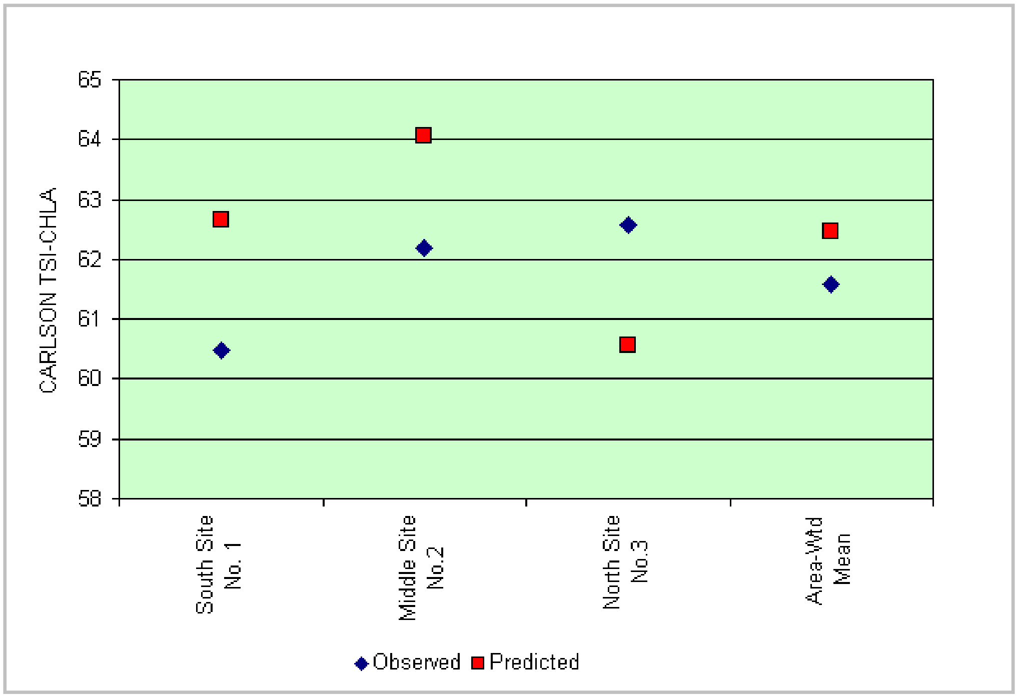


Figure 53 Lake Redstone Seasonal Chlorophyll *a* TSI: Control Internal Load Scenario and Reduce Load From West Big Creek Watershed by 65 Percent

