LAKE OKEECHOBEE WATERSHED LONG-TERM WATER QUALITY TRENDS PROJECT

Long-term Water Quality Trends in the Lake Okeechobee Watershed, Florida

Joyce Zhang[1,*], Patricia Burke[1], Nenad Iricanin[1], Steven Hill[1], Susan Gray[1], and Richard Budell[2]
[1] South Florida Water Management District, West Palm Beach, Florida
[2] Florida Department of Agriculture and Consumer Services, Tallahassee, Florida
*Corresponding author, Phone: 561-682-6341, Fax: 561-640-6815, Email: jzhang@sfwmd.gov

Abstract

A Seasonal Kendall Tau test was used to determine statistical significance of mean monthly total phosphorus (TP) and total nitrogen (TN) concentration trends during the time period of 1991 to 2007, by station and basin at 35 long-term water quality monitoring stations located within the northern Lake Okeechobee watershed. One drainage basin (S-154) had a significant decreasing trend for mean monthly TP concentrations during the analysis period. A significant increase in TN concentrations was detected for four basins during this same time period. The S-154 basin which had the significant decreasing trend for TP also had the highest percentage of implemented Best Management Practices (BMPs) and the most rigorous types of nutrient control projects. These findings emphasize the need for continued implementation of intensive P management strategies. The increasing trend in TN for this watershed signals the need for added focus on reductions of TN in future nutrient source control projects and BMPs.

Keywords: Phosphorus; Nitrogen; Nutrient management; BMPs; Land use; Trend analysis

1. Introduction

Lake Okeechobee, the largest freshwater lake in the southeastern United States, is located in south central Florida. The watershed of Lake Okeechobee encompasses an area of approximately 14,000 km^2. Over the past 30 years, the lake has experienced accelerated eutrophication due to excessive nutrient loads from agricultural and urban activities that dominate land use in the watershed (Boggess et al., 1995; Flaig and Havens, 1995; Hiscock et al., 2003). Phosphorus (P) is of particular concern in this watershed because it has been identified as the key element that contributes to the eutrophication of the lake (Davis and Marshall, 1975; Federico et al., 1981). Total P (TP) loads were 558 metric tons (t) per year (yr) averaged over the water years 2004 to 2008 (May 2004 to April 2008), which is about three times higher than the Total Maximum Daily Load (TMDL) of 140 t/yr considered necessary to achieve the in-lake TP target of 40 parts per billion (ppb) by 2015 (FDEP, 2001).

Despite a long history of regulatory and voluntary incentive-based programs to control P inputs into Lake Okeechobee, no substantial reduction in loading to the lake occurred during the 1990s. Internal loadings due to wind-driven resuspension of P rich muck within the lake also have contributed to the declining health of the lake (James et al., 2008). In 2000, the Florida legislature passed the Lake Okeechobee Protection Act (LOPA) [Section 373.4595, Florida Statutes], mandating that the lake TMDL of 140 t/yr be met by 2015 and that the coordinating agencies work together to implement an aggressive program to address the issue of excessive TP loading. In 2007, the Florida legislature amended LOPA to include the protection of the Caloosahatchee and St. Lucie River watersheds and estuaries. Section 373.4595, Florida Statues is now known as the Northern Everglades and Estuaries Protection Program (NEEPP), which promotes a comprehensive, interconnected watershed approach to protecting these water bodies.

The South Florida Water Management District (SFWMD or the District), Florida Department of Environmental Protection (FDEP), Florida Department of Agriculture and Consumer Services (FDACS), and the U.S. Army Corps of Engineers (USACE) have worked cooperatively to undertake an array of state and federal projects in the watershed to reduce TP loading (SFWMD et al., 2007; SFWMD et al., 2008). Watershed projects, along with on-site agricultural and urban Best Management Practices (BMPs), have begun to be implemented to reduce P transport from uplands and capture runoff during high rainfall periods. Examples of the most commonly implemented types of BMP's in the Lake Okeechobee watershed include the fencing of cattle to exclude them from waterways and wetland areas, improvements to on-site storm water management systems and the installation of on-site retention facilities.

In 2000, the District also initiated the Dairy Best Available Technology (BATs) program in an effort to implement the most advanced source control technologies available to reduce TP discharge from dairy operations. The most effective technology is the edge-of-farm stormwater treatment, which calls for the reuse of all runoff if possible and the chemical treatment (e.g. Alum flocculation) of any runoff that must be discharged. Total P reduction rates for this technology ranges from 66 to 100% based on data collected from 2004 to 2008 (SWET, 2008b).

A comprehensive research and assessment program for water quality in the watershed is conducted by the SFWMD, in cooperation with FDEP and FDACS, to evaluate the effectiveness of specific agricultural BMPs and other water management alternatives in reducing P loads (Zhang et al., 2009). The SFWMD has monitored the inflows to Lake Okeechobee at the District-operated control structures and maintained an extensive water quality monitoring network in the Lake Okeechobee watershed since 1972 (Figure 1). These data were used to evaluate the effectiveness of BMPs and TP reduction projects that have been implemented so far. The level of actual implementation of BMPs is calculated based on when funding is provided to individual land owners. It is important to note that actual BMP construction projects may not be completed until one year after funding was received and thus the total effect of the implementation of the BMPs may be delayed.

Water quality data for 1977 through 2001 were summarized by Medri et al. (2003). Two periods were considered in that study: The pre-BMP period from 1977 to 1990, and the post-BMP transition period from 1991 to 2001. The study used data collected from 24 tributary stations located in the four drainage basins: S-191, S-154, S-65D, and S-65E (Figure 1). These four basins are named as priority basins due to their higher contribution of P loads to Lake Okeechobee (SFWMD, 1997). Results showed that there was a general decline in P loads and concentrations discharged to Lake Okeechobee, but the trend was not continued for the S-191, S-65D, and S-65E basins for the post-BMP transition period from 1991 to 2001 (Medri et al., 2003). The nutrient control projects implemented prior to 1991 were primarily focused on the dairies in the watershed and the initial reductions in P were seen immediately due to the closing of several of these large scale operations in the watershed, mostly in the S-154 basin. The lack of a trend in three of the priority basins from 1991 to 2001 could be due to the fact that the BMPs implemented had not yet had time to take effect on the downstream water quality and also to the minimum level of BMPs actually implemented during that time.

The study presented in this article expands on previous work by including additional data from 2002 to 2007, as well as data from 51 tributary stations within the lake's northern hydrologic basins (Figure 1) that have been monitored since 1991. Statistical summaries were also developed for the period of 2002 to 2007 when BMP measures were intensified and more resources were provided for nutrient control projects within the watershed under LOPA. Though water quality restoration strategies have primarily focused on the reduction of P in the watershed, the availability of a long-term data set for nitrogen (N) gave us the opportunity to see the trends occurring for another nutrient of concern. The study objectives were to determine baseline conditions and long-term water quality trends for TP and total N (TN) concentrations, and to assess the relationships between these trends and the current land use, the level of BMP implementation, and the presence of P source control projects within each basin's hydrologic boundary. This study used BMP implementation percentages that were based on basin acreage totals where construction of cost share BMPs was complete, or a plan for operational BMP changes had been implemented. These analyses were used to determine the impact of various projects implemented thus far in reducing nutrient loads to Lake Okeechobee.

2. Materials and Methods

2.1 Water Quality Monitoring

The District's current monitoring network is configured to function on three spatial levels: 1) basin monitoring for flow, TP, TN, and other parameters at control structures discharging directly to Lake Okeechobee (loading stations); 2) sub-basin or tributary monitoring at 35 stations for both TP and TN concentrations in key locations that contribute disproportionately large P loads within the northern Lake Okeechobee drainage basins (ambient monitoring stations); and 3) farm-level monitoring at 16 dairy stations for TP concentrations (Figure 1).

The basin level monitoring stations have calculated loads that can be linked to the water quality conditions summarized for this study at the individual tributary locations. The tributary monitoring network is a long-term, ambient monitoring network in the Lake Okeechobee watershed. The network consists of 27 sampling locations within the four priority basins and eight sampling stations along the Kissimmee River within basins S-65A and S-65BC (Figure 1). Due to cost constraints and the logistics of installing reliable flow instrumentation, the tributary monitoring network only provides nutrient concentrations (as well as other chemical concentration data), and does not enable the calculation of nutrient loads at the tributary level. The sampling protocol for the 27 tributary stations is to collect bi-weekly grab samples regardless of flow conditions and the Kissimmee River stations are sampled monthly. Data collection at the 16 stations located at outfalls from the dairy operations began in the mid-1980s in response to the implementation of the FDEP Dairy Rule. These land-use related monitoring data remain a critical tool in providing information to identify the most effective strategies for reducing P discharges from these operations.

2.2 Basin Characteristics

Land use in the northern part of the Lake Okeechobee watershed is primarily agricultural (46%) and mostly improved pasture. Basins S-65A and S-65BC are located immediately south of Lake Kissimmee with a drainage area of 41,825 hectares (ha) and 72,894 ha, respectively (Zhang et al., 2009). Four monitoring stations are located along the Kissimmee River in basin S-65A, and four stations are located along the river in basin S-65BC (Figure 1).

