BRADEN RIVER WATERSHED MANAGEMENT PLAN
SURFACE WATER RESOURCE ASSESSMENT
FINAL REPORT

Volume II. Evers Reservoir Water Quality Report

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 EXECUTIVE SUMMARY

Under contract with the Southwest Florida Water Management District (SWFWMD), the Singhofen Team (Singhofen and Associates; Jones Edmunds & Associates, Inc. (Jones Edmunds); and Toxicological & Environmental Associates, Inc.) is developing a watershed management plan (WMP) for the Braden River watershed. This report concludes the water quality portion of the Surface Water Resource Assessment (SWRA), which is a part of the overall WMP process.

With respect to water quality the SWRA had two primary goals:

1. A primary water quality concern in the Evers Reservoir is the increasing difficulty with algae blooms. Treatment of the blooms has lead to concerns over copper concentrations. Recent research has also hinted at potential health impacts due to toxins released by algae into drinking water reservoirs. Modeling of the various forms of nitrogen and phosphorus is an important aspect of this phase. A goal of this study was to determine the potential impacts to water quality that may be attributed to changes in the watershed since the early to mid 1980's.
2. The watershed is expected to continue undergoing significant conversion from agricultural land uses to urban land uses. As previously identified, one goal of this study was to make future water quality projections and determine the effects of various runoff treatment recommendations.

Water quality analysis of the Evers Reservoir was performed using the USEPA ecosystem model AQUATOX using water loadings derived from the SWRA water quantity model and constituent concentrations derived from the FDEP Impaired Water Rule Database (IWR) using the USGS empirical model MVUE.

Simulation of nutrient loads and corresponding ecosystem response for Evers Reservoir was achieved using AQUATOX. The model was run for the calibration period from 1997 through 2001 and the verification run performed for the years 1992 through 2005. The model reasonably predicted nutrient loads, algal biomass as indicated by chlorophyll *a* and green and blue-green algal dynamics within the Evers Reservoir system. The model also predicted the responses of blue green algae to chemical controls (algaecides copper sulfate and peroxide). Results show that the algal levels in the system are currently being controlled by additions of algaecides. The model also showed that recent trends in both nutrients and resulting Trophic State Index (TSI) are decreasing, indicating improving water quality conditions.

2.0 INTRODUCTION

Under contract with the Southwest Florida Water Management District (SWFWMD), the Singhofen Team (Singhofen and Associates, Jones Edmunds & Associates, Inc., and Toxicological & Environmental Associates, Inc.) developed a watershed management plan (WMP) for the Braden River watershed. This report presents the water quality portion of the WMP and concludes the Surface Water Resource Assessment (SWRA), which is a part of the overall WMP process. This report presents the water quality modeling of the Bill Evers Reservoir (Figure 1), which is a critical component of water supply in the Braden River watershed and surrounding areas.

The evaluation for this report was divided into two connected efforts: a water quality analysis and a water quantity (supply) analysis. For the water quantity portion of the evaluation, Jones Edmunds built a Visual Basic for Applications water budget model. Toxicological & Environmental Associates, Inc. (TEA) used a U.S. Environmental Protection Agency (USEPA) ecosystem model, AQUATOX, to simulate water quality conditions in the Evers Reservoir. Details of the water quality modeling effort and the recommendations derived from that exercise are provided in this report. Further investigations will be completed during the third part of the WMP process, including the creation of a third model. This final model will be an Interconnected Channel and Pond Routing (ICPR) model that will further characterize water quantity and flood risk in the Braden River watershed.

2.1 AUTHORIZATION

This project was performed under Work Order #5 under Agreement No. 03CONC00015 to Singhofen and Associates and their respective subcontractors.

2.2 PROJECT LOCATION AND GENERAL DESCRIPTION

The Braden River watershed (Figure 1) is located in Manatee and Sarasota Counties and is approximately 57 square miles. In 1936 the Braden River was dammed to create Ward Lake, with a storage capacity of about 585 million gallons (DelCharco and Lewelling 1997, Trommer et al. 1999). In 1985 the storage capacity of the lake was increased to about 1,400 million gallons, and it was renamed the Bill Evers Reservoir. This reservoir contains three hydrologic reaches: 1) an upper reach about 8.6 miles long composed of naturally incised free-flowing channel; 2) a middle reach about 6.4 miles long containing a meandering, impounded channel; and 3) a lower reach about 6 miles long consisting of a tidal estuary (DelCharco and Lewelling 1997, Trommer et al. 1999).

2.3. PURPOSE AND OBJECTIVES

The SWRA was intended to evaluate the Evers Reservoir from both a water quantity and a water quality perspective and to use the models from the evaluation to predict future impacts to the reservoir. The SWRA was also intended to develop recommendations to address current and future impacts. Specific objectives related to each type of modeling are discussed below.

Surface Water Budget Assessment Objectives

The four primary water budget goals for this portion of the Braden River Watershed Management Plan were presented previously (see Methodology Memo by the Singhofen and Associates Team written for the SWFWMD). These goals are summarized below:

1. Beginning in the spring dry season of 1997 and continuing through 2002, large declines in water level occurred in the Bill Evers Reservoir from March to mid-July. These declines were several feet greater than what had historically been experienced. Withdrawals from the reservoir did not increase to any significant degree over that period. A primary goal of this assessment was to understand the reasons for these observed declines (e.g., if they were induced by changes in the watershed, if they were a function of unusual rainfall patterns, or if they were a combination the two).
2. As development continues in this increasingly urbanized watershed, the hydrology will be further altered, primarily with increased imperviousness coupled with wet detention ponds. Agricultural irrigation will decrease and lawn irrigation will increase, which may alter the amount of water imported into the watershed from outside supplies. A primary goal of this assessment was to accurately determine the impacts of development on the

reliability of the water supply (i.e., will this conversion from agricultural land to urban land affect the firm yield of the Reservoir).

3. Outstanding Florida Waters criteria apply within this watershed, resulting in wet detention ponds for new developments that are approximately 50 percent larger than under the standard criteria. Although greater pollutant removal efficiencies are achieved by the larger ponds, the increased evaporation from the ponds may affect the firm yield of the Evers Reservoir. A goal of this assessment was to determine how these larger ponds may impact the firm yield of the Reservoir.
4. Stormwater is being reused in portions of the watershed to reduce the amount of groundwater withdrawals required, and expansion of this reuse is being considered. Although this is likely a benefit to the regional groundwater supply, it may have an adverse impact on the firm yield of the Reservoir. A goal of this assessment was to determine if stormwater reuse is having an impact on the firm yield of the Reservoir.

As identified in the Surface Water Resource Assessment Approach memorandum, the following points were important in the modeling approach/model selection process for this phase of the project:

- The ability to simulate the interaction between infiltration to, evapotranspiration from, and groundwater flow from the surficial aquifer is paramount because of the percentage of total annual flow reaching the Reservoir via surficial groundwater flow to the channels or the Reservoir itself.
- The model must be able to regenerate infiltration capacity during dry periods and account for time-variable rates such as evapotranspiration.
- The use of reclaimed water for irrigation in the watershed is being evaluated. Depending on the ultimate decision to use reclaimed water, the model may also need to account for the import of this water and associated nutrients into the watershed.

In the Surface Water Resource Assessment Approach memorandum, the Singhofen Team proposed a two-phased approach, with the first phase using a continuous simulation model with a spreadsheet interface for pilot areas and the second phase using SWMM with the groundwater routine for the entire watershed. A primary advantage of using a continuous simulation spreadsheet model is that it would give greater control and flexibility over the simulation of evapotranspiration—the largest and arguably the most important loss term in the model. A primary strength of a model such as SWMM is that it could easily handle whatever flow routing would be required. However, once the continuous simulation had been developed in MS Excel, the Singhofen Team determined that it could be readily extended to the whole watershed—especially since flow routing for this project is not critically important. A daily time step is sufficient to fulfill the goals of this project and travel times are generally less than 1 day throughout the watershed, so detailed routing is not necessary. Thus our final approach discarded SWMM and relied solely on the continuous simulation spreadsheet model.

The results of the surface water quantity assessment model, is presented in Volume I of this report presented by Jones Edmunds & Associates, Inc. and Singhofen and Associates, Inc. (Singhofen, et al. 2007).

Surface Water Quality Modeling Objectives

The purpose of the water quality portion of the project was to model water quality in the Evers Reservoir and to use the model to make predictions about future impacts to the Reservoir. After construction and calibration, model simulations were conducted for the continuous time period from 1992 through 2004. The model was then used to make comparisons between current and predicted changes in nutrient loading levels and subsequent eutrophication response. This response was evaluated by observing trends in the frequency of algal blooms and measured by evaluating the frequency of exceedance of chlorophyll *a* levels of 20 μg/l.

With respect to water quality the SWRA had two primary goals:

1. A primary water quality concern in the Evers Reservoir is the increasing difficulty with algae blooms. Treatment of the blooms has lead to concerns over copper concentrations. Recent research has also hinted at potential health impacts due to toxins released by algae into drinking water reservoirs. Modeling of the various forms of nitrogen and phosphorus is an important aspect of this phase. A goal of this study was to determine the potential

impacts to water quality that may be attributed to changes in the watershed since the early to mid 1980's.

2. The watershed is expected to continue undergoing significant conversion from agricultural land uses to urban land uses. As previously identified, one goal of this study was to make future water quality projections and determine the effects of various runoff treatment recommendations.

3.0 SURFACE WATER QUALITY MODEL

3.1 SURFACE WATER QUALITY DATA

3.1.1 Tributaries

Surface water quality data from the Braden River were derived from the Florida Department of Environmental Protection's Impaired Water Rule (IWR) database (FDEP, 2007). This database contains the most recent data available for the various stations both within the reservoir itself, as well as upstream in the Braden River, maintained by Manatee County.

3.1.2 Watershed

Flows from the Braden River main stem derived from the water budget model (discussed in Section 1.0) were used to drive the water quality model.