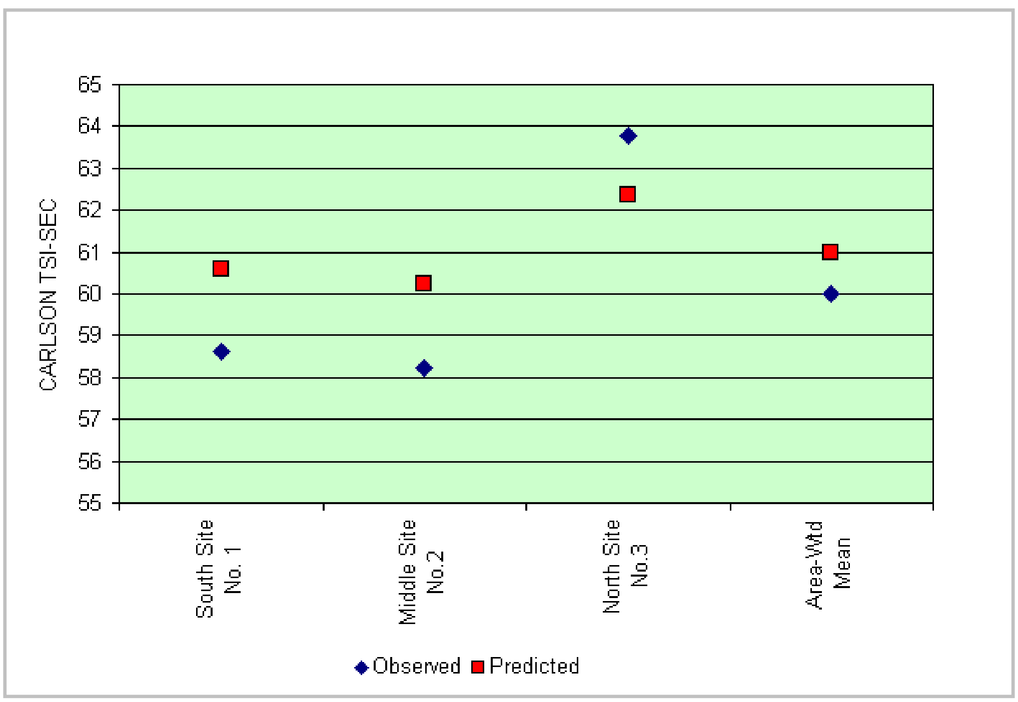


Figure 54 Lake Redstone Seasonal Secchi Disc Transparency TSI: Control Internal Load Scenario and Reduce Load From West Big Creek Watershed by 65 Percent

4.3 Control Internal Load and Reduce Loading From East and West Big Creek Watershed by 65 Percent

In 2007, watershed loading from East and West Big Creek increased by about 35 and 43 percent, respectively, from 1996 loading rates. As discussed previously, internal phosphorus loading increased by more than an order of magnitude in 2007 from 1996 loading rates. Using BATHTUB, a modeling scenario estimated the lake's water quality if 90 percent of the 2007 internal phosphorus load and 65 percent of the watershed phosphorus loads from East and West Big Creek were controlled. The modeling scenario assumed 2007 watershed and internal phosphorus loading rates applied to 1996 precipitation. The modeled water quality was compared with the 1996 observed water quality. Figures 55 through 57 present the modeled and 1996 observed total phosphorus, chlorophyll *a*, and Secchi disc TSI values. The data indicate the lake's water quality following control of 90 percent of the internal phosphorus load and 65 percent of the watershed phosphorus load from East and West Big Creek (i.e., 2007 loads) would, on average, be the same as 1996 conditions (chlorophyll *a* and Secchi disc TSI) or better by approximately 2 TSI units (total phosphorus TSI). The northern site would note the largest improvement in water quality and the southern site would realize the least benefit.