The drainage basins S-154, S-191, S-65D, and S-65E, make up the four priority basins in the Lake Okeechobee watershed. Basin S-154 has a drainage area of 12,796 ha. The primary land use in this basin is agriculture, including improved and unimproved beef pastures; several dairy farms in the basin have ceased operation or being converted to residential land use. The S-154 basin has four tributary monitoring stations and one dairy station. Due to its size and the numbers of monitoring stations, basin S-191 is further divided into two sub-basins: Taylor Creek (S-191TC) and Nubbin Slough (S-191NS). The S-191TC and S-191NS sub-basins have drainage areas of 27,276 ha and 21,592 ha, respectively. The land use distribution is similar to the S-154 basin, but the majority of the dairy farms in these two sub-basins remain in operation. Sub-basin S-191TC contains eight tributary stations and four dairy stations, while sub-basin S-191NS has six tributary stations and six dairy stations. The S-65E basin covers an area of 11,799 ha with major land uses including beef pasture, citrus grove, row crop, and dairy. The S-65E basin has four tributary monitoring stations and two dairy stations. The S-65D basin is the northernmost of the four priority basins in the Lake Okeechobee watershed and covers an area of approximately 47,210 ha. Improved pasture is the primary land use in this basin, followed by citrus groves, row crops, and dairy. The S-65D basin contains five tributary monitoring stations and three dairy stations.

Upland soils in the drainage basin are predominantly poorly-drained, sandy Spodosols. Approximately 80% of the TP in the basin is stored in soils in both stable and unstable forms (Reddy et al. 1996; Hiscock et al., 2003). This type of soil has little P retention capacity in the surface A and E horizons, but it has high retention capacity in the spodic horizon. Vertical movement of phosphorus through the soil profile would allow P to be retained by the spodic horizon. However, P may be lost via subsurface drainage before it reaches the spodic horizon.

2.3 Statistical Analyses

Two study periods were defined: 1) the baseline period from 1991 to 2001; and 2) the period of LOPA-mandated BMP implementation from 2002 to 2007. Summary statistics included the number of samples, means, medians, minima, maxima, and standard deviations for each station. Monthly mean concentrations were used for all other statistical analyses. Notched box-and-whisker plots summarize selected statistical properties of the data sets for each study period and were used to test for statistical significance between data sets at roughly a 95 percent confidence interval and to detect changes in constituent concentration variability over time (McGill et al., 1978). These plots consist of the median, the lower quartile (25th percentile), the upper quartile (75th percentile), the smallest and the largest values in the distribution of each set of data. The narrowest point of the notch represents the median of the data.

A comparison of TP and TN concentrations measured during the baseline period (1991 to 2001) and the LOPA BMP implementation period (2002 to 2007) was performed using the Mann-Whitney test (a non-parametric equivalent of the 2-sample t-test) to determine if statistically significant differences existed between the two periods. A significance level (α) of 0.05 was used to identify statistical significance. Non-parametric tests perform analyses based on the ranks of the data, and are therefore not influenced by outliers or skewed data that may have been present within the 2002 to 2007 data period (due to the occurrence of four hurricanes impacting the study area during this period).

The Seasonal Kendall Tau test was used to verify the statistical significance of the trends in the time series of TP and TN concentrations from 1991 to 2007. The Seasonal Kendall Tau is a non-parametric test frequently used to detect trends for water quality time series data. It is a rank-order statistic that can be applied to time series data exhibiting seasonal cycles, missing and censored data, and indications of non-normality (Yu and Zou, 1993).

When data are collected over time, significant autocorrelation may exist between data values. The Seasonal Kendall Tau provides an adjusted p-value for data that exhibit a significant level of dependence (Reckhow et al., 1992). For the purpose of determining statistical significance, an alpha (α) level of 0.05 was selected. Results of the Seasonal Kendall Tau test indicate if a statistically significant increase or decrease in concentrations is present at both the station and basin levels.

3. Results and Discussion

3.1 Summary Statistics

Summary statistics of the TP and TN data collected from the 27 tributary monitoring stations within the four priority basins and eight stations along the Kissimmee River within basins S-65A and S-65BC are presented in Tables 1 and 2, respectively. Among the eight stations along the Kissimmee River, six stations exhibited higher median TP concentrations and three stations had higher median TN concentrations during the LOPA implementation period when compared to the baseline conditions (Tables 1 and 2). There is no quantitative data to determine the exact amount of flow that upland basin areas contribute to these locations. Although there has been minimal BMP implementation within these basins, this should not be considered a definitive reason for these nutrient increases over this time period.

Among the 27 tributary stations located in the four priority basins (S-65D, S-65E, S-154, and S-191), 15 stations had lower median TP concentrations and five (5) stations exhibited lower median TN concentrations during the post LOPA period (Tables 1 and 2). When examining the data at the basin monitoring stations, all the monitoring stations in basins S-65D and S-154 exhibited significant differences in median TP concentrations for the two monitoring periods. Significantly lower median TP concentrations ($p < 0.05$) were observed in basin S-154 for the post LOPA period (Table 1). Median concentrations in this basin for the post LOPA period were between 50% to 60% lower than the baseline period. Conversely, basin S-65D exhibited significantly higher median TP concentrations ($p < 0.05$) for the post LOPA period at the four out of fives monitoring stations. Station KREA 04 was the only station in this basin that had significantly lower median concentrations ($p < 0.015$) for the post LOPA period (Table 1). Overall, ten stations in the priority basins exhibited statistically higher median TP concentrations during the post LOPA period, while eight stations exhibited statistically lower median TP concentrations for the baseline period (Table 1). A graphical comparison of TP concentrations at each basin for the two monitoring periods is provided in Figure 2 (top graph). From this plot it is very evident that a distinct decrease in TP concentrations is observed for basin S-154 during the post LOPA period. The tributary stations in the S-154 basin are located downstream of areas with relatively high levels of BMP implementation (Table 3). In addition, this basin has experienced a decrease in the overall intensity of upland use for agriculture. The S-154 basin also had two Dairy Best Available Technology (BAT) projects implemented, a large operating ranch cooperating in a cow/calf BMP project, and two dairy closings between 1989 through 1992 under the Dairy Remediation Program. In 2000, the District initiated the dairy BAT projects to implement advanced source control technologies to reduce TP discharge from dairy operations. The most effective technology is the edge-of-farm stormwater treatment, which calls for the reuse of runoff if possible and the chemical treatment of any runoff that must be discharged.

The northern tributary basins of Lake Okeechobee generally had lower median TN concentrations for the baseline period than for the LOPA period (Figure 2, bottom graph). Twenty-one of the 27 stations located in the priority basins exhibited higher median TN concentrations for the post LOPA period (Table 2). Of these 21 stations, statistically significant increases in TN were observed at 13 stations. Only station TCNS 217 exhibited a statistically significant higher TN concentration during the baseline period (Table 2). Increases in TN at the tributary stations may be the result of large stores of bioavailable N that have accumulated in soils and sediments. This anthropogenic accumulation of N is due mainly to the intense spreading of biosolids in the four priority basins before rigorous restrictions were put in place under LOPA (http://www.dep.state.fl.us/southeast/water/Residuals). The data reported by FDEP showed over 50,000 t of biosolids (as dry weight) were applied to these basins from 1991 to 2000. A moratorium on residual spreading took effect at the beginning of 2001 and since that time, marked decreases in the application of this form of imported nutrients have been reported by FDEP (Table 4). A total of 23,600 t of biosolids residuals (translated to 613 t of N and 183 t of P) were applied within the watershed over the period of 2001 to 2007 (Table 4). This amount indicated a 33% reduction in the rate of residuals applied in the watershed on a yearly basis, as compared to the 1991-2000 period.

3.2 Trend Analyses with Data Collected at the Tributary Stations

Among the eight stations along the Kissimmee River within Basins S-65A and S-65BC, five stations displayed a significant increasing trend in TP concentration (Table 5). A significant trend was not found for TN concentrations at these stations. Additional information relating to basin runoff and lateral flow is needed to determine if these significant trends are mainly the result of contributions from the Upper Kissimmee Basin and to determine to what degree, if any, changes in the water quality characteristics of the upland basin areas are contributing to these findings.

Total P concentrations at four stations in basin S-65D exhibited a significant increasing trend during the study period (1991 to 2007), with no stations showing a significant decreasing trend (Table 5). Station KREA 01 exhibited the highest Sen slope (0.011) for TP. The Sen slope indicates the change in annual concentration for a constituent, and the higher the slope, the more likely the station will continue to follow its current direction within the upcoming years. Stations with high positive or negative slopes can be targeted for in-depth investigations to help evaluate success stories, or identify areas where more intense nutrient control measures need to be implemented. Median TP concentrations at KREA 01 during the implementation period were twice as high as those during the baseline period (Table 1). Although BMP planning activities have taken place in the drainage basin, this tributary station is located directly downstream of an intense row crop operation that also receives biosolids residuals. Changes in land use may have also influenced two of the other stations with significantly increasing trends in TP. Stations KREA 22 and KREA 23 are directly downstream of a large area of land previously classified as agricultural and natural areas that was cleared for development in the late 1990's.

Station KREA 17A in the S-65E basin exhibited significant increasing trends for concentrations of TP and TN. This station also had the highest Sen slope for TP and TN (Table 5). Although BMPs and source control projects have been implemented in this basin (Table 3), the drainage area for this particular station received high levels of residuals and poultry litter spreading as late as 2002 (Medri et al., 2003). Although permitted biosolids spreading is no longer occurring in the station's drainage area, the effectiveness of the BMPs initiated in this basin may be offset by the legacy of these earlier nutrient loadings.

No significant trends were found for TN in the S-154 basin. Concentrations for TP at three of the four stations within this basin exhibited a significant decreasing trend from 1991 to 2007 (Table 5). Median TP concentrations at all three of these stations were reduced by half during the BMP implementation period (Table 1). TP concentrations at the most downstream station, KREA 30A, had a Sen slope of -0.041 mg/L per year (Table 5). This may be a reflection of the S-154 basin having the largest BMP implementation rate (63%) (Table 3), large acre changes in land use (from intensive usage to pasture and low density residential), and the completion of four P source control projects that include two dairy BATs.