3.1.3 Potable Supply Reservoirs

The original water quality assessment approach was to use a USGS technique incorporating observed flow (Figure 2) and existing water quality data to statistically calculate the daily water quality loads to the Reservoir using QMLE (Quasi-maximum Likelihood Estimator). However, the latest technique is to use MVUE (the Minimum Variance Unbiased Estimator), and when this technique was applied a better result was achieved. This approach is based on obtaining the inflows to the system (the Bill Evers Reservoir) and then using those flows to calculate daily loads by the statistical method. This estimated daily load is in turn used to drive the USEPA model AQUATOX. This approach bypasses the problems associated with calibrating and producing the input data necessary for AQUATOX from a continuous simulation model. Previous experience using this approach has been very successful in estimating daily loads for various nutrient parameters for other systems.

When conducting the statistical calculations, inflow data from the water budget assessment portion of the SWRA were used. Prior to performing the calculations, existing water quality data were obtained for the following constituents: dissolved nitrate+nitrite (NO_3+NO_2), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), ammonia (NH_3), biological oxygen demand (BOD_5), and pH. Water quality constituent data from 1996 through 2005 for Station BR1 at the entrance to the Bill Evers Reservoir were obtained from the Impaired Water Rule (IWR) database, Run 24: New Data from FLSTORET/FDEP STORET, which was compiled on March 23, 2006 by Joe Hand of FDEP. Data for this station were also obtained from the U.S. Geological Survey (USGS) National Water Information System Web Interface found at: http://waterdata.usgs.gov/nwis/inventory. The data for station BR1 were assumed to reflect the incoming concentrations from the Braden River.

3.2 SURFACE WATER QUALITY MODEL

3.2.1 Model Description

AQUATOX was used to continuously simulate algae and other water quality constituents in the Bill Evers Reservoir (see http://www.epa.gov/ost/models/aquatox/). AQUATOX is a PC-based ecosystem model that predicts the fate of nutrients and organic chemicals in water bodies as well as their direct and indirect effects on the resident organisms. Most water quality models predict only concentrations of pollutants in water; they do not project effects of pollutants on organisms. AQUATOX simulates multiple environmental stressors (including nutrients, organic loadings and chemicals, and temperature) and their effects on the algal, macrophyte, invertebrate, and fish communities. Therefore, AQUATOX can help identify and understand the cause-and-effect relationships between chemical water quality, the physical environment, and aquatic life. AQUATOX can represent a variety of aquatic ecosystems, including vertically stratified lakes, reservoirs and ponds, as well as rivers and streams.

3.2.2 Source Generation

The U.S. EPA describes AQUATOX as a simulation model for aquatic ecosystems. The model and supporting documentation can be found at the USEPA Water Quality Models and Tools webpage (http:/www.epa.gov/waterscience/models). The source code is currently not provided for AQUATOX.

3.2.3. In-Stream Processes

Within the AQUATOX model, simulated ecosystem components are called *state variables* and include organisms, detritus, toxicants, nutrients, dissolved oxygen, water inflow, temperature, pH, light, and wind. Individual state variables may be added or deleted and require initial values and loadings for inclusion in simulations. Initial small constant loadings for plants and invertebrates are often used as "seed" values to account for all ochthonous inputs (i.e., upstream drift of periphyton or zoo benthos) and seasonal reestablishment of plant populations from rhizomes. Upstream loadings are in the form of constant or dynamic inputs. AQUATOX can derive daily dynamic loadings from irregular data points through a flexible interpolation routine. Multipliers may be used to alter loadings as a way to correct or convert data series or analyze various loading scenarios.

Organism state variables include plants, invertebrates, and fish. The AQUATOX data libraries contain a list of plants for each taxonomic group, from which the user may select those needed for a particular simulation. Likewise, there are invertebrate and fish lists in the data libraries. Pelagic and benthic invertebrates are available for inclusion, and available fish species include forage fish, bottom fish, and game fish. Additional library entries may be made to include important component species.

Detrital inputs (both initial conditions and loadings) may be in the form of organic matter (dry weight), organic carbon, or biochemical oxygen demand (BOD). There are four compartments for inputting suspended and dissolved detritus: particulate refractory and particulate labile detritus; and dissolved refractory and dissolved labile organic matter.

Three of the most important abiotic characteristics included in the AQUATOX simulation setup are: mean depth, which controls light penetration, volatilization, and attached plant distribution; mean annual evaporation, which is used to compute the water balance; and latitude, which is used to compute photoperiod. As an alternative, the user can specify a constant photoperiod. Light may be entered as a constant, time series, or annual mean and range in Langleys/day. Water volume can be held constant at the initial condition or it can be simulated by inputting inflow or discharge values, or volume. If the inflow and outflow are known, AQUATOX will factor in evaporation and calculate dynamic water volume.

In AQUATOX, temperature is not computed as a state variable, but is instead a driving variable that can be entered as a constant, annual mean and range, or a time-series. In systems where stratification is not a concern, a sinusoidal function based on the annual mean and range is typically sufficient.

The values for wind can be held constant, entered as a time series specific to the site in question, or entered as the default time series (a 140-day record for Columbia, Missouri, represented by a Fourier series with a mean value that can be specified by the user).

The user must specify pH and may do so as a constant or as a time series.

Up to 20 organic chemicals can be simulated simultaneously in AQUATOX, with the assumption that toxic effects are additive. Atmospheric deposition/direct precipitation loadings are on an areal basis (i.e. the water surface). Point- and nonpoint-source loadings are in units of mass per day (g/d) to the water body.

Paired simulations of perturbed and control conditions can be performed using AQUATOX. During control simulations, all organic toxicants are typically zeroed or omitted. Simulations can be performed for a wide range of time periods, from a few days to several decades.

3.3 FACTORS AFFECTING WATER QUALITY

3.4 WATER QUALITY MODELING RESULTS

The volume and bathymetric parameters (depths) were set in AQUATOX using published information provided by Trommer, et al. 1999. Surface water inflows from the watershed into the Bill Evers Reservoir (Ward Lake) were calculated using the water budget model prepared by Jones Edmunds. These inflows were used to drive the hydrodynamic portion of the AQUATOX model as shown in Figure 3.

Using the daily loadings derived by the MVUE approach described below, daily simulations of algal groups in the Reservoir were performed using AQUATOX. The model was calibrated for 1997 through 2001 and the verification simulation was done continuously for 1992 through 2005.

3.4.1 Model Calibration and Verification

Water Quantity Loading

Figure 3 compares the daily inflow from the SWRA water quantity model and the corresponding total daily inflow values used in the AQUATOX simulation. No changes were made to the hydrodynamic inflows for the AQUATOX runs.

Total daily inflows (m^3/day) as calculated by the water quantity model were entered into AQUATOX to simulate the daily reservoir volume (m^3), inflow (m^3/day), and discharge (m^3/day). Figure 4. compares the total daily reservoir volumes (m^3/day) calculated by the water quantity model with those simulated by AQUATOX. There was a very good correlation with volume calculations by both models. Figure 5. compares the total daily reservoir outflow (m^3/day) calculated by the water quantity model and the USGS-measured flows with those calculated by AQUATOX during simulations. Overall, there was very good agreement between the two models in volume predictions, with the AQUATOX model slightly over-predicting during high level events. Similarly, AQUATOX also slightly over-predicted outflow compared to the water quantity model. Thus, the AQUATOX model predicted slightly higher flushing than observed for the very high flow events.

Constituent Loading

Constituent loadings were calculated using an empirical approach Multi-Variate Unbiased Estimator method (MVUE), which employs a seven-parameter log-linear model (Bradu and Mundlak 1970, Cohn et al. 1989, Gilfory et al. 1990). The equation for the model is:

$$\ln[C] = \beta_0 + \beta_1 (\ln[Q/\tilde{Q}]) + \beta_2 (\ln[Q/ \tilde{Q}])^2 + \beta_3 (T-\tilde{T}) + \beta_4 (T-\tilde{T})^2 + \beta_5 \sin(2*\Pi*T) + \beta_6 \cos(2*\Pi*T)+ e \text{ (I)},$$

where ln [ ] = natural logarithm function, C = constituent concentration in milligrams per liter (mg/L), βx = parameters estimated by ordinary least squares, Q = water discharge in cubic meters per second (m^3/sec), T = time measured in years, sin = sine function, cos = cosine function, $\Pi = 3.14159$, and e = independent, random error. The parameter β_0 is a constant, while β_1 and β_2 describe the relationship between concentration and inflow, β_3 and β_4 describe trends in concentration data, and β_5 and β_6 describe seasonal variability in concentration data. Errors (e) are assumed to be independent and normally distributed with zero mean and variance. Parameters Q and T are "centering" variables that improve the numerical precision of the estimates (Draper and Smith 1981), and are defined such that there is no correlation between β_1 and β_2 or between β_3 and β_4.

The model explains the relationship between constituent concentration and inflow by using a linear term $(\ln [Q/\tilde{Q}])$ for constituent concentration and a quadratic term $(\ln [Q/\tilde{Q}])^2$ for the relationship between concentration and inflow. Similarly, the relationship between constituent concentration and time is explained by using a linear term $(T-\tilde{T})$ for concentration, while using a quadratic term $(T-\tilde{T})^2$ for the relationship between concentration and time. Finally, seasonal variation is explained by the terms $\sin(2 *\Pi* T)$ and $\cos(2 *\Pi* T)$.

The MVUE regression model was run using the SWRA water quality model output and the constituent concentrations for the lower Braden River (BR1) IWR water quality station.
Once the regression was implemented, the output was compared with observed constituent concentrations over three time periods: 1996-2005; 1996-2000; and 2001-2005. The model performed poorly for the longer time period (1996 through 2005) presumably due to changes in flow-concentration relationships within the basin because of changing landuse. Better fits were observed for the shorter period analyses. Overall, the model output was found to "fit" general patterns in the observed values when run separately for the periods 1996-2000 and 2001-2005. For example, the model produced a highly significant r^2 of 0.65 for total phosphorus for 1996-2000 time period (Table 1). The regression produced more scattered, but highly significant relationships (r^2 of 0.303 and 0.356) for the respective periods for total nitrogen. During the

validation time period (1996-2000) for all parameters calculated, MVUE regressions showed statistically significant relationships, except for BOD. However, during periods of extremely high or low inflows, particularly during the 2001-2005 time periods, the model output showed much greater variability than was depicted in the observed values for those periods.