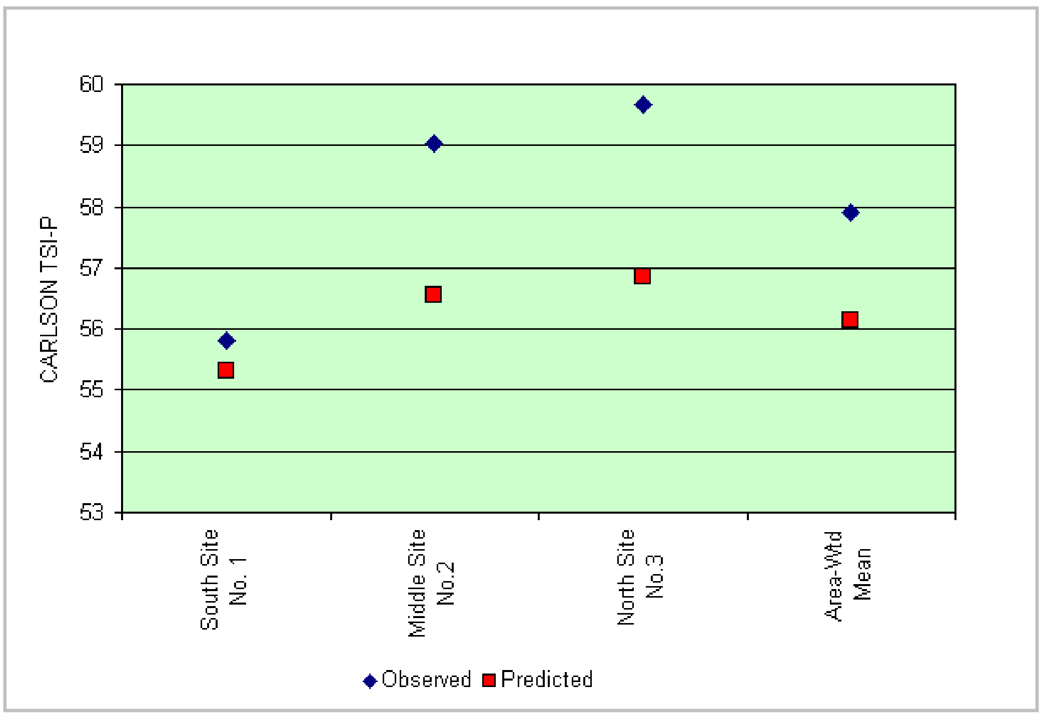


Figure 55 Lake Redstone Seasonal Total Phosphorus TSI: Control Internal Load and Reduce Load From East and West Big Creek Watershed by 65 Percent

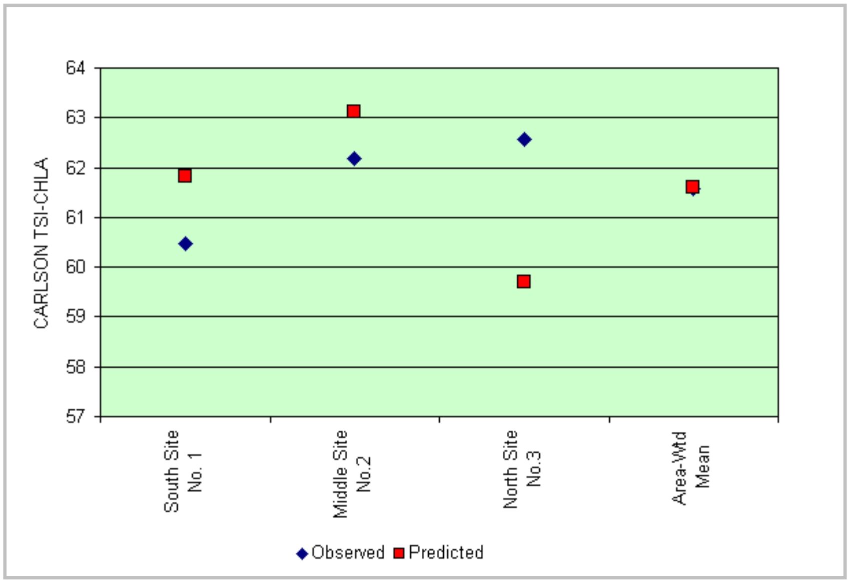


Figure 56 Lake Redstone Seasonal Chlorophyll *a* TSI: Control Internal Load Scenario and Reduce Load From East and West Big Creek Watershed by 65 Percent

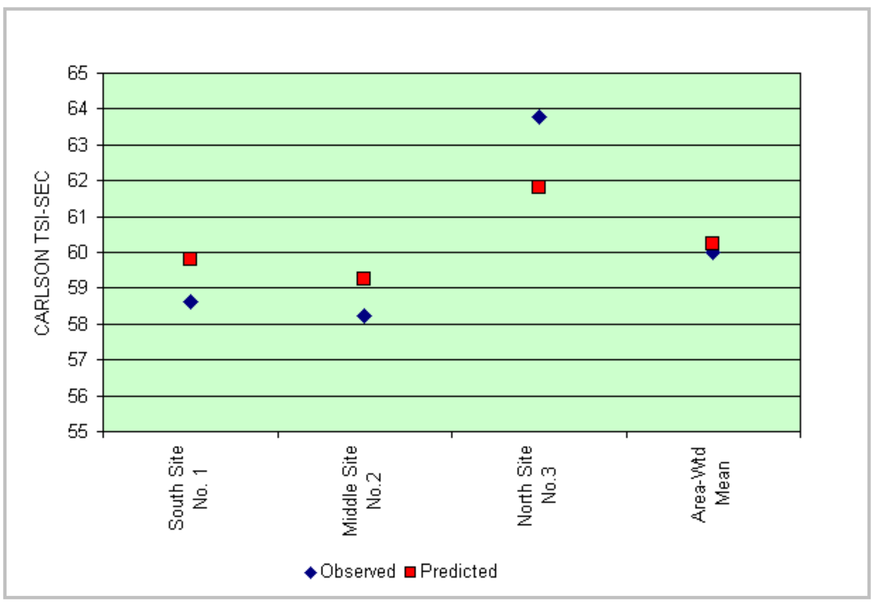


Figure 57 Lake Redstone Seasonal Secchi Disc Transparency TSI: Control Internal Load Scenario and Reduce Load From East and West Big Creek Watershed by 65 Percent