In the Taylor Creek sub-basin of S-191, TP and TN increased significantly during the study period at station TCNS 207 and TN also increased at stations TCNS 201 and 213 (Table 5) even though the overall BMP implementation rate was 53% (Table 3) in the sub-basin. There is a large dairy operation located within station TCNS 213's drainage boundary that is not part of the dairy BATs program and currently implements only the basic BMPs, without water reuse or chemical treatment. If funding allows, the most successful solution to addressing dairy runoff within this basin would be to implement the highly effective Dairy BAT mentioned above.

In the Nubbin Slough sub-basin of S-191, TP concentrations at stations TCNS 222 and TCNS 249 showed a significantly decreasing trend, while two other stations exhibited a significant increasing trend for TP (TCNS 230 and TCNS 233). Station TCNS 233 is located downstream of a historic residual and poultry litter spreading station (Medri et al., 2003). As mentioned earlier, although these practices are no longer occurring, the legacy of these residuals may still be playing a role in surface runoff upstream of this station. The TCNS 249 station is directly downstream of two completed Dairy BAT projects. The presence of a significant decreasing trend in TP conversely occurring with a significant increasing trend in TN at station TCNS 222, cannot be explained by the land use or the overall implementation rates within the drainage boundary. Land uses within the boundary of TCNS 222 include beef pasture, urban, and dairy. The station is downstream of a Dairy BAT, and maintains the overall pattern of a significant decreasing trend in TP, which is typically observed at stations downstream of these projects. The increasing trend in TN provides a further indication of unknown changes in the role nitrogen is playing in watershed agricultural operations, and the degree to which unknown levels of legacy N may be contributing to measured concentrations.

A recent study of legacy P in the watershed concluded that there is an abundance of mobile legacy P present, which can maintain elevated P levels going to Lake Okeechobee for many years (SWET, 2008a). This conclusion was derived based on previous research conducted by the University of Florida and others (Graetz and Nair, 1995; Reddy et al., 1996; Steinman et al., 1999; Hiscock et al., 2003). Therefore, the reduction (through abatement practices) of new sources of P and its mobility to the lake will be an effective means of addressing P loads to the lake. These P reduction measures must address legacy P sources in uplands, wetlands, and streams, in order to encompass the full range of watershed features where transport of P to the lake occurs (SWET, 2008a).

3.3 Trend Analyses with Data Collected at the Dairy Stations

Total P concentrations averaged over the LOPA period were generally lower than those from the baseline period for the 16 dairy stations (Figure 3). TP concentrations for six dairy stations were significantly decreased (Table 6). These observations may be attributed to the intensive BMP implementations at these particular dairy stations, as well as the high initial concentrations that were greatly reduced over a short period of time to get to the levels currently present (Figure 4). There has also been a general decrease in the intensity of operations and a marked decrease in the amount of P that is being used at dairy operations (Hiscock et al., 2003). The cumulative effects of the Dairy Rule, Dairy BAT, and other P control measures and practices illustrate the possible reductions in P when more intense control measures are employed.

3.4 Comparison of Nutrient Data Collected at Structures with Data Collected in Basins

Based on the Seasonal Kendall Tau analysis of data at the basin level, the S-154 basin exhibited a statistically significant decreasing trend and the stations along the Kissimmee River in the S65A basin showed a significant increasing trend in TP concentrations (Figure 4). Four basins displayed a significant increasing trend for TN concentrations (Figure 5). Flow data were not collected at the tributary monitoring stations, so annual flow-weighted mean concentrations of TP and TN from structures S-191, S-154, and S-65 through S-65E were calculated for comparison with median TP and TN concentrations in the corresponding basins to ensure consistency in terms of water quality trends. Flow-weighted TP concentration at structure S-154 displayed a significant decreasing trend during the study period (Table 7). This is consistent with the basin result for concentrations at the S-154 tributary stations (Figure 4). Flow -weighted TP concentrations at structures S-65, S-65A and S-65C had significant increasing trends for TP and

TN. This is coherent with the TP concentration findings for the eight stations along the Kissimmee in basins S-65A and S-65BC. The significant increasing trend for TN at structure S-65C is however, not reflected in the TN trends found at the four stations along the Kissimmee in Basin S-65BC. While not statistically significant, the TN concentrations all had negative slopes for these stations (Table 5).

The average annual TP load to the lake from all sources, excluding the 35 t/yr from atmospheric deposition, was 511 t/yr averaged from 1991 to 2005 (Zhang et al., 2009). Basin S-154, with a drainage area of one percent, contributed about five percent of the TP load to the lake. Basin S-191, with a drainage area of 3.5 percent, contributed about 17 percent of the TP load to the lake. Basins S-65A through S-65E, with a drainage area of 12 percent, contributed about 15 percent of TP load to the lake. The flow-weighted TP concentrations are 0.760, 0.644 and 0.167 mg/L for basins S-154, S-191, S-65A through E, respectively, which are much higher than the tributary TMDL of 0.113 mg/L (113 ppb) specified by the U.S. Environmental Protection Agency in the 2008 TMDL evaluation (http://www.epa.gov/region4/water/tmdl/florida/). The percentage of load contributions per drainage area shows that basin S-191 remains a high source of TP loading to the lake. Basin S-154 has shown significant decreasing trends in TP and contributes a low percentage of loads to the lake. However, relative to its very small drainage area and very high flow-weighted concentrations, S-154 still needs to be viewed as a basin of concern and to be targeted for future nutrient source control projects and BMPs.

4. Summary and Discussion

A comprehensive array of state and federal projects has been initiated within the watershed to reduce P loading to Lake Okeechobee. These source control projects, along with on-site BMPs, have been implemented to reduce P transport from uplands, and to capture water runoff during periods of high rainfall. Ongoing research and monitoring in the watershed are helping to guide the design of TP load reduction projects that will improve water quality and attenuate flows.

An ongoing assessment of water quality trends in the watershed is necessary to evaluate progress toward achieving the Lake Okeechobee TMDL goal of 140 mt of P per year by 2015. A total of 51 monitoring stations were studied: 35 long-term, ambient monitoring stations that included 27 stations in the four priority basins and eight along the Kissimmee River within basins S-65A and S-65BC; and 16 stations located at the outfalls of the dairy operations. Only TP data were collected at the 16 dairy stations. The baseline data and trend analysis for TP and TN concentrations were summarized at the basin-level using the data collected at the 35 long-term, ambient monitoring stations. Data collected in basin S-154 displayed a significant decreasing trend in terms of mean monthly TP concentrations from 1991 to 2007. Stations along the Kissimmee River within the S-65A basin exhibited a significant increasing trend for TP concentrations. Significant increases in TN were also observed for the S-65D, S-65E, S-154, and S-191TC basins during the 1991 to 2007 period. Among the 27 long-term, ambient monitoring stations located in the four priority basins, five stations had a significant decreasing trend, while eight stations showed a significant increasing trend in terms of mean monthly TP concentrations. Although BMPs have been initiated to a certain degree, there is still a large percentage of the watershed that needs dedicated resources in order to realize the full level of BMP implementation needed for nutrient reductions. The high levels of legacy P in the soils play a role in the delayed response of the watershed to show TP concentration reductions. The distance from the BMP implementation area to the actual tributary monitoring station, as well as nearby land use practices such as residual spreading are also factors in the trends displayed at the sampling stations. Among the 16 dairy stations, 11 stations displayed a decrease in TP concentrations and six of these stations had statistically significant decreasing trends. The implementation of dairy best available technologies, former dairy remediation, wetland restoration, and other P control projects have contributed to the reduction in the concentrations realized at these dairy stations.

Based on data collected at the basin structure outlets, discharges from S-154 displayed a significant decreasing trend in terms of flow-weighted mean TP concentrations from 1991 to 2007. However, flow-weighted TP and TN concentrations have shown a significant increase at structures S-65, S-65A and S-65C. These findings indicate the need for additional information to better understand the relationship between upland basin contributions and water quality transport and fate within the Kissimmee River itself. Increased attention to hydrologic conditions for these basins and the establishment of long term water quality monitoring within the upland tributaries would serve this goal. The continued import of biosolids (municipal residuals) and a lower level of overall BMP implementation efforts (due to budget constraints) during the study period may have had an influence on the tributary water quality observed in these two northern basins. Under the NEEPP, additional P control strategies have been identified, not only for these four priority basins, but also for all the other basins in the Lake Okeechobee watershed. A combination of BMPs and public works projects are being initiated to achieve further reductions in nutrient loads from the watershed. In summary, more aggressive nutrient control measures still need to be implemented in all the surrounding basins that discharge to the lake in order to reach the lake's TMDL goal of 140 t of P per year.

5. Relevance to Everglades Restoration and Future Directions

An integral part of the NEEPP is monitoring water quality, flow, and other physical parameters. Both the long-term tributary monitoring network and the dairy stations will continue to play a role in providing critical information necessary to document the effectiveness of BMPs and other P control projects in reducing nutrient loads to Lake Okeechobee.