Table 1. Statistics Calculated for MVUE derived constituents for Braden River Station BR1

	R^2 Value			Significance F		
Nutrients	**Period 1996-2005**	**Period 1996-2000**	**Period 2001-2005**	**Period 1996-2005**	**Period 1996-2000**	**Period 2001-2005**
Nitrogen Ammonia	0.1302	0.6332	0.3648	0.4894	0.0322	0.1729
NitrateNitrite	0.2288	0.4348	0.1697	0.0267	0.0277	0.5917
pH	0.0802	0.5546	0.2122	0.5856	0.0038	0.3778
Total Phosphorus	0.1108	0.6595	0.1369	0.4800	0.0002	0.8699
BOD5	0.4279	0.2792	0.6427	0.0001	0.2777	0.0007
Total TSS	0.1636	0.5292	0.1952	0.1408	0.0064	0.4924
Total Nitrogen	0.1156	0.3039	0.3562	0.3249	0.0070	0.0088

For performing the AQUATOX model runs, the SWRA water quantity predictions and concentrations derived using MVUE for total phosphorus and total nitrogen concentrations (Figure 6 and Figure 7 respectively) were used to calculate incoming nutrient loads to the Evers reservoir.

The initial model coefficients for water quality and biological parameters were obtained from the AQUATOX built-in libraries for all parameters. The model setup included all standard water quality state variables, six algal state variables representing diatoms (two groups), greens, crypto monads, and blue-green algae (three groups). In addition, two toxicant state variables were included for the two algaecides, copper sulfate and calcium peroxide. The addition of calcium peroxide was a new component for the AQUATOX model and required some minor modifications to the toxicity records. The resulting new toxicity records were added to the AQUATOX standard database.

Calibration of the model is generally achieved by applying factors to both input nutrients and/or to toxicant loads in order to bring the resulting predicted and observed concentrations within reasonable agreement with observed data for the reservoir. The calibration was optimized to derive the best results for chlorophyll *a*, a key variable in managing the reservoir. For the AQUATOX Evers Reservoir runs, no toxicant loads was necessary to derive reasonable simulation results. All loads for toxicants were set to 1.0 times observed loads meaning it was not necessary to adjust nutrient loads to derive a reasonable calibration. Phosphorus loading, likewise, was set for 1.0. For nitrogen loading, however, it was necessary to reduce total nitrogen loading to half of the calculated loads for nitrogen from MVUE and to increase the organic carbon loads by a factor of 9 in order to force nitrate-nitrogen calues to reasonable levels. It was also necessary to make 99.9 percent of the organic carbon load as refractory in order to get an overall reasonable nitrogen balance. Only by adjusting these loads by those factors was the stoichiometric forced nitrogen balance was made to reflect reasonable simulations for all nitrogen species, that is, for the simulated total nitrogen, nitrate and ammonia levels to behave as expected, based on observed values.

Results of the various water quality constituents for the calibration period are presented in Figures 8 through 12. Data for all reported stations of the Reservoir are included to give a range of values for each observation period and account for observed variability between the model and the measured data. A review of these figures shows that there is relatively good agreement for total nitrogen and total phosphorus during the calibration period with a slight underprediction for both parameters. Nitrate-nitrogen and ammonia nitrogen are both still slightly over-predicted by AQUATOX, as mentioned above, but this is due to the assumptions used in the stoichiometric equations within the model.

Algal biomass simulations, based on chlorophyll *a*, showed a relatively good agreement in range, based on the standard AQUATOX library algal parameters. However, a comparison of the peaks in simulated and observed algal biomass showed some phase differences that was not being accounted for by the model. This was particularly true for spring peaks of biomass, based on observed chlorophyll *a*. In order to account for the spring blooms, the light extinction, optimal temperature and growth coefficients for cryptomonads and high nutrient diatoms were slightly adjusted to increase productivity for these two groups. In addition, we simultaneously reduced the same coefficients for the dominant blue-green *Cylindrospermopsis*. This effectively altered the "competition" between these algal groups, slightly favoring the cryptomonads and high nutrient diatoms during the spring period. This resulted in additional spring peaks in biomass for these two groups and reflected much better agreement between the observed and simulated peaks in chlorophyll *a* (Figure 12).

3.4.1.1 Constituent Concentrations

Plots of water quality constituent concentrations for the entire simulation period (1992 through 2005) are presented in Figures 13 through 17. These graphs demonstrate results similar to those during the calibration period, mimicking the annual periodicity for all parameters. As occurred in the calibration period, relative annual ranges show good agreement for all parameters except nitrate-nitrogen. More importantly, chlorophyll *a* numbers (Figure 17) showed very reasoable range and periodicity between simulated and observed values throughout the simulated periods.

A more useful comparison is demonstrated using percent exceedance graphs to determine the distribution of simulated and observed data. Figure 18 presents the exceedance chart for nutrients, which shows a relatively good correlation between observed and simulated values for total phosphorus and total nitrogen and ammonia. The frequency of simulated chlorophyll *a* values (Figure 19) overestimated the observed values for this constituent throughout the range of the simulation. This indicates that the model will give conservatively higher estimates for the frequency of critical chlorophyll *a* values.

Final simulated algal biomass for all algal groups for the calibration period is presented in Figure 20. Many algal groups remain at the minimal biomass values. The simulations predicts that when conditions are conducive to particular species growth, the biomass of that group respond in an expected manner. For example, blue-greens, represented by the invasive *Cryptospermopsis* and the algal groups cryptomonads and high nutrient diatoms, all show expected biomass response curves in the simulations.

3.4.1.2 Constituent Loads

Annual total nitrogen and total phosphorus loads calculated for this project are presented in Figure 21. Previous reports (Blanchard, 1997) have indicated that annual loads for total nitrogen for the 1990-94 period ranged around 25 tons for phosphorus and 75 tons for nitrogen. Loadings calculated by Trommer *et al*. (1999) report somewhat lower loads entering the Bill Evers Reservoir, but higher loads downstream from the outfall. While some elevated loads have been observed within the last decade, the calculations in this report indicate that in more recent years, the levels have been coming down. The most recent years calculated (2002-2004) show phosphorus loads ranging generally below 20 tons, whereas nitrogen is trending down and now runs less than 60 tons (Figure 21). Of course, the loads are highly dependent upon annual rainfall events, and it is likely that in wet years elevated nutrient loading may be observed.

3.4.1.3 Algal Biomass

A primary outcome of this work is to develop an algal prediction model that can be used as a planning tool to provide managers information regarding future water quality, and particularly chlorophyll *a* and other algal trends within the reservoir. The chlorophyll *a* output of the AQUATOX model provides the best quantitative predictive measure of nutrient management strategies in response to changing nutrient regimes. Algal biomass frequency, particularly the major algal taxa (Cylindrospermopsis, cryptomonads, high nutrient diatoms) Figure 23), corresponds reasonably well when compared to dominant algal groups based on cell counts provided by the City of Bradenton (Figure 24). It also predicts well the responses from the early spring cryptomonad and diatom blooms and the summer blue-green blooms. The algal response in AQUATOX responds well to the algaecide additions of both copper sulfate and peroxide (Figure 25 and Figure 26). Simulated blue-green algal biomass shows a very good response to the loading of algaecides, showing declines that correlate well to the timing of algaecide applications (Figure 26).

One disturbing trend in the simulations is the dominance of blue-greens in the most recent periods, perhaps reflecting the simulated impacts of the invasive blue-green *Cylindrospermopsis*.

Additional control measures may be necessary to counter the water quality impacts from this invasive species.

3.4.2 Tributary Water Quality Summary

Tributary water quality trend for the nutrients nitrogen and phosphorus, based on concentration and loading trends (Figures 6 and 7 and Figure 20 respectively), indicate improvements in water quality, i.e. a downward trend since 2001. Again, as with loading, this decreasing trend in concentrations may be the result of a temporary difference in hydrologic conditions due to annual weather regimes, or may be indicative of a reduction of concentrations in the surficial storages of nutrients within the aquifer. In any case, periodic increases may be likely, but future conditions should not exceed observed nutrient concentrations unless other impacts to the watershed are manifested (such as an increase in applied fertilizers in the watershed).

3.4.3 Watershed Water Quality Summary

During the period 1992 through 2000, the nutrient loading trend was increasing. Since 2001 however, the trend for nutrient loading to the Evers reservoir seems to be downward. In part this is likely due to the landuse conversions within the basin from agricultural to moderate-density residential. One must also consider the surficial groundwater storages, however, which will probably retain nutrients as part of a system memory for some period of time to come. Therefore, there will likely be a lag in watershed response until the storage of nutrients within the surficial groundwater aquifers is reduced by storage turnover. Also, during periods of high rainfall it is expected that flushing of these surficial groundwater storages could result in periodically higher loadings to the reservoir.

To determine the trend of nutrient loading changes due to landuse conversion from agriculture to low density residential, data from the University Lakes development (including Cypress Place and University Place developments) located in the upper Braden River watershed were obtained from Manatee County. Data were obtained from that neighborhood development from the construction period to the post- construction period (1995 through 2006) and were analyzed to determine resulting trends in total nitrogen and total phosphorus as a result of land-use conversion from these former agricultural lands to moderate density residential. The results are presented in Figures 27 and 28 for available groundwater and surface water samples, respectively. These data show that for nitrogen, there is no trend either upward or downward in either groundwater or surface water regimes. Total phosphorus concentrations, however, show a downward trend in both surface and groundwater concentrations during the period observed (1996 to 2007). For groundwaters, this trend was statistically significant, with a concentration reduction in phosphorus to about one-third its initial concentration. For surface water data, a similar but non-significant trend in total phosphorus concentration was observed. The trend was non-significant primarily because of the fewer data points available for analysis.