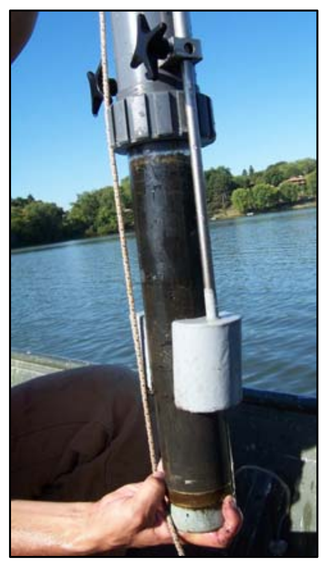
5.0 Recommendations

2007 watershed and lake monitoring and modeling indicate the lake's water quality was poorer in 2007 than 1996. Although trend analyses indicate the change is not significant, the change provides a reason to proactively initiate programs to prevent a significant degradation in the lake's water quality. The primary cause of the water quality change in 2007 was increased internal phosphorus loading, but increased watershed phosphorus loading was also observed. Water quality changes in 2007 are associated with unusual climatic conditions. Nonetheless, the water quality change observed during 2007 indicates a need for the following programs recommended herein:

1. **Sediment Study**
2. **Upgraded Lake Monitoring Program**
3. **Additional monitoring of East and West Big Creek**
4. **Study to determine feasibility of inflow alum treatment facility**

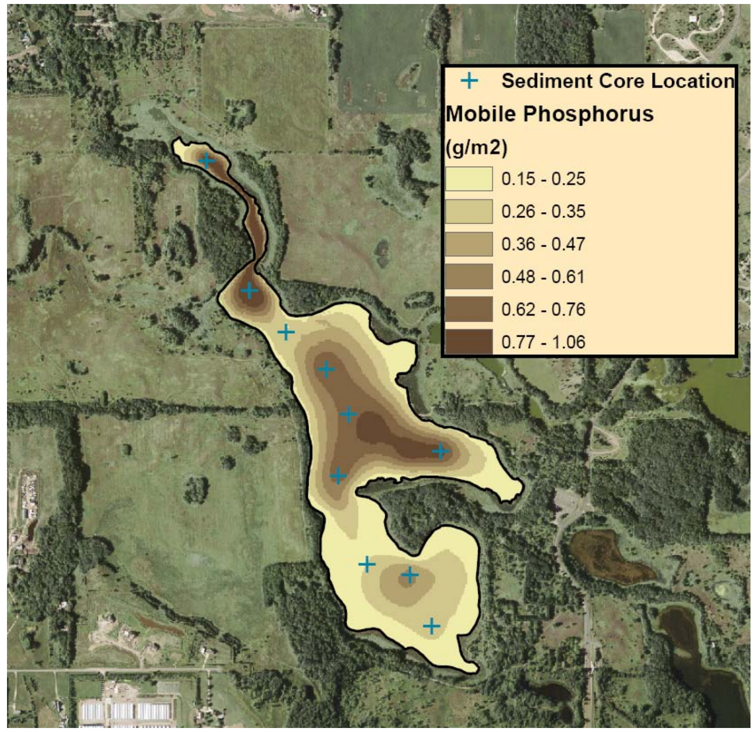
5.1 Sediment Study

A sediment study of Lake Redstone is recommended as the first step toward addressing the lake's internal phosphorus loading problem. Part of the phosphorus entering the lake sinks into the sediment, where it can be released back into the water colum n and be available for uptake by algae. Phosphorus can be released from the sediments during anoxic conditions. The potential for phosphorus release under anoxic conditions will be determined in a sediment study recommended for Lake Redstone.



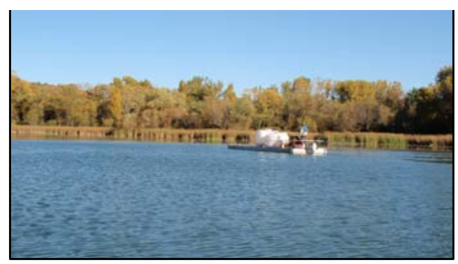
Sediment cores would be analyzed to determine spatial variation in Lake Redstone's sediment.