The documented results of this study are also relevant to the future objectives of the NEEPP because they confirm the need for advanced TP reduction technologies at the watershed scale to reduce P loads and concentrations as part of the restoration effort. The results of this study also revealed a clear trend of increasing TN concentrations within the watershed. Since the NEEPP now allows for programmatic approaches for the entire Northern Everglades watershed, it is critical to begin implementing control projects that focus on reducing overall nutrient loads, with an added focus on ways to abate TN levels in the watershed. This is timely for the protection of the lake, and especially for the downstream receiving estuarine waters on both coasts. The N inputs from Lake Okeechobee represent a significant portion of nitrogen entering the St. Lucie estuary. Since the estuary system is N limited (Phlips, 2008), the impacts of increasing N loads to the lake from the northern watersheds would have negative effects in the future on the more easily impacted ecosystem.

The decreases in nutrient loads in the Lake Okeechobee watershed are critical to improving conditions in the lake, and will also reduce nutrient loads to downstream systems (estuaries and the Everglades). We are seeing some signs that the various projects implemented in the watershed are having an effect, but we are still far from achieving the required load reductions. While it has been imperative to concentrate a large portion of the restoration efforts on the four priority basins, it is also important to begin increasing attention on the other contributing basins through assessments of historical data and continued research studies. This will ensure a system-wide comprehensive approach to the restoration efforts being carried out for Lake Okeechobee and the Everglades ecosystem. Future research and assessment efforts should concentrate on gaining a more thorough understanding of the effectiveness of specific BMPs on specific land use types in order to determine which measures result in the most effective abatement of legacy P in the watershed. Farm-level research projects need to be continued in order to obtain necessary data for statistically-relevant assessments. More detailed correlations between water quality trends at specific tributary stations with land use changes, types of nutrient control projects and specific BMP measures implemented within an individual station drainage boundary would also provide a much needed management tool. Stations that exhibited high Sen slopes in this study would be initial, logical areas where detailed characteristics should be investigated. A clearer understanding of the current imports and exports of fertilizer in the watershed, as well as quantifiable information for biosolids residual imports, would provide much needed data for evaluating the success of nutrient reduction efforts.

Acknowledgment

The authors thank David Unsell, Paul McCormick, Tom James, Steffany Gornak, Temperince Morgan, Christopher King, Cheol Mo, Brad Jones, and the three anonymous reviewers for their valuable comments and suggestions on an early version of this paper. Appreciation also goes to Denise Watts, Greg Kennedy, John Folks, and Jim Laing for the

information regarding biosolids applications.

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Figure Captions

Figure 1. Location of ambient water quality sampling stations where total phosphorus (TP) and total nitrogen (TN) were collected in the tributary basins that drain into Lake Okeechobee (triangles), sampling stations where TP data were collected at dairy outfalls (dots), and the loading stations at the inflow structures (squares).

Figure 2. Box and whisker plot of total phosphorus (top) and total nitrogen (bottom) concentrations for the periods 1991 – 2001 and 2002 – 2007.

Figure 3. Box and whisker plot of total phosphorus concentrations for the periods 1991 – 2001 and 2002 – 2007 for monitoring stations located at individual dairy farms.

Figure 4. Seasonal Kendall trends and 12-month moving average plots of mean monthly total phosphorus concentrations for the period 1991 – 2007.

Figure 5. Seasonal Kendall Tau trends and 12-month moving average plots of mean monthly total nitrogen concentrations for the period 1991 – 2007.

Table 1. Summary of total phosphorus data (in mg/L) collected during the baseline period 1991 through 2001 and BMP implementation period 2002 through 2007 in the Lake Okeechobee watershed. Bolded and italicized rows indicate a statistically significant difference for the two sampling periods at α = 0.05.

Basin	Station	Summary Statistics for the Period from 1991 to 2001						Summary Statistics for the Period from 2002 to 2007						Mann-Whitney p-value
		No of Samples	Mean	Standard Deviation	Minimum	Median	Maximum	No of Samples	Mean	Standard Deviation	Minimum	Median	Maximum	
S-65A	***KREA 79***	***68***	***0.050***	***0.032***	***0.017***	***0.043***	***0.228***	***69***	***0.078***	***0.030***	***0.031***	***0.072***	***0.172***	***<0.001***
	KREA 91	***53***	***0.054***	***0.030***	***0.018***	***0.043***	***0.139***	***58***	***0.059***	***0.021***	***0.026***	***0.054***	***0.106***	***0.048***
	KREA 92	63	0.066	0.034	0.026	0.057	0.206	70	0.062	0.022	0.023	0.060	0.112	0.950
	KREA 97	***52***	***0.073***	***0.031***	***0.025***	***0.069***	***0.185***	***50***	***0.126***	***0.059***	***0.040***	***0.118***	***0.283***	***<0.001***
S-65BC	KREA 93	59	0.077	0.039	0.018	0.071	0.213	67	0.085	0.041	0.043	0.074	0.272	0.180
	KREA 94	54	0.108	0.099	0.029	0.085	0.641	68	0.085	0.041	0.046	0.074	0.273	0.271
	KREA 95	63	0.078	0.057	0.015	0.061	0.309	67	0.065	0.035	0.025	0.057	0.272	0.341
	KREA 98	***41***	***0.066***	***0.040***	***0.017***	***0.060***	***0.176***	***66***	***0.083***	***0.042***	***0.032***	***0.071***	***0.242***	***0.025***
S-65D	***KREA 01***	***223***	***0.158***	***0.174***	***0.004***	***0.103***	***1.259***	***93***	***0.313***	***0.294***	***0.042***	***0.206***	***1.522***	***<0.001***
	KREA 04	***141***	***0.191***	***0.175***	***0.030***	***0.138***	***1.191***	***77***	***0.136***	***0.068***	***0.039***	***0.123***	***0.320***	***0.049***
	KREA 06A	***228***	***0.237***	***0.138***	***0.050***	***0.208***	***0.970***	***78***	***0.286***	***0.158***	***0.057***	***0.253***	***0.758***	***0.015***
	KREA 22	***114***	***0.069***	***0.113***	***0.010***	***0.041***	***1.032***	***80***	***0.068***	***0.060***	***0.025***	***0.054***	***0.447***	***0.005***
	KREA 23	***90***	***0.044***	***0.048***	***0.007***	***0.027***	***0.320***	***71***	***0.121***	***0.168***	***0.019***	***0.055***	***0.928***	***<0.001***
S-65E	***KREA 14***	***123***	***0.537***	***0.328***	***0.096***	***0.487***	***1.946***	***54***	***0.407***	***0.268***	***0.058***	***0.347***	***1.210***	***0.005***
	KREA 17A	***182***	***0.242***	***0.211***	***0.026***	***0.167***	***1.155***	***88***	***0.398***	***0.248***	***0.086***	***0.334***	***1.388***	***<0.001***
	KREA 19	392	0.581	0.760	0.035	0.219	4.005	118	0.537	0.495	0.038	0.395	2.050	0.197
	KREA 41A	263	0.549	0.632	0.054	0.332	6.547	64	0.452	0.512	0.034	0.212	2.360	0.089
S-154	***KREA 20***	***90***	***2.266***	***1.126***	***0.050***	***2.114***	***6.550***	***20***	***1.059***	***0.571***	***0.184***	***1.120***	***2.423***	***<0.001***
	KREA 25	***85***	***1.337***	***0.881***	***0.185***	***1.010***	***4.145***	***29***	***0.663***	***0.419***	***0.160***	***0.615***	***1.652***	***<0.001***
	KREA 28	***335***	***1.395***	***0.728***	***0.367***	***1.257***	***4.940***	***84***	***0.899***	***0.528***	***0.250***	***0.748***	***2.510***	***<0.001***
	KREA 30A	***203***	***1.114***	***0.596***	***0.129***	***0.967***	***3.869***	***25***	***0.618***	***0.268***	***0.167***	***0.518***	***1.140***	***<0.001***
S-191TC	TCNS 201	179	0.462	0.232	0.009	0.388	1.378	64	0.482	0.258	0.142	0.455	1.370	0.734
	TCNS 204	206	0.922	0.549	0.108	0.702	2.779	73	0.768	0.381	0.352	0.617	2.000	0.114
	TCNS 207	***368***	***0.677***	***0.759***	***0.081***	***0.438***	***5.834***	***116***	***0.897***	***0.448***	***0.199***	***0.790***	***2.258***	***<0.001***
	TCNS 209	354	0.532	0.483	0.040	0.381	3.422	89	0.449	0.330	0.043	0.371	1.610	0.179
	TCNS 212	***95***	***0.161***	***0.153***	***0.030***	***0.116***	***1.213***	***38***	***0.238***	***0.174***	***0.028***	***0.189***	***0.664***	***0.017***
	TCNS 213	359	0.486	0.296	0.039	0.417	1.725	123	0.421	0.225	0.085	0.350	1.237	0.100
	TCNS 214	***366***	***0.242***	***0.115***	***0.054***	***0.218***	***1.034***	***141***	***0.270***	***0.112***	***0.081***	***0.246***	***0.591***	***0.005***
	TCNS 217	362	0.380	0.302	0.030	0.296	1.893	132	0.349	0.287	0.023	0.261	1.520	0.372
S-191NS	TCNS 220	181	0.615	0.289	0.236	0.543	1.788	66	0.620	0.450	0.249	0.482	2.860	0.116
	TCNS 222	***341***	***0.579***	***0.230***	***0.079***	***0.537***	***1.458***	***84***	***0.507***	***0.222***	***0.222***	***0.446***	***1.580***	***<0.001***
	TCNS 228	313	0.512	0.274	0.091	0.444	2.183	88	0.502	0.260	0.138	0.401	1.160	0.644
	TCNS 230	***310***	***0.407***	***0.251***	***0.080***	***0.341***	***1.861***	***67***	***0.614***	***0.268***	***0.196***	***0.591***	***1.440***	***<0.001***
	TCNS 233	***360***	***0.390***	***0.260***	***0.069***	***0.298***	***1.758***	***101***	***0.646***	***0.391***	***0.176***	***0.556***	***2.237***	***<0.001***
	TCNS 249	***174***	***0.457***	***0.396***	***0.045***	***0.315***	***2.379***	***30***	***0.230***	***0.167***	***0.063***	***0.175***	***0.739***	***0.002***

Table 2. Summary of total nitrogen data (in mg/L) collected during the baseline period 1991 through 2001 and BMP implementation period 2002 through 2007 in the Lake Okeechobee watershed. Bolded and italicized rows indicate a statistically significant difference for the two sampling periods at α = 0.05.