3.5 RECOMMENDED MANAGEMENT POLICIES

If one considers the water quality trends described above which indicate that the trend in nutrient loads and trophic state are downward, future water quality trends will likely improve for the Evers reservoir, resulting in lower nutrient loading and an improving trophic state index (TSI). However, as pointed out above, it is also possible that during wet years, excess nutrients, particularly the limiting nutrient nitrogen, may be flushed from the aquifer storages resulting in periodically higher annual nutrient loads. Based on the observed trends in both surface waters and groundwaters in the vicinity of the University lakes developments in the upper Braden River watershed, it is likely the reduction in trophic state observed is a real trend. Also, we can reasonably predict that the loads to the Evers reservoir will continue to be reduced in the future. At present, approximately 80 percent of the watershed is developed. If future development trends continue, it is likely that additional conversion from agricultural lands to moderate density residential developments will continue. If we conservatively assume that currently agricultural lands contribute twice the total phosphorus loads to the reservoir compared to moderate density residential, then a reduction to one-third of the loading from agricultural lands will result in a reduction of approximately 5 tonnes of phosphorus per year. If the remaining 20 percent of agricultural lands are converted to moderate density residential, we can expect approximately an additional 3 – 7 tonnes per year reduction in total phosphorus loading to the reservoir when full conversion to moderate density residential is realized in the basin. To observe the results of this decreased loading on the Evers reservoir, we have prepared two AQUATOX simulations to predict the results of decreasing the total phosphorus loads by 3 and 7 tonnes respectively, in a 5 year period reflective of changing hydrologic regimes.

The results of these simulations show that under the worst case loading reduction of only 15% phosphorus load reductions, chlorophyl *a* would exceed the 20 μg/l critical limit for approximately 66% of the time, versus 69% of the time observed between 2001 and 2005. The simulations show "best case" scenario with reduced phosphorus loadings of approximately 35% of current loads, chlorophyll *a* would exceed 20 μg/l for approximately 63% of the time. The model thus predicts that there is a likely lag between decreasing nutrient load to the reservoir and response in chlorophyll *a*.

These model observations support the premise that water quality conditions are improving and will likely continue to improve into the future. Periodic perturbations may occur during exceedingly wet years that will likely result in periodic increases in loadings and decreased water quality conditions, as nutrients are flushed from storages in the surficial aquifer. Also, the reservoir currently provides storage of nutrients that are being recycled within the system. This will cause a lag in system response, requiring continued algal management controls for the near future.

3.5.1 Target Water Quality Trends

Water quality trends for the Evers Reservoir (Ward Lake) are conveniently measured by comparing the changes in the Florida lake trophic state index (TSI). This resulting annual index is based on an overall average of the seasonal lake-wide averages. The overall average TSI calculated for the Evers reservoir are presented in Figure 32. It should be noted that these results depict the TSI as based on chlorophyll *a* and nitrogen value, since the TN:TP ratios, by weight, are less than 10. Similar to trends previously noted for both nutrient concentrations and loads, the trend in TSI for the most recent years is showing a downward pattern indicating improving water quality conditions in the reservoir.

The trend for predicted and observed chlorophyll *a* within Evers reservoir does not follow the downward trend observed for either nitrogen or the TSI (Figure 17). While the frequency of peak observations of chlorophyll *a* seem to be lower more recently (2002-2004), the overall trend has increased slightly, particularly in 2004 and 2005. This is likely due to in-lake storages and perhaps other internal processes such as nitrogen fixation.

3.5.2 Target Water Quality Goals

The water quality goals for the Evers reservoir are to achieve levels in key water quality parameters consistent with criteria for Outstanding Florida Waters (OFW). To achieve these goals, it will be necessary to continue with application of BMP's which will reduce nutrient loads to the Braden River. In particular, stormwater BMP's within new developments designed to retain nutrients within the sub-basin, will be particularly important to maintain. While this may be achieved in principal by the ongoing conversion from agricultural landuse to medium density residential within the watershed, full realization of the reduction will require education and continued BMP controls within the watershed to insure reduction in nutrient loading.

Given the expected reductions from land use conversions within the watershed, it is likely additional measures will be necessary to control algal growth within the Evers reservoir system. One observation from the modeling exercise, is that in spite of significant load reductions in phosphorus loading, algal response was minimal with chlorophyll *a* exceedance reductions of only 66% and 63% versus 69% exceedances in the baseline simulation. Thus, additional measures will be necessary. Given the amount of apparent recycle within the system, one management strategy may be periodic alum treatment to accelerate sedimentation in the system. This may help break the algal cycle that is dominated by blue-greens, alter light conditions to allow more growth by more "beneficial" algae, and promote nutrient precipitation.

4.0 CONCLUSIONS

Simulation of nutrient loads and corresponding ecosystem response for Evers Reservoir was achieved using AQUATOX. The model was run for the calibration period from 1997 through 2001 and the verification run performed for the years 1992 through 2005. The model reasonably predicted nutrient loads, algal biomass as indicated by chlorophyll *a* and green and blue-green algal dynamics within the Evers Reservoir system. The model also predicted the responses of blue green algae to chemical controls (algaecides copper sulfate and peroxide). Results show that the algal levels in the system are currently being controlled by additions of algaecides. The data also showed that recent trends in both nutrients and resulting Trophic State Index (TSI) are decreasing, indicating improving water quality conditions.

The model was run for two management scenarios, simulating an decrease of 15% phosphorus loading and a decrease of 35% phosphorus loading, as predicted from changing land use conversions. Given the observation that the loading trend is decreasing, we expect the scenario showing an improving algal bloom frequency (i.e. less frequent) is applicable. When more precise quantitative estimates of the decrease in loadings from the watershed model are available, the AQUATOX model can be re-run to compare predicted and observed chlorophyll *a* frequencies.

The primary factor affecting water quality in the Braden River watershed is stormwater driven loadings from different landuse types. Historically, the upper Braden River watershed was dominated by agricultural landuses and this has likely impacted the Evers reservoir in terms of excessive loading of nutrients resulting in impacted water quality conditions in the reservoir. In more recent years, much of these lands have been converted to low-to-moderate density residential, reflecting the changes is landuse patterns of the growing cities such as Bradenton and Sarasota. Based on observations in developments within the upper basin, this will likely result in a reduction of phosphorus loading to the downstream reservoir. This conversion, along with county and water management district promulgated stormwater best management practices (BMPs), have the potential for improving the water quality conditions within the reservoir.

5.0 REFERENCES

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FIGURES

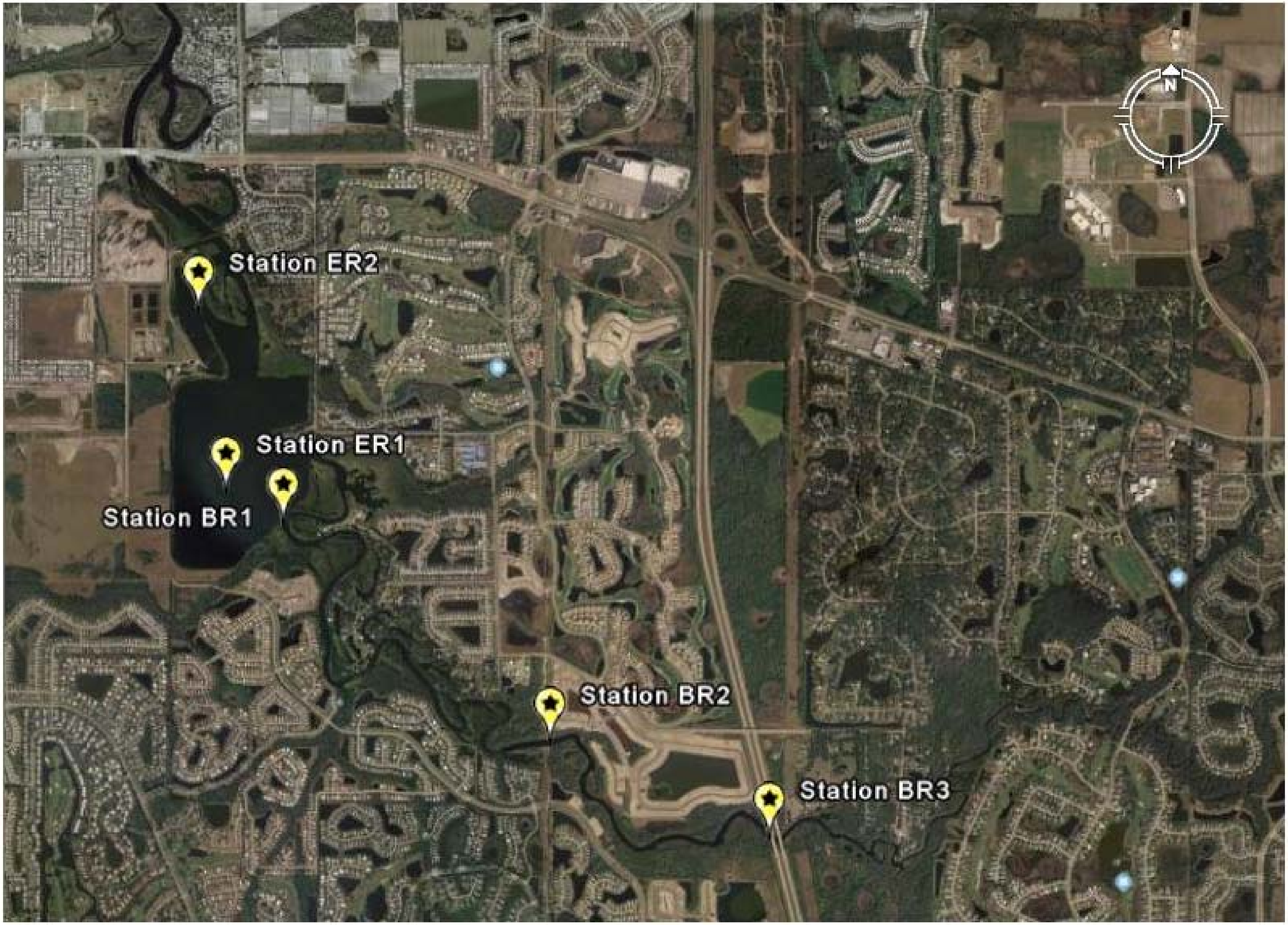

Figure 1. Map of the study area including location of water quality stations used for this analysis.