Because significant spatial variation in sediment phosphorus concentrations is common, samples are collected from several locations within the lake. On average, one sample is collected per 50 to 150 acres of lake surface area. This sample frequency is necessary to accurately determine the spatial variation of phosphorus within a lake at varying water column depths and the corresponding potential for internal phosphorus loading from sediments. The sediment of each core would be sliced into 2 centimeter 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. 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). Using the results from the sediment study, lake-wide internal loading rates can be determined (Pilgrim et al. 2007).

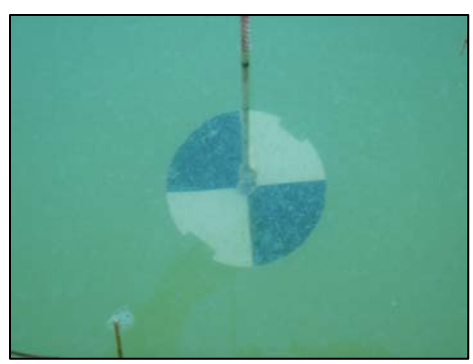


Significant spatial variation in sediment phosphorus concentrations is common as noted in Eagle Point Lake (above).

Phosphorus that already exists in lakes can be treated with alum. A slurry of alum is sprayed into the lake, where the phosphorus in the lake bonds to the alum and sinks to the sediment at the bottom of the lake. In the sediment, the alum bonds to mobile phosphorus. This permanent bond between the mobile phosphorus and the alum traps the phosphorus in the sediment so that it is unable to enter the water. Effective for ten years, alum treatments have been shown to reduce total phosphorus by 50 percent and improve clarity to six meters in Lake Calhoun, a well known lake in Minneapolis, Minnesota. The alum dose required to control internal loading and alum treatment cost would be determined from the Lake Redstone sediment study.



This lake is being treated with alum (above). Alum floc (below) settles to the bottom of the lake, where it binds the phosphorus found in sediment, preventing it from going back into the lake.



5.2 Upgraded Lake Monitoring Program

Lake Redstone Protection District currently monitors temperature, dissolved oxygen, and Secchi disc transparency from three locations monthly during the growing season and also collects a winter sample to monitor conditions during the ice-in period. Upgrading the current program to include total phosphorus and chlorophyll *a* and increasing sample frequency to twice per month during May through September is recommended. It is recommended that total phosphorus samples be collected from 2 feet from the surface and 2 feet from the bottom. Chlorophyll *a* samples would be collected two feet from the surface. The additional data would be used by the Lake Redstone Protection District to determine year-to year changes in the lake's water quality as well as long-term trends.

5.3 Additional Monitoring of East and West Big Creek

Past monitoring studies of East and West Big Creek have involved the collection of data from a single location near the point where each branch of the stream flows into Lake Redstone. While the data indicate the total phosphorus load to the lake, sources of phosphorus within the watershed are not pinpointed. A monitoring program that involves the collection of data from multiple locations along each stream is recommended to better understand phosphorus sources from the watershed and where best to focus future District efforts to reduce phosphorus loading to Lake Redstone.

5.4 Study to Determine Feasibility of Inflow Alum Treatment Facility

One option to improve lake water quality is preventing the phosphorus from reaching the lake in the first place. One method to achieve this is constructing an inflow alum treatment facility on the West Branch of Big Creek and possibly a second facility on the East Branch of Big Creek. Inflow alum treatment facilities take water from the creek and pump it to a pond, where alum is added. When alum enters water it forms large flakes that attract phosphorus. The heavy flakes then settle to the bottom of the pond, removing the sediment, dissolved, and total phosphorus from the water before it enters the lake. (Periodically, this pond is cleaned out). The treated water then flows into Lake Redstone.

Alum is stored in the pictured tank (above). The phosphorus remains in this pond (below).

Completion of a feasibility study to determine both the technical and economic feasibility of either one alum treatment facility on West Big Creek or an alum treatment facility on both East and West Big Creek is recommended.

6.0 References

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