Basin	Station	Summary Statistics for the Period from 1991 to 2001						Summary Statistics for the Period from 2002 to 2007						Mann-Whitney p-value
		No of Samples	Mean	Standard Deviation	Minimum	Median	Maximum	No of Samples	Mean	Standard Deviation	Minimum	Median	Maximum	
S-65A	KREA 79	65	1.259	0.414	0.580	1.140	2.290	67	1.288	0.406	0.790	1.220	2.850	0.642
	KREA 91	50	1.395	0.495	0.250	1.310	2.860	57	1.398	0.355	0.820	1.320	2.880	0.820
	KREA 92	59	1.114	0.281	0.510	1.080	1.790	68	1.099	0.123	0.920	1.085	1.520	0.944
	KREA 97	50	1.281	0.325	0.550	1.275	2.000	49	1.341	0.285	0.960	1.250	2.580	0.554
S-65BC	***KREA 93***	***55***	***1.442***	***0.465***	***0.710***	***1.300***	***2.820***	***65***	***1.266***	***0.276***	***0.880***	***1.190***	***2.110***	***0.027***
	KREA 94	48	1.417	0.463	0.820	1.250	2.950	66	1.257	0.286	0.870	1.180	2.140	0.068
	KREA 95	***59***	***1.291***	***0.358***	***0.770***	***1.210***	***2.340***	***66***	***1.128***	***0.214***	***0.680***	***1.085***	***1.790***	***0.014***
	KREA 98	41	1.373	0.387	0.740	1.330	2.340	64	1.292	0.279	1.010	1.210	2.380	0.246
S-65D	***KREA 01***	***162***	***1.436***	***0.564***	***0.250***	***1.305***	***5.400***	***85***	***1.617***	***0.429***	***0.880***	***1.570***	***2.870***	***<0.001***
	KREA 04	***72***	***1.358***	***0.401***	***0.520***	***1.370***	***2.690***	***75***	***1.498***	***0.382***	***0.910***	***1.480***	***3.150***	***0.018***
	KREA 06A	33	1.355	0.383	0.250	1.300	2.280	46	1.529	0.671	0.860	1.390	4.890	0.684
	KREA 22	***104***	***1.443***	***1.035***	***0.510***	***1.245***	***8.980***	***73***	***1.428***	***0.357***	***0.590***	***1.360***	***2.810***	***0.008***
	KREA 23	80	1.322	0.352	0.640	1.265	2.370	63	1.459	0.542	0.950	1.290	4.080	0.230
S-65E	KREA 14	--NA--	--NA--	--NA--	--NA--	--NA--	--NA--	34	2.116	0.645	1.140	1.940	4.200	--NA--
	KREA 17A	***112***	***1.413***	***0.381***	***0.250***	***1.350***	***2.970***	***86***	***1.782***	***0.432***	***0.850***	***1.710***	***3.140***	***<0.001***
	KREA 19	40	2.112	0.719	0.850	2.115	3.380	84	2.145	0.856	0.910	2.020	4.070	0.814
	KREA 41A	***29***	***2.319***	***1.430***	***0.690***	***1.850***	***8.890***	***37***	***2.785***	***0.910***	***0.900***	***2.710***	***4.760***	***0.004***
S-154	KREA 20	55	2.625	0.971	1.160	2.440	6.010	18	2.976	1.489	0.620	2.920	7.060	0.234
	KREA 25	77	2.292	0.683	0.600	2.160	4.180	28	2.214	0.521	1.120	2.280	3.300	0.925
	KREA 28	326	2.158	0.565	0.250	2.120	4.210	160	2.251	0.769	1.260	2.170	6.510	0.613
	KREA 30A	201	1.973	0.493	0.620	1.900	4.480	25	1.874	0.293	1.270	1.910	2.470	0.577
S-191TC	TCNS 201	113	1.492	0.571	0.520	1.480	4.290	57	1.609	0.599	0.650	1.630	2.830	0.185
	TCNS 204	***25***	***2.574***	***1.197***	***1.500***	***2.330***	***6.740***	***45***	***3.659***	***0.755***	***2.200***	***3.520***	***5.790***	***<0.001***
	TCNS 207	***324***	***2.013***	***2.644***	***0.250***	***1.450***	***27.860***	***112***	***3.077***	***2.375***	***0.750***	***2.410***	***22.920***	***<0.001***
	TCNS 209	***335***	***1.613***	***1.680***	***0.250***	***1.360***	***17.560***	***89***	***1.773***	***0.609***	***0.660***	***1.730***	***3.300***	***<0.001***
	TCNS 212	19	1.821	0.536	0.810	1.760	2.730	24	1.642	0.554	0.990	1.570	2.690	0.231
	TCNS 213	***323***	***1.689***	***0.909***	***0.250***	***1.520***	***9.270***	***124***	***2.014***	***0.657***	***0.800***	***1.925***	***3.960***	***<0.001***
	TCNS 214	359	1.250	0.601	0.250	1.200	3.740	138	1.210	0.617	0.330	1.035	2.890	0.407
	TCNS 217	***345***	***2.319***	***5.743***	***0.250***	***1.580***	***89.620***	***126***	***1.277***	***0.593***	***0.430***	***1.090***	***3.900***	***<0.001***
S-191NS	***TCNS 220***	***31***	***2.694***	***1.105***	***1.630***	***2.410***	***5.740***	***49***	***3.160***	***1.546***	***1.750***	***2.850***	***10.830***	***0.015***
	TCNS 222	***337***	***1.912***	***0.736***	***0.250***	***1.800***	***9.680***	***82***	***2.047***	***0.529***	***0.950***	***1.980***	***4.340***	***0.003***
	TCNS 228	306	2.299	0.915	0.250	2.200	9.030	87	2.313	0.935	0.980	2.230	6.370	0.839
	TCNS 230	***304***	***1.786***	***0.527***	***0.250***	***1.705***	***4.600***	***65***	***2.045***	***0.508***	***1.090***	***1.970***	***3.950***	***<0.001***
	TCNS 233	***354***	***1.758***	***0.547***	***0.250***	***1.675***	***4.320***	***100***	***2.324***	***1.793***	***1.060***	***1.965***	***16.130***	***<0.001***
	TCNS 249	32	1.102	0.643	0.250	1.160	2.960	14	1.261	0.679	0.570	1.030	3.250	0.519

Table 3. Percent of Best Management Practice (BMP) implementation and significant trends in total phosphorus (TP) and total nitrogen (TN) concentrations from 1991 to 2007.

Basin	Total Basin Area (ha)	BMPs Being Implemented (ha)	% of BMPs Being Implemented	TP Significant Trend	TN Significant Trend
S-65A	41,825	-	0%	Increase	No
S-65BC	72,894	7,080	10%	No	No
S-65D	47,207	20,707	44%	No	Increase
S-65E	11,799	4,226	36%	No	Increase
S-154	12,796	8,095	63%	Decrease	Increase
S-191TC	27,276	14,545	53%	No	Increase
S-191NS	21,592	8,688	40%	No	No
Total	235,389	63,342	27%		

Table 4. Total nutrient loading from residual applications for basins within the Lake Okeechobee watershed (in metric tons)

Basin	2001		2002		2003		2004		2005		2006		2007		Totals	
	N	**P**	**N**	**P**	**N**	**P**	**N**	**P**	**N**	**P**	**N**	**P**	**N**	**P**	**N**	**P**
S-65BC							8.6	1.8	84.0	21.9	49.9	8.6	16.0	0.5	158.5	32.8
S-65D					182.9	60.1	0.0	0.0	0.0	0.0	2.4	1.0	1.0	0.2	186.2	61.2
S-191	3.9	3.0	3.9	2.1	96.7	28.5	56.6	14.4	103.3	37.4	0.0	0.0	3.5	3.4	267.9	88.8
Total Nutrient Loads (mt)															**612.7**	**182.9**

Source: FDEP, 2001 to 2007 RAS Reports (http://www.dep.state.fl.us/southeast/water/Residuals).