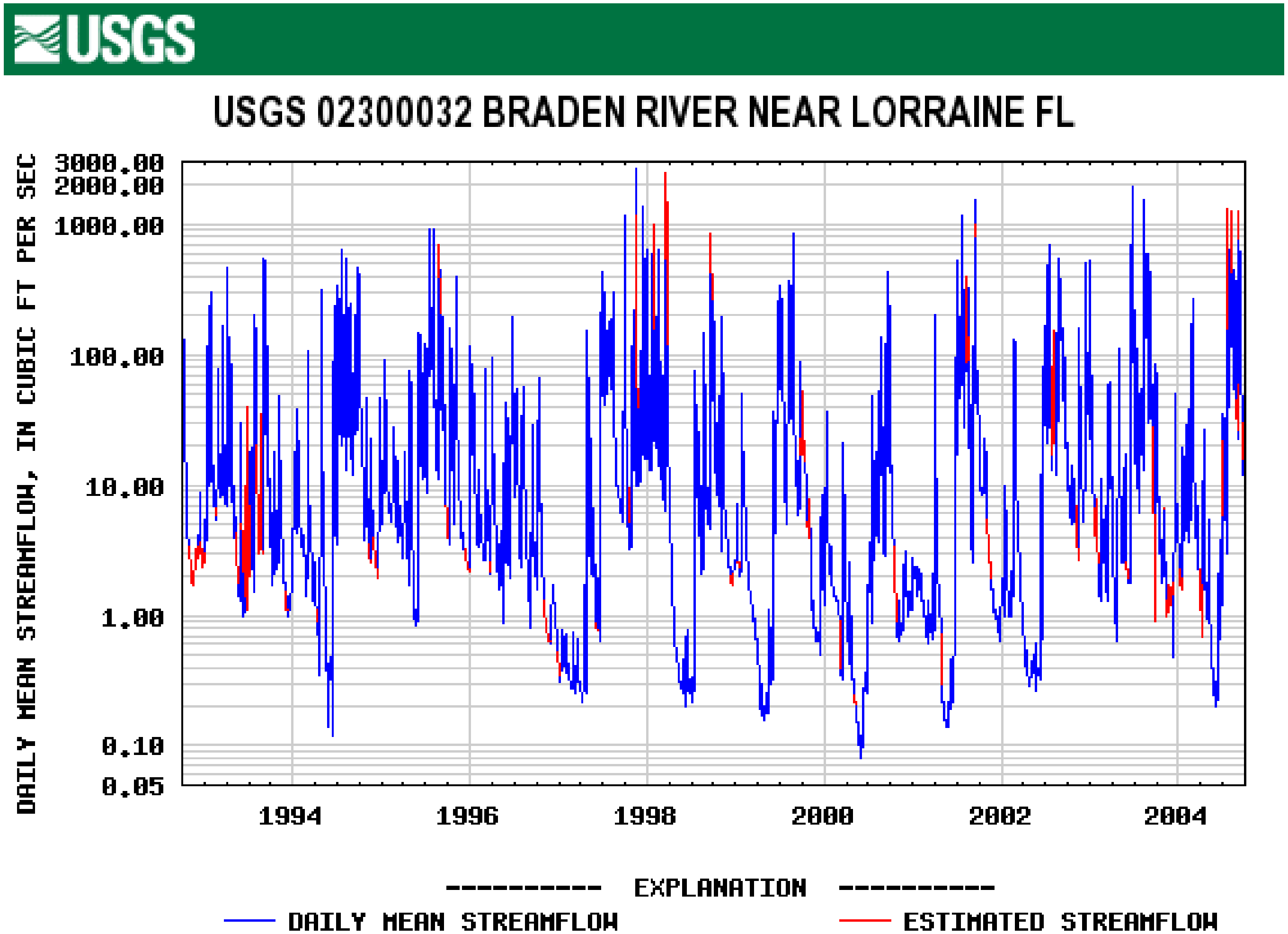

Figure 2. USGS Data for Braden River near Lorraine, Florida 1992-2004.

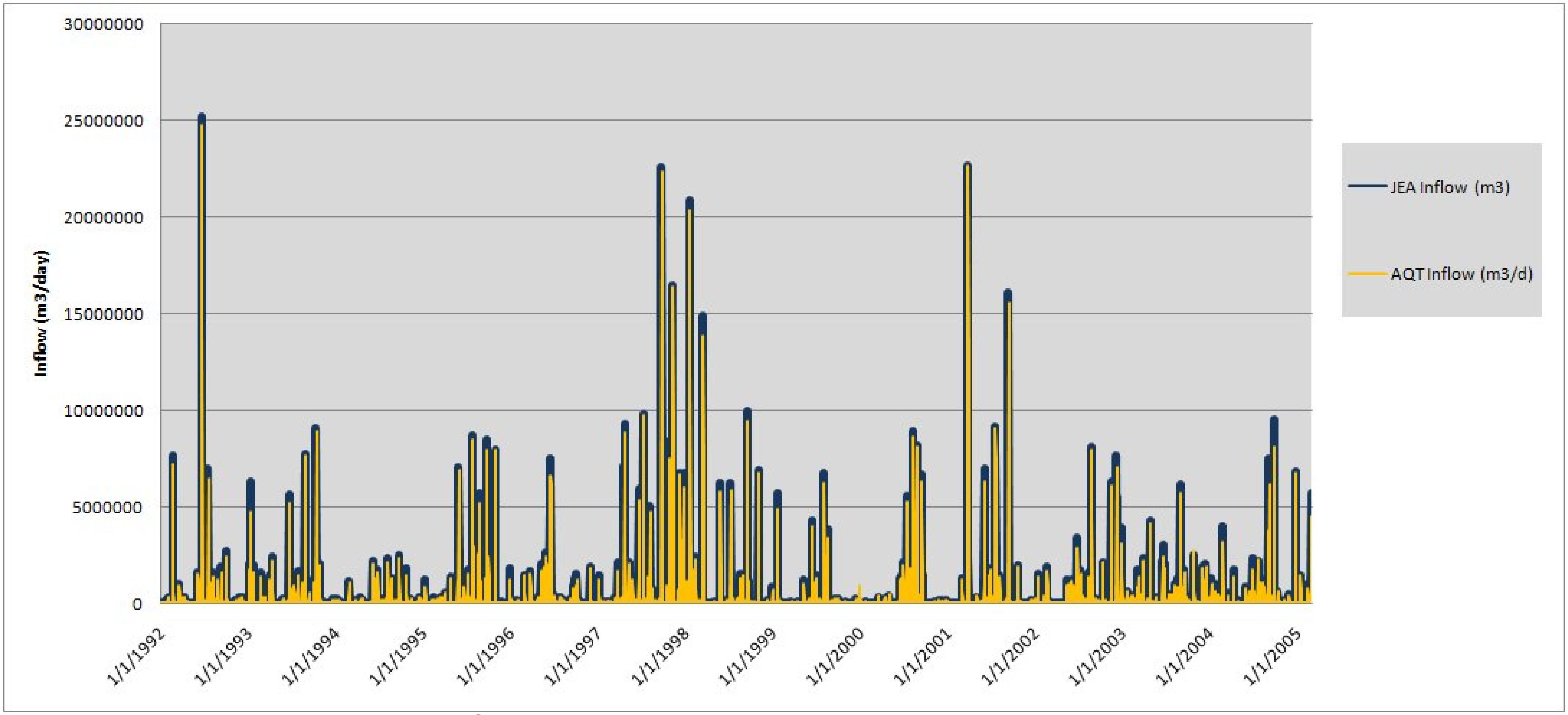

Figure 3. Total daily inflow to the reservoir (m^3/day) used in driving the AQUATOX model. Dark blue represents the inflow used in the water quantity mopdel produced by JEA and the yellow line represents the values used in AQUATOX.

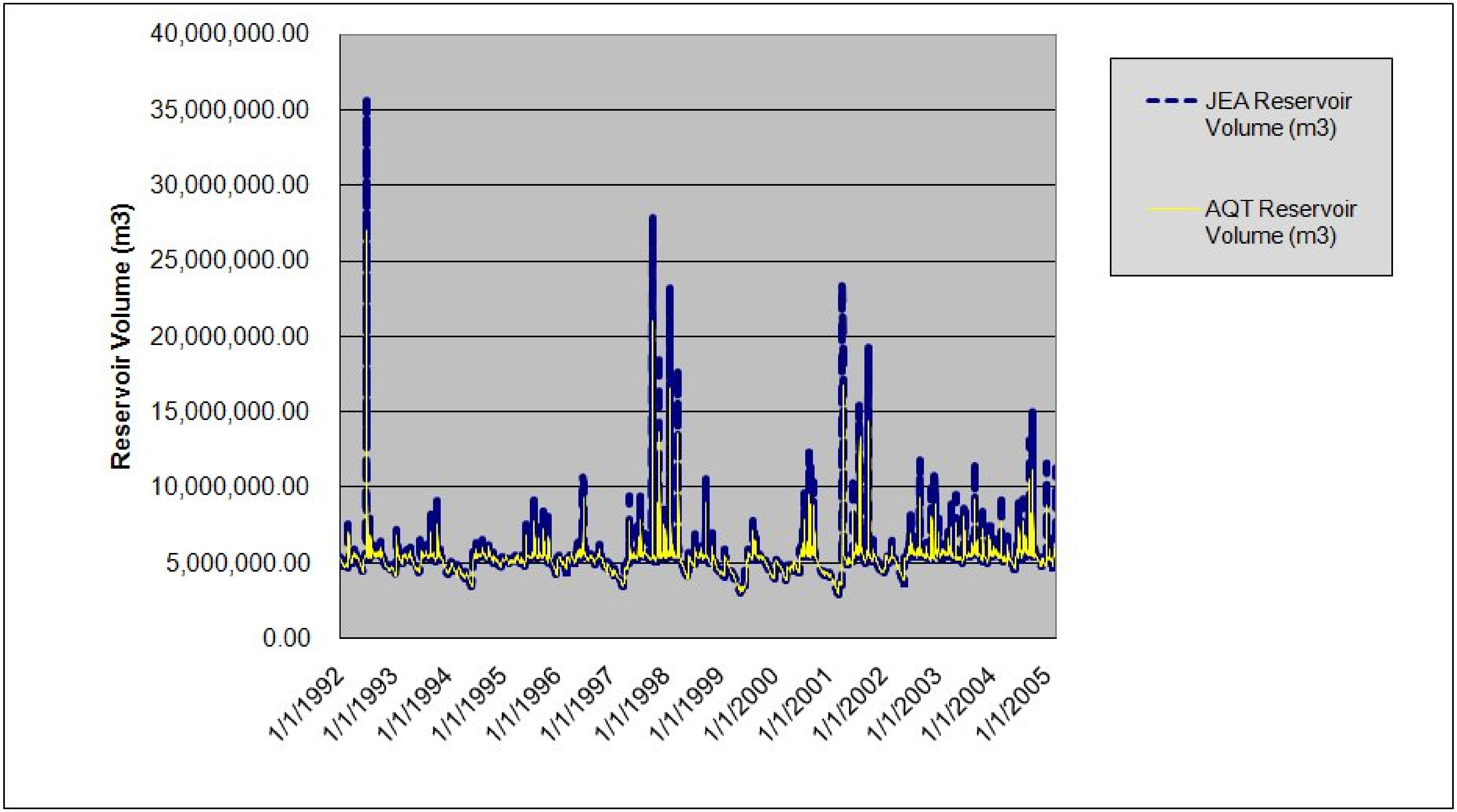

Figure 4. Comparison of daily reservoir volume (m^3) by the JEA model and AQUATOX. The dark blue lines represent the prediction of reservoir volume from the JEA Water Quantity Model and the yellow line represents the reservoir volume represented in AQUATOX.

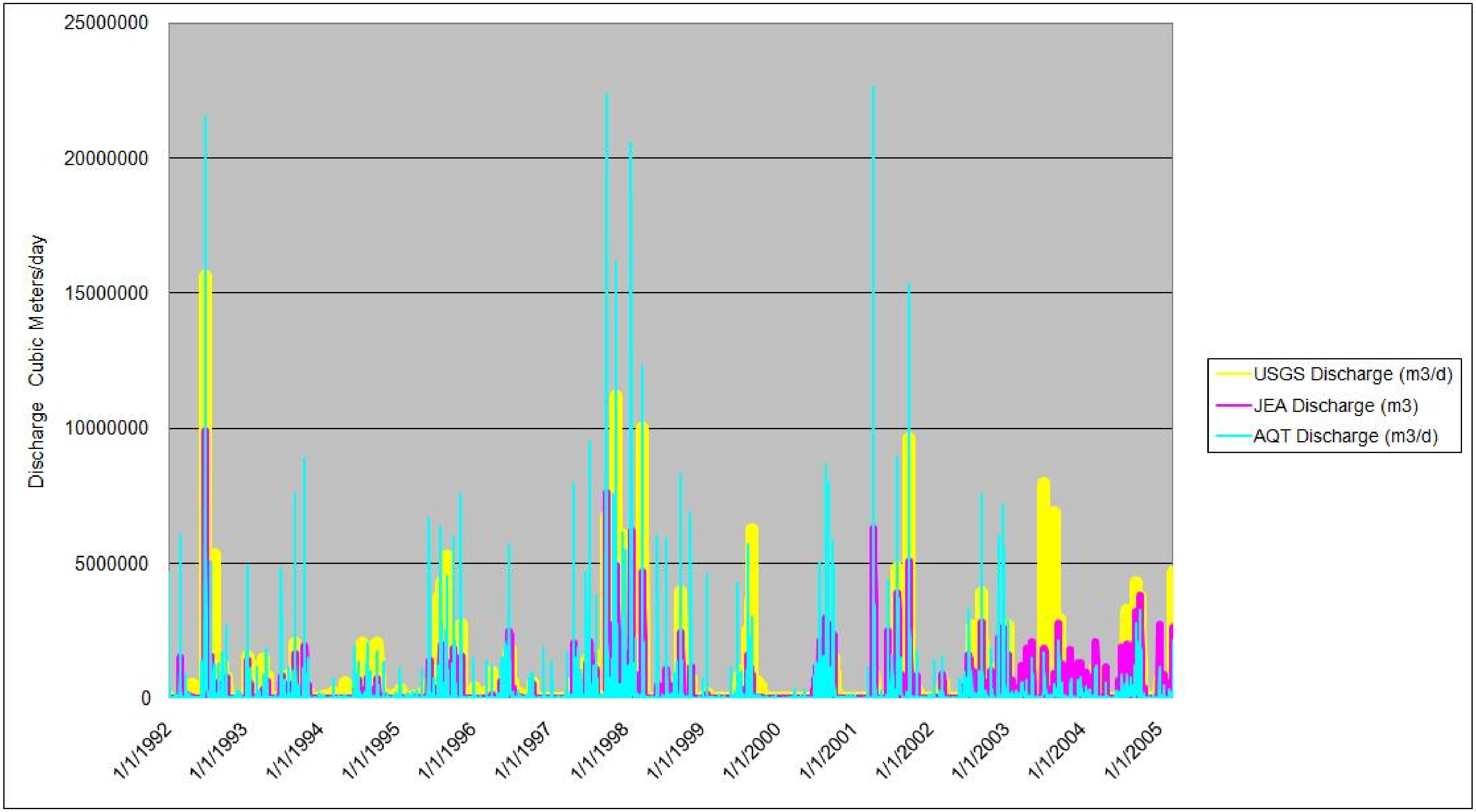

Figure 5. Daily discharge from the reservoir (m^3/day) as calculated by JEA and AQUATOX models, compared to USGS reported discharges.

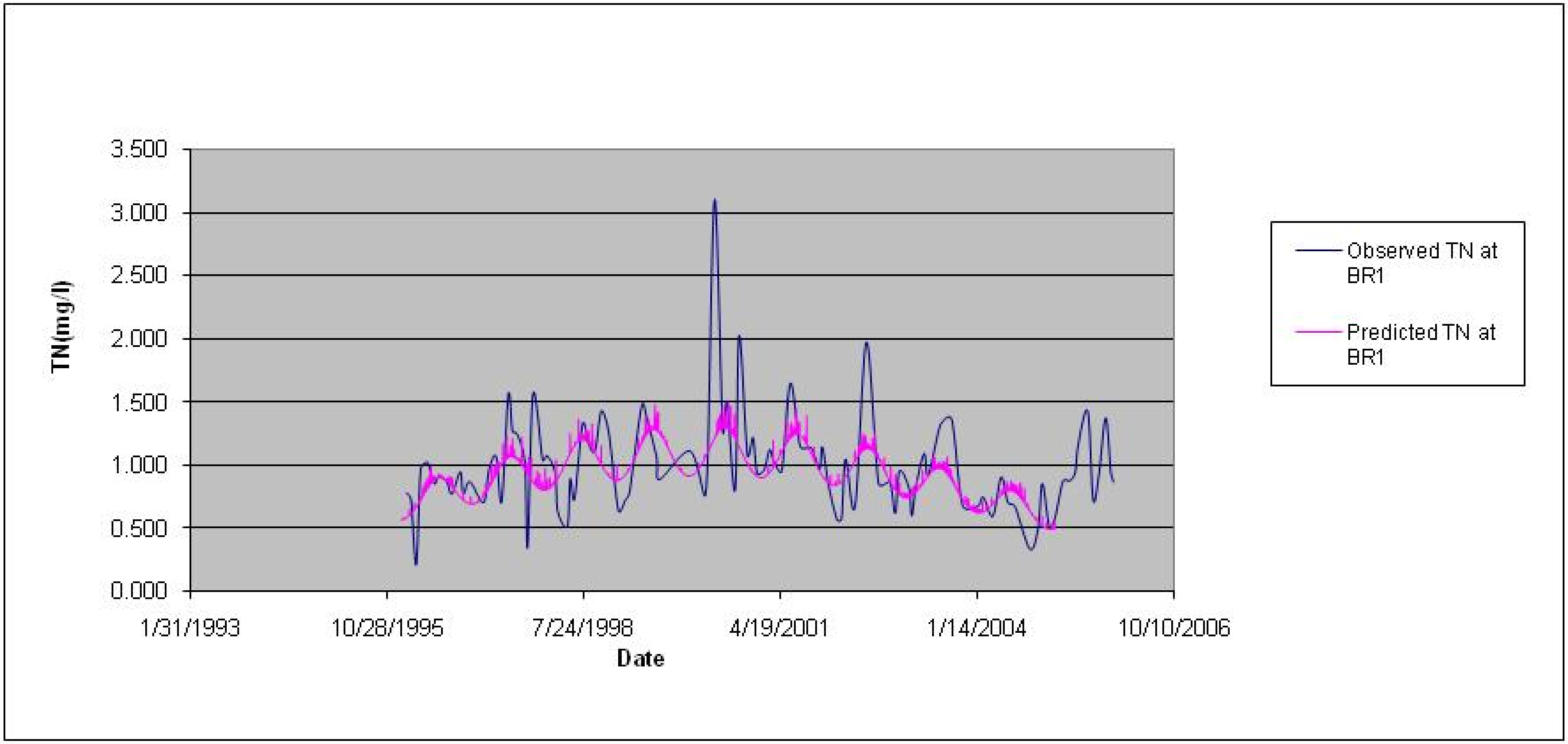

Figure 6. Graph comparing total nitrogen values predicted by the MVUE model with actual observations from Station BR1 in Braden River, for the years 1995-2006.