Table 5. Seasonal Kendall Tau trend analyses of total phosphorus (TP) and total nitrogen (TN) for the period from 1991 to 2007.
(Bolded and italicized results indicate significant changes in concentrations)

Basin	Station	Total Phosphorus					Total Nitrogen				
		Number of Samples[a]	Sen Slope[b]	Intercept	tau	p-Value[c]	Number of Samples[a]	Sen Slope[b]	Intercept	tau	p-Value[c]
S-65A	***KREA 79***	***129 / 204***	***0.0035***	***0.029***	***0.448***	***0.001***	124 / 204	0.0067	1.133	0.066	0.468
	KREA 91	***110 / 144***	***0.0018***	***0.040***	***0.240***	***0.005***	106 / 144	0.0217	1.190	0.151	0.300
	KREA 92	131 / 144	0.0007	0.054	0.054	0.711	124 / 144	-0.0053	1.122	-0.108	0.250
	KREA 97	***100 / 144***	***0.0054***	***0.050***	***0.355***	***0.038***	97 / 144	0.0050	1.240	0.046	0.604
S-65BC	***KREA 93***	***120 / 144***	***0.0038***	***0.049***	***0.340***	***0.023***	114 / 144	-0.0025	1.235	-0.016	0.876
	KREA 94	117 / 144	0.0010	0.069	0.101	0.176	109 / 144	-0.0073	1.234	-0.058	0.505
	KREA 95	124 / 144	0.0013	0.050	0.106	0.343	119 / 144	-0.0100	1.200	-0.089	0.497
	KREA 98	***101 / 132***	***0.0051***	***0.043***	***0.394***	***0.028***	99 / 132	-0.0029	1.246	-0.019	0.886
S-65D	***KREA 01***	***168 / 204***	***0.0112***	***0.040***	***0.343***	***0.007***	***138 / 204***	***0.0333***	***1.102***	***0.299***	***<0.0001***
	KREA 04	120 / 192	-0.0016	0.167	-0.081	0.273	86 / 192	0.0167	1.287	0.134	0.344
	KREA 06A	***158 / 204***	***0.0060***	***0.176***	***0.196***	***0.001***	37 / 204	0.0374	1.042	0.286	0.322
	KREA 22	***138 / 204***	***0.0016***	***0.033***	***0.215***	***0.001***	***125 / 204***	***0.0200***	***1.130***	***0.212***	***0.036***
	KREA 23	***118 / 204***	***0.0050***	***0.004***	***0.475***	***0.004***	106 / 204	0.0100	1.215	0.144	0.070
S-65E	KREA 14	100 / 168	-0.0048	0.470	-0.047	0.587	24 / 168	0.2200	0.395	0.444	0.111
	KREA 17A	***137 / 204***	***0.0172***	***0.081***	***0.387***	***0.004***	***106 / 204***	***0.0557***	***1.076***	***0.553***	***0.001***
	KREA 19	131 / 204	0.0011	0.265	0.015	0.842	25 / 204	-0.0650	2.642	-0.333	0.367
	KREA 41A	162 / 204	-0.0068	0.384	-0.100	0.347	34 / 204	-0.0038	2.633	-0.027	1.000
S-154	***KREA 20***	***74 / 204***	***-0.0738***	***2.295***	***-0.403***	***0.019***	47 / 204	0.0288	2.266	0.079	0.715
	KREA 25	***66 / 192***	***-0.0623***	***1.313***	***-0.464***	***0.022***	63 / 192	0.0141	2.037	0.109	0.501
	KREA 28	109 / 192	-0.0466	1.458	-0.265	0.052	104 / 192	0.0041	2.042	0.037	0.751
	KREA 30A	***109 / 204***	***-0.0415***	***1.237***	***-0.315***	***0.024***	106 / 204	0.0042	1.854	0.033	0.741
S-191TC	TCNS 201	136 / 204	0.0019	0.393	0.045	0.513	***103 / 204***	***0.0276***	***1.225***	***0.264***	***0.001***
	TCNS 204	153 / 204	-0.0028	0.697	-0.028	0.789	38 / 204	0.0959	2.580	0.227	0.240
	TCNS 207	***195 / 204***	***0.0323***	***0.375***	***0.293***	***0.025***	***178 / 204***	***0.0827***	***1.117***	***0.389***	***0.003***
	TCNS 209	182 / 204	-0.0111	0.505	-0.127	0.189	177 / 204	0.0274	1.287	0.173	0.137
	TCNS 212	91 / 204	0.0052	0.085	0.140	0.294	26 / 204	-0.0457	2.049	-0.250	0.391
	TCNS 213	197 / 204	-0.0073	0.469	-0.118	0.151	***186 / 204***	***0.0338***	***1.423***	***0.222***	***0.016***
	TCNS 214	202 / 204	0.0028	0.209	0.118	0.095	201 / 204	-0.0045	1.319	-0.030	0.755
	TCNS 217	197 / 204	-0.0062	0.354	-0.118	0.170	192 / 204	-0.0325	1.691	-0.185	0.051
S-191NS	TCNS 220	160 / 204	-0.0024	0.554	-0.032	0.602	40 / 204	0.0247	2.640	0.094	0.612
	TCNS 222	***178 / 204***	***-0.0080***	***0.577***	***-0.199***	***0.004***	***176 / 204***	***0.0250***	***1.668***	***0.184***	***0.001***
	TCNS 228	175 / 204	-0.0046	0.510	-0.063	0.402	173 / 204	-0.0085	2.342	-0.070	0.223
	TCNS 230	***158 / 204***	***0.0154***	***0.284***	***0.239***	***0.023***	156 / 204	0.0060	1.774	0.055	0.523
	TCNS 233	***186 / 204***	***0.0115***	***0.281***	***0.225***	***0.020***	185 / 204	0.0167	1.658	0.164	0.100
	TCNS 249	***136 / 204***	***-0.0119***	***0.398***	***-0.197***	***0.008***	20 / 204	0.0442	0.789	0.400	0.289

[a] Number of samples indicates the total number of monthly values used in the analysis out of a total number of possible samples for the period of record.
[b] Sen Slope estimator for the Seasonal Kendall Tau shows the change in concentration of a constituent per year.
[c] p-Value <0.05 indicates that the Sen Slope is statistically significant.

Table 6. Seasonal Kendall Tau trend analyses of total phosphorus (TP) at monitoring stations located on individual dairy farms for the period from 1991 to 2007. (Bolded and italicized results indicate significant changes in concentrations)

Station	Number of Months[a]	Sen Slope[b]	Intercept	tau	p-Value[c]
KREA 07	100 / 204	-0.0094	0.558	-0.101	0.4133
KREA 08	109 / 204	-0.0174	1.144	-0.143	0.2960
KREA 10D	***136 / 204***	***-0.0275***	***0.632***	***-0.268***	***0.0215***
KREA 43A	139 / 204	0.0088	0.577	0.077	0.4406
KREA 46A	84 / 204	0.0126	0.711	0.069	0.5901
KREA 49	86 / 204	-0.1155	4.719	-0.231	0.1106
TCNS 210	124 / 204	0.0378	0.688	0.160	0.2188
TCNS 211	***173 / 204***	***-0.0050***	***0.150***	***-0.223***	***0.0476***
TCNS 231	***149 / 204***	***0.0407***	***0.754***	***0.219***	***0.0350***
TCNS 243	84 / 204	-0.0023	0.134	-0.055	0.7009
TCNS 262	***178 / 204***	***-0.0710***	***1.749***	***-0.462***	***0.0004***
TCNS 263	166 / 204	-0.0397	1.488	-0.195	0.1599
TCNS 265	147 / 204	0.0014	0.340	0.027	0.8062
TCNS 277	***151 / 204***	***-0.0765***	***1.806***	***-0.458***	***0.0005***
TCNS 280	***91 / 156***	***-0.3483***	***7.590***	***-0.452***	***0.0007***
TCNS 281	***107 / 168***	***-0.0255***	***0.739***	***-0.323***	***0.0114***

[a] Number of samples indicates the total number of monthly values used in the analysis out of a total number of possible samples for the period of record.
[b] Sen Slope estimator for the Seasonal Kendall Tau shows the change in concentration of a constituent per year.
[c] p-Value <0.05 indicates that the Sen Slope is statistically significant

Table 7. Seasonal Kendall Tau trend analyses of phosphorus and nitrogen flow-weighted mean concentrations at structures discharging to Lake Okeechobee for the period from 1991 to 2007. (Bolded and italicized results indicate significant changes in concentrations)

Data Summaries	Structures						
	S65	S65A	S65C	S65D	S65E	S154	S191
Total Phosphorus							
Number of Months[a]	***159 / 204***	***191 / 204***	***196 / 204***	***194 / 204***	193 / 204	***121 / 204***	176 / 204
Tau	***0.393***	***0.317***	***0.363***	***0.199***	0.008	***-0.328***	-0.079
Sen Slope[b]	***0.003***	***0.002***	***0.002***	***0.001***	0.000	***-0.028***	-0.003
Intercept	***0.037***	***0.041***	***0.041***	***0.051***	0.083	***0.792***	0.507
p-Value[c]	***0.010***	***0.013***	***0.006***	***0.031***	0.944	***0.005***	0.300
Total Nitrogen							
Number of Months[a]	***159 / 204***	***191 / 204***	***196 / 204***	194 / 204	193 / 204	121 / 204	176 / 204
Tau	***0.303***	***0.289***	***0.216***	0.114	0.051	-0.065	0.143
Sen Slope[b]	***0.019***	***0.018***	***0.012***	0.006	0.003	-0.005	0.012
Intercept	***1.07***	***1.04***	***1.01***	1.06	1.11	1.94	1.65
p-Value[c]	***0.018***	***0.005***	***0.048***	0.175	0.488	0.610	0.181

[a] Number of samples indicates the total number of monthly values used in the analysis out of a total number of possible samples for the period of record.
[b] Sen Slope estimator for the Seasonal Kendall Tau shows the change in concentration of a constituent per year.
[c] p- Value <0.05 indicates that the Sen Slope is statistically significant.