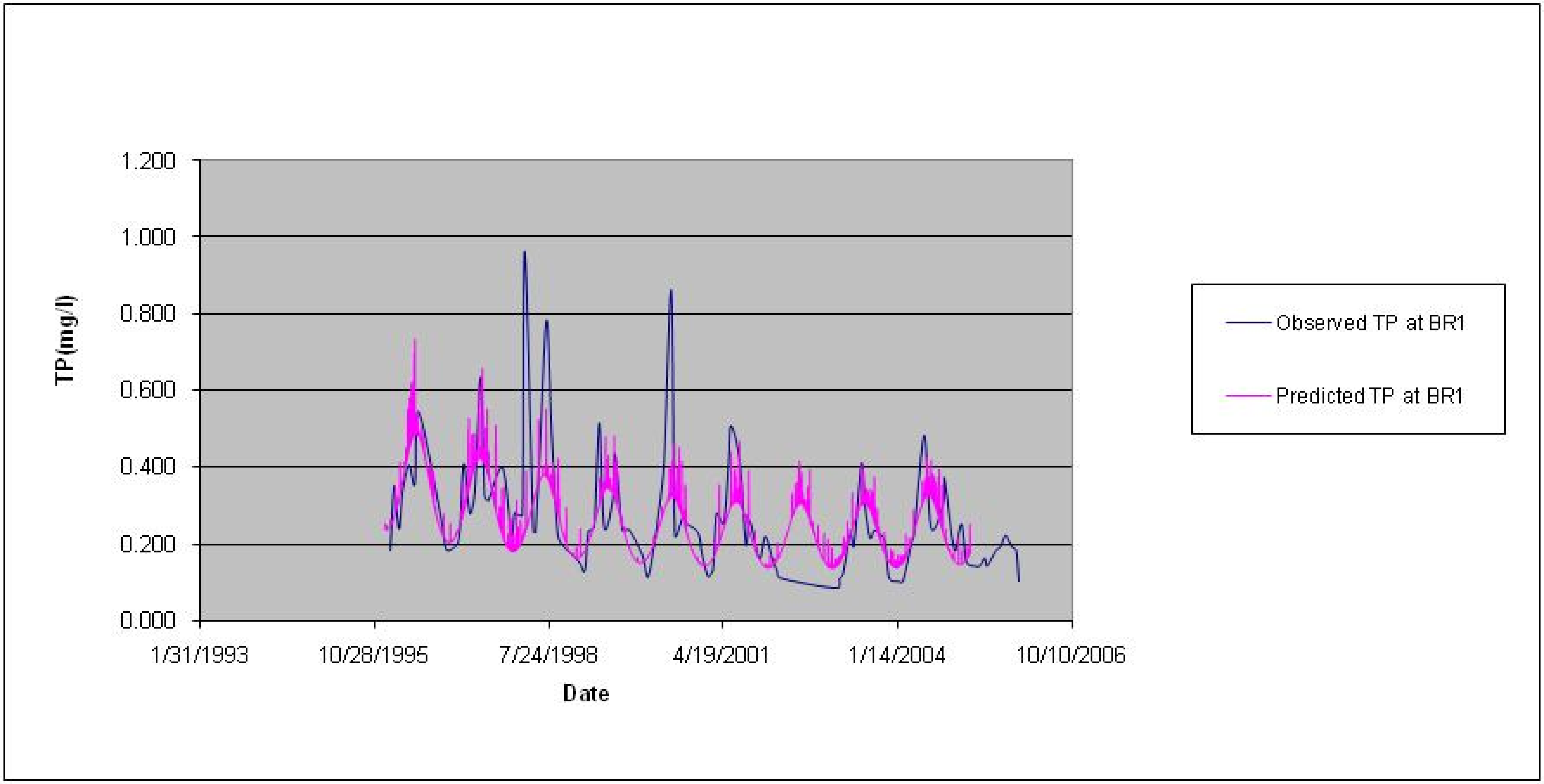

Figure 7. Graph comparing total phosphorus values predicted by the MVUE model with actual observations from Station BR1 in Braden River, for the years 1995-2006.

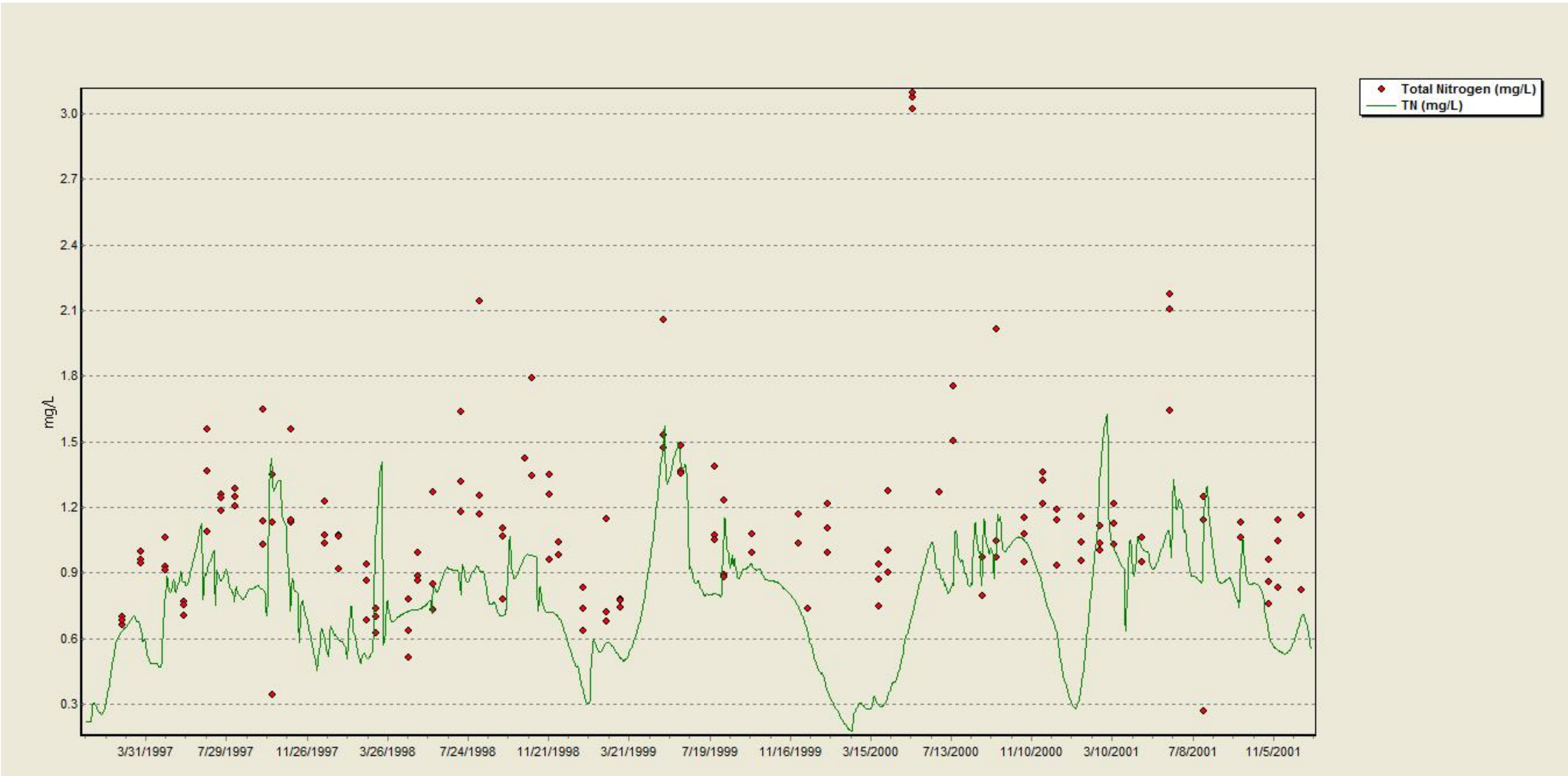

Figure 8. Comparison of predicted (green line) and observed (red points) Total Nitrogen for the calibration period (1997-2001).