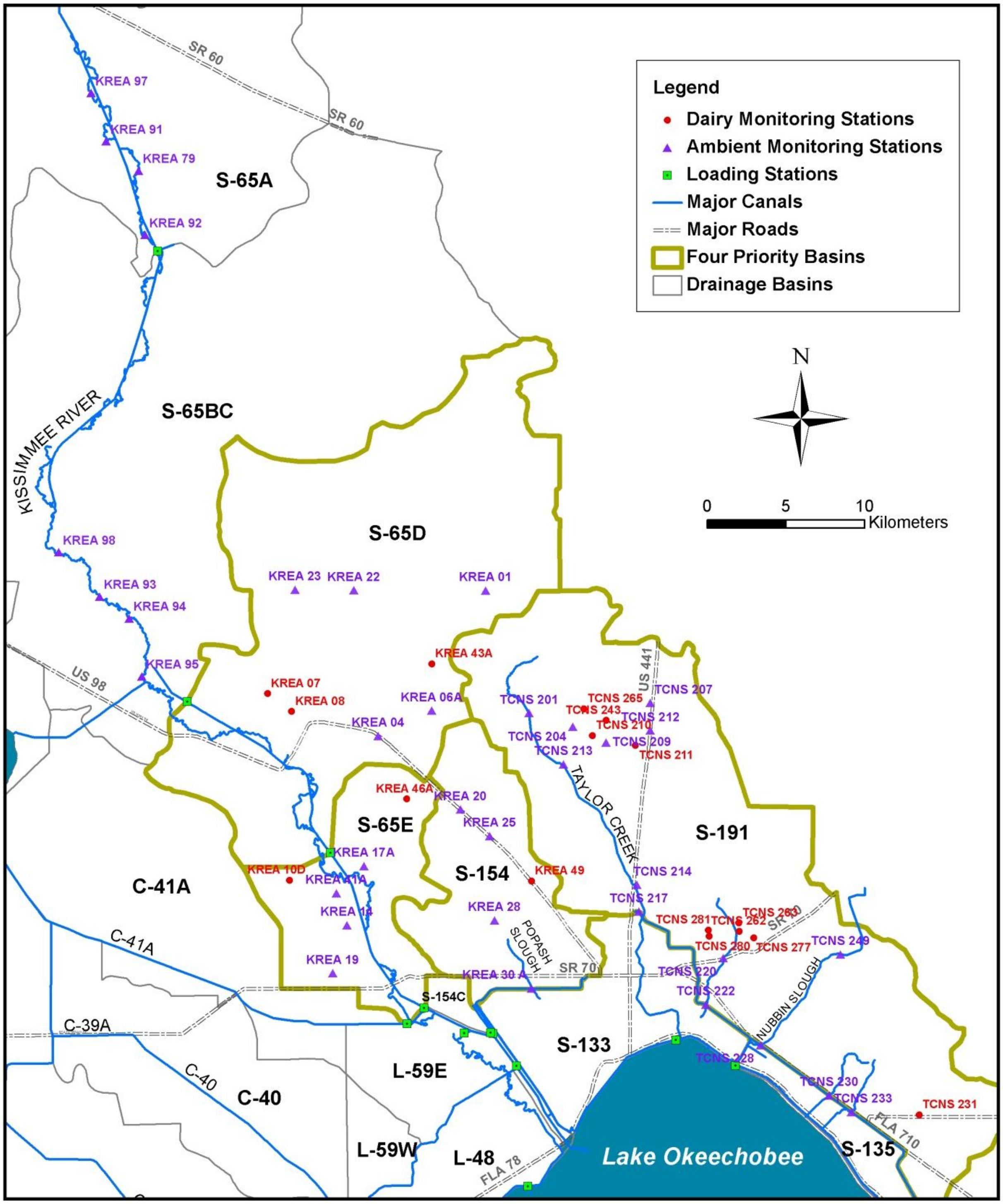
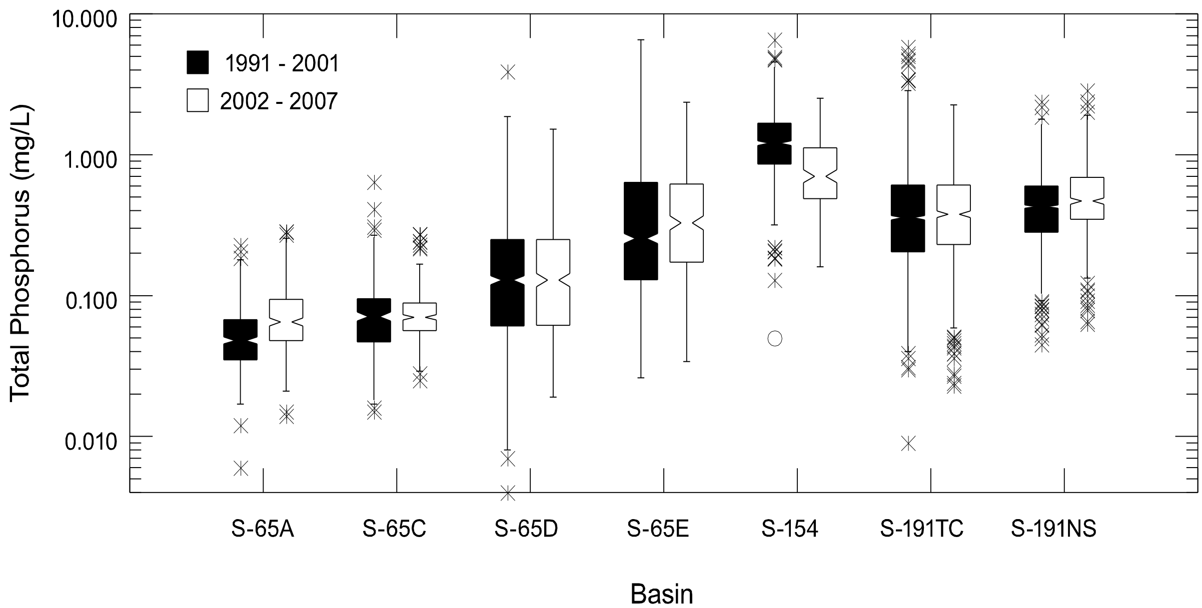


Figure 1. Location of ambient water quality sampling stations where total phosphorus (TP) and total nitrogen (TN) were collected in the tributary basins that drain into Lake Okeechobee (triangles), sampling stations where TP data were collected at dairy outfalls (dots), and the loading stations at the inflow structures (squares).



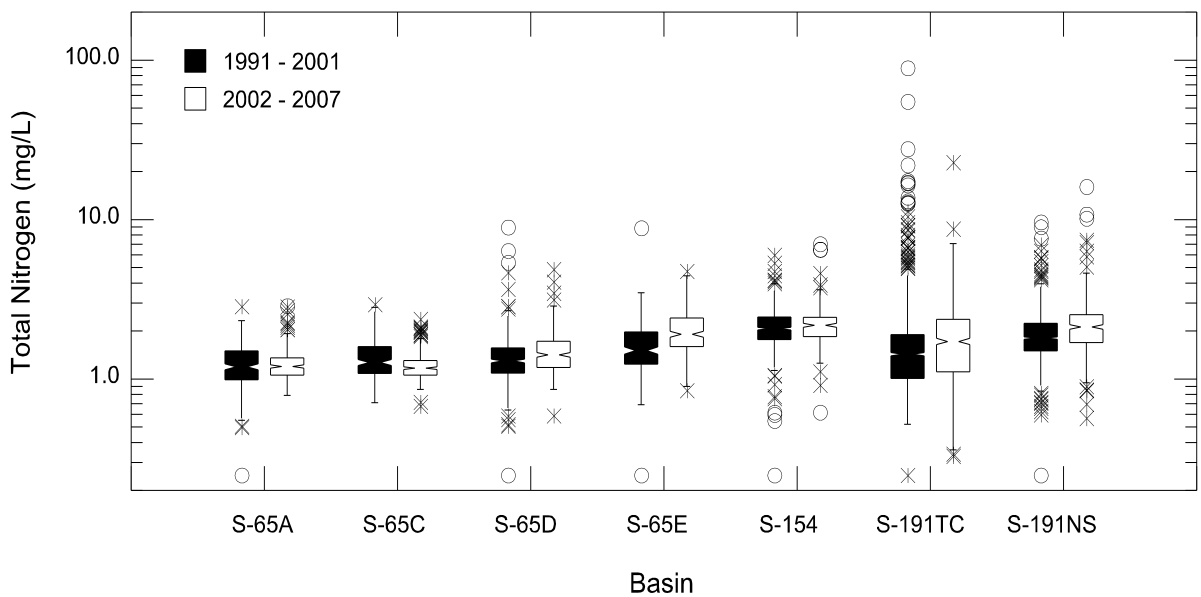


Figure 2. Box and whisker plot of total phosphorus (top) and total nitrogen (bottom) concentrations for the periods 1991 – 2001 and 2002 – 2007.

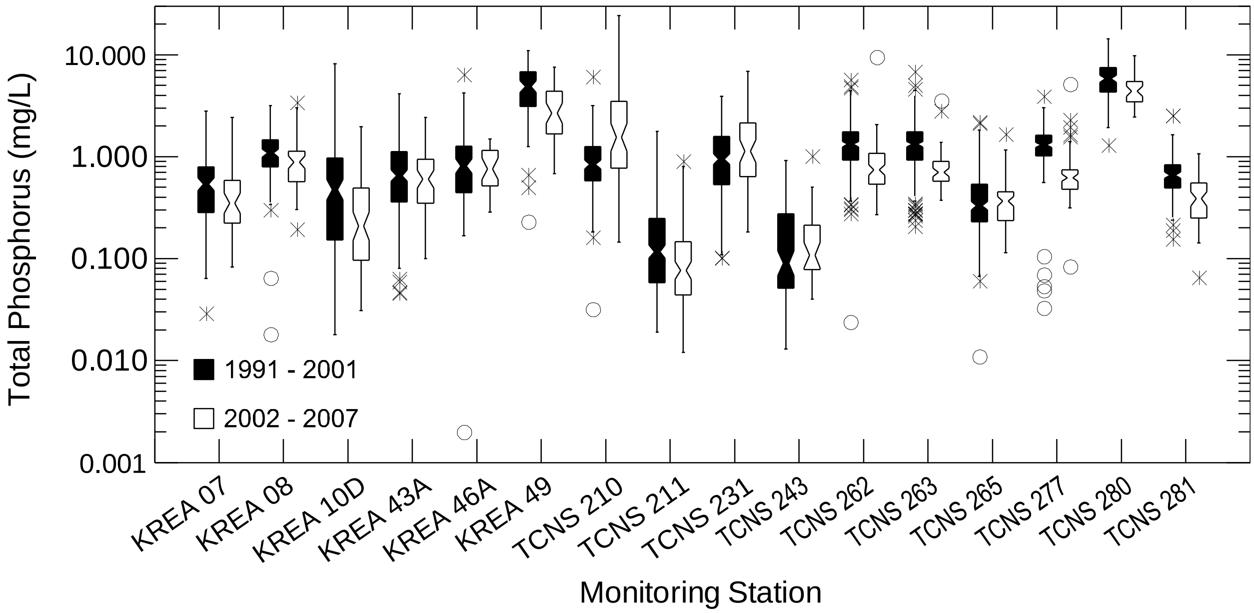


Figure 3. Box and whisker plot of total phosphorus concentrations for the periods 1991 – 2001 and 2002 – 2007 for monitoring stations located at individual dairy farms.

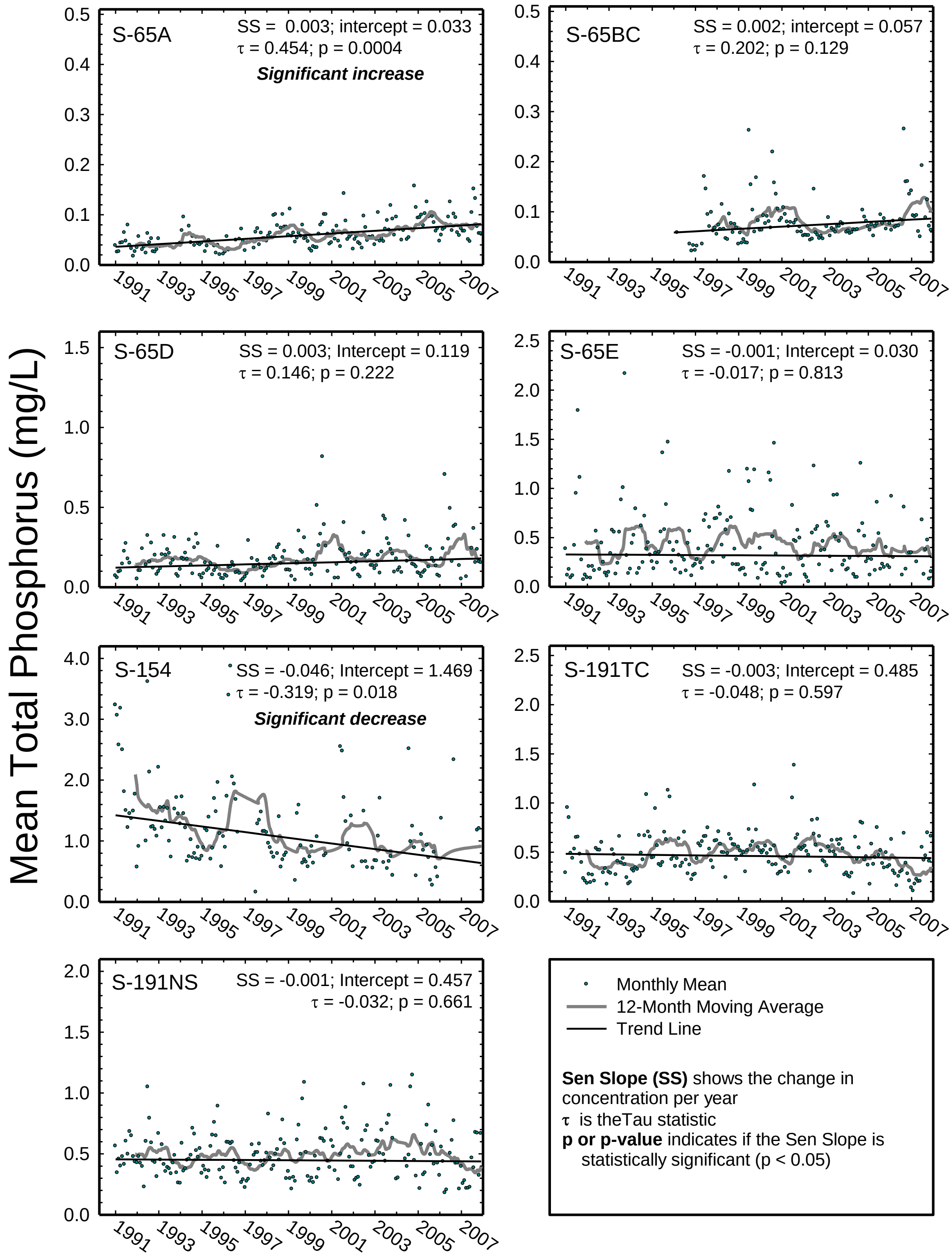


Figure 4. Seasonal Kendall trends and 12-month moving average plots of mean monthly total phosphorus concentrations for the period 1991 – 2007.

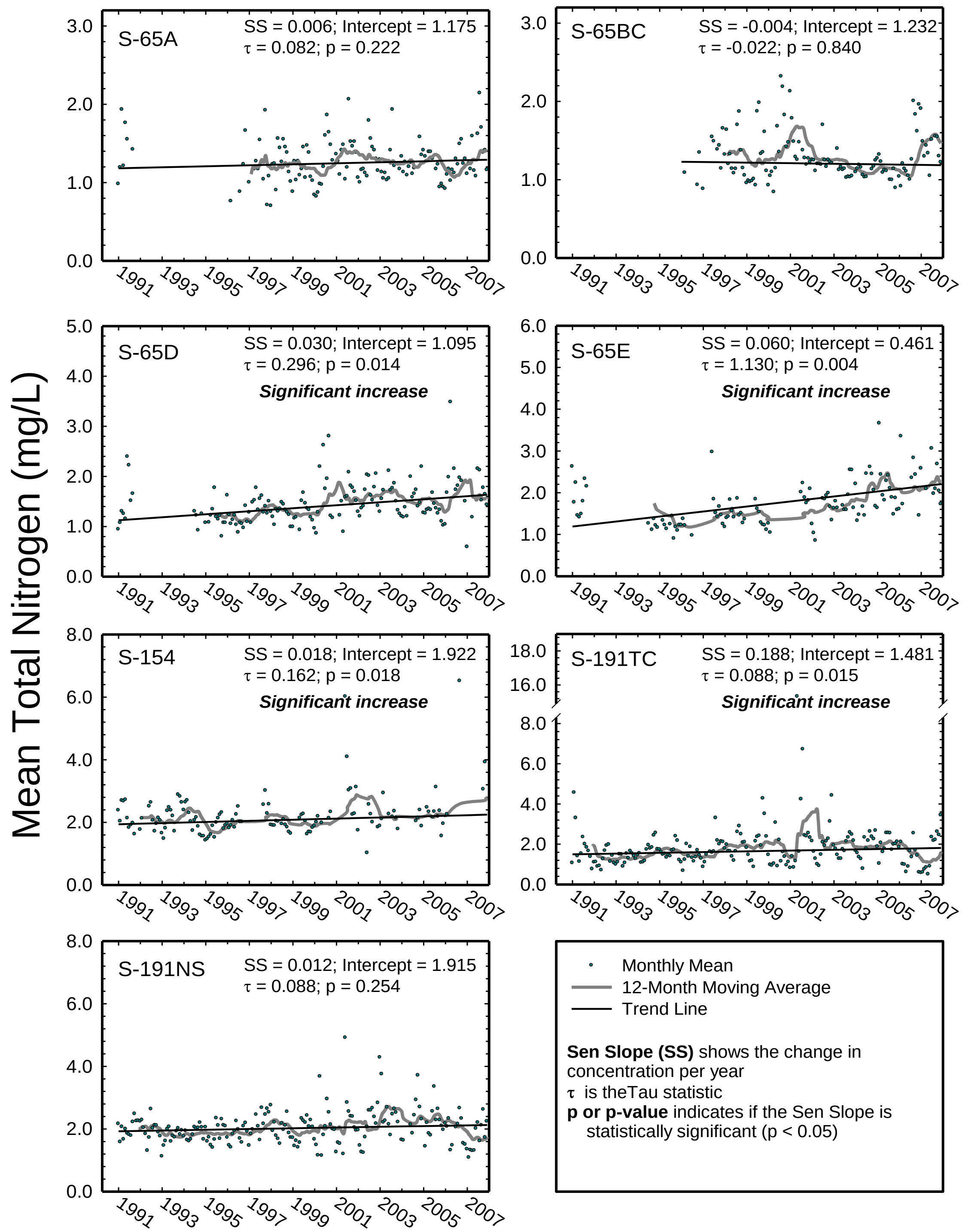


Figure 5. Seasonal Kendall Tau trends and 12-month moving average plots of mean monthly total nitrogen concentrations for the period 1991 – 2007.