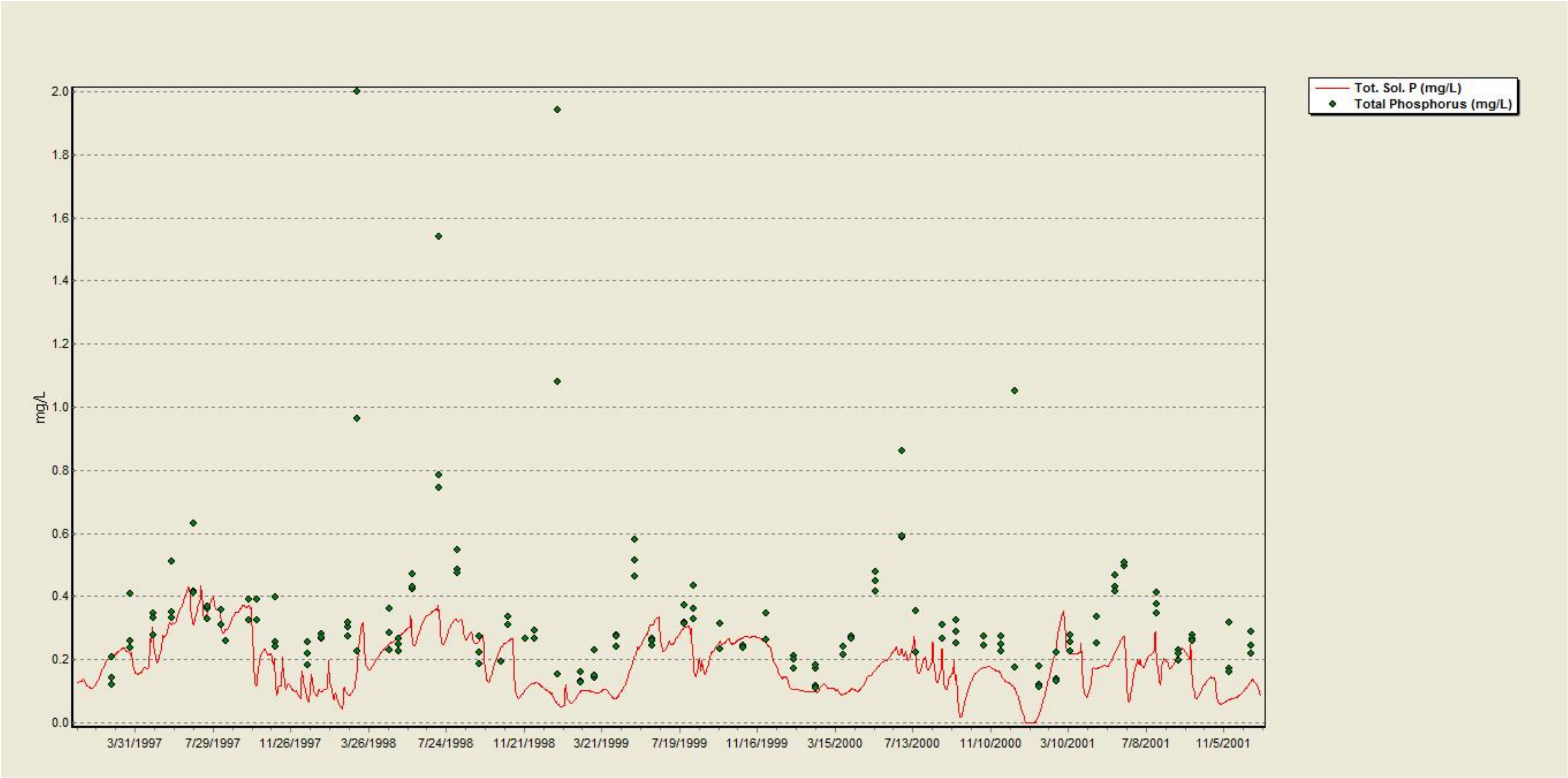

Figure 9. Comparison of predicted (red line) and observed (green points) Total Phosphorus for the calibration period (1997-2001).

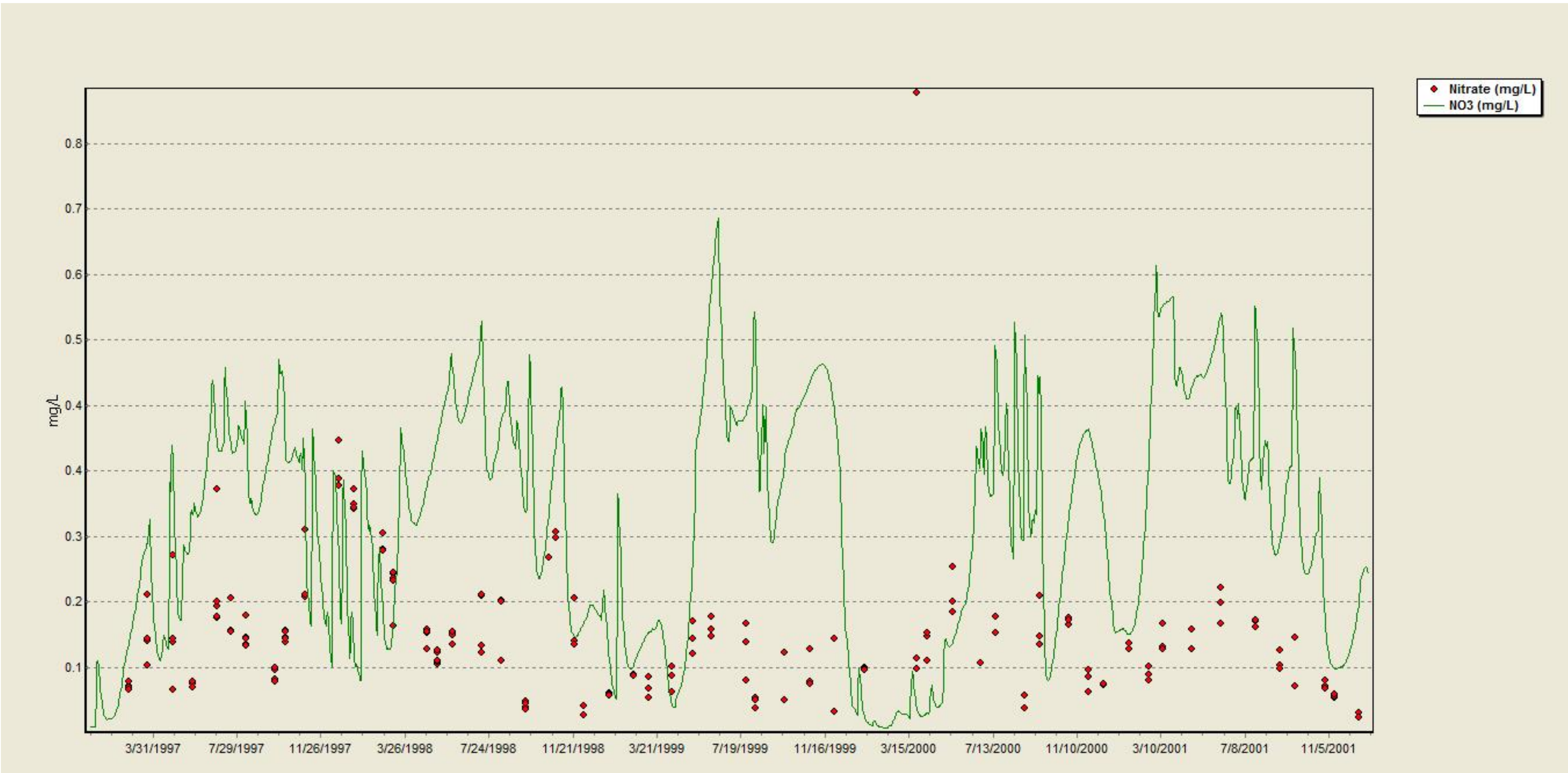

Figure 10. Comparison of predicted (green line) and observed (red points) Nitrate-Nitrogen for the calibration period (1997-2001).

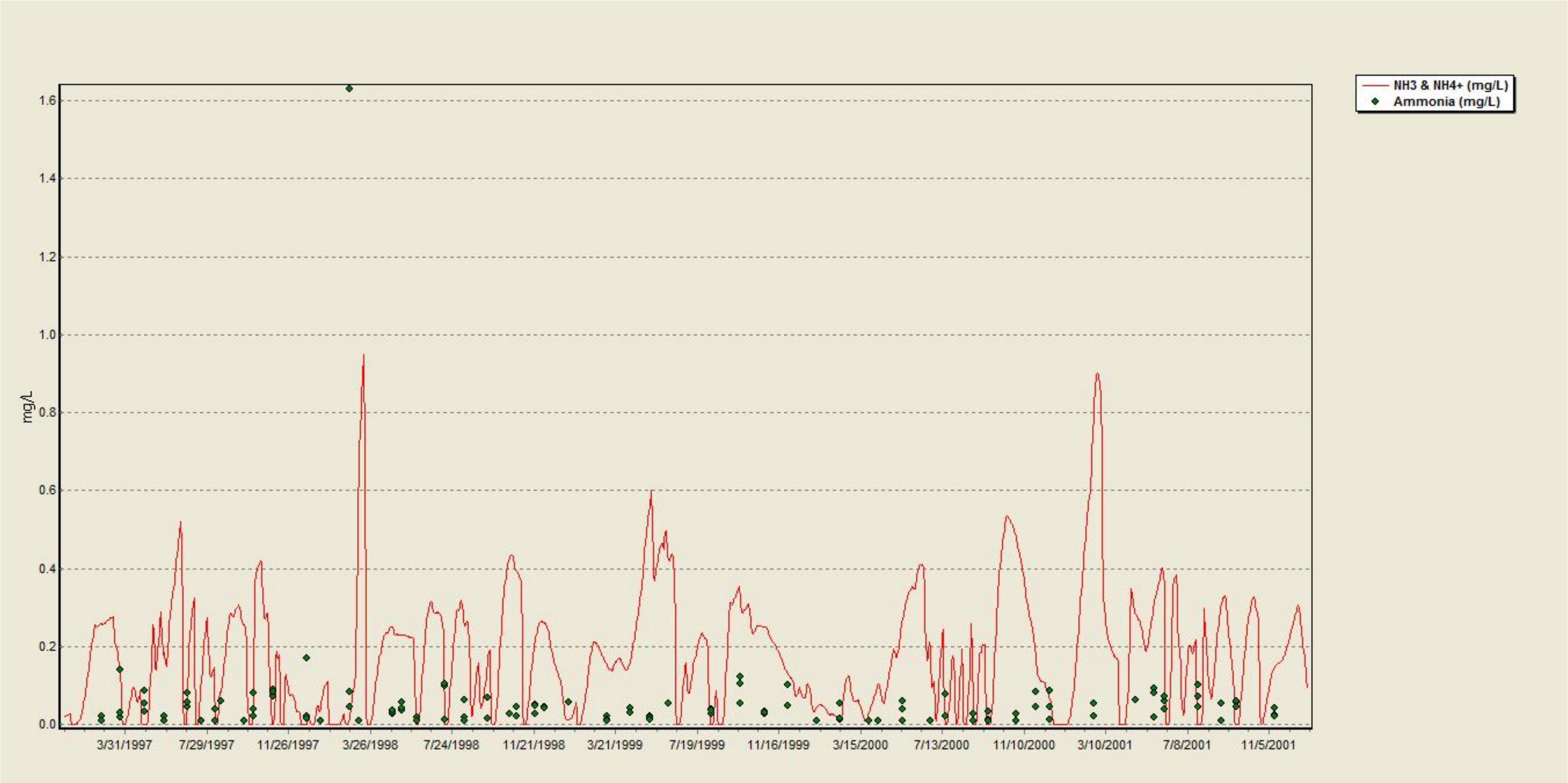

Figure 11. Comparison of predicted (red line) and observed (green points) Ammonia-Nitrogen for the calibration period (1997-2001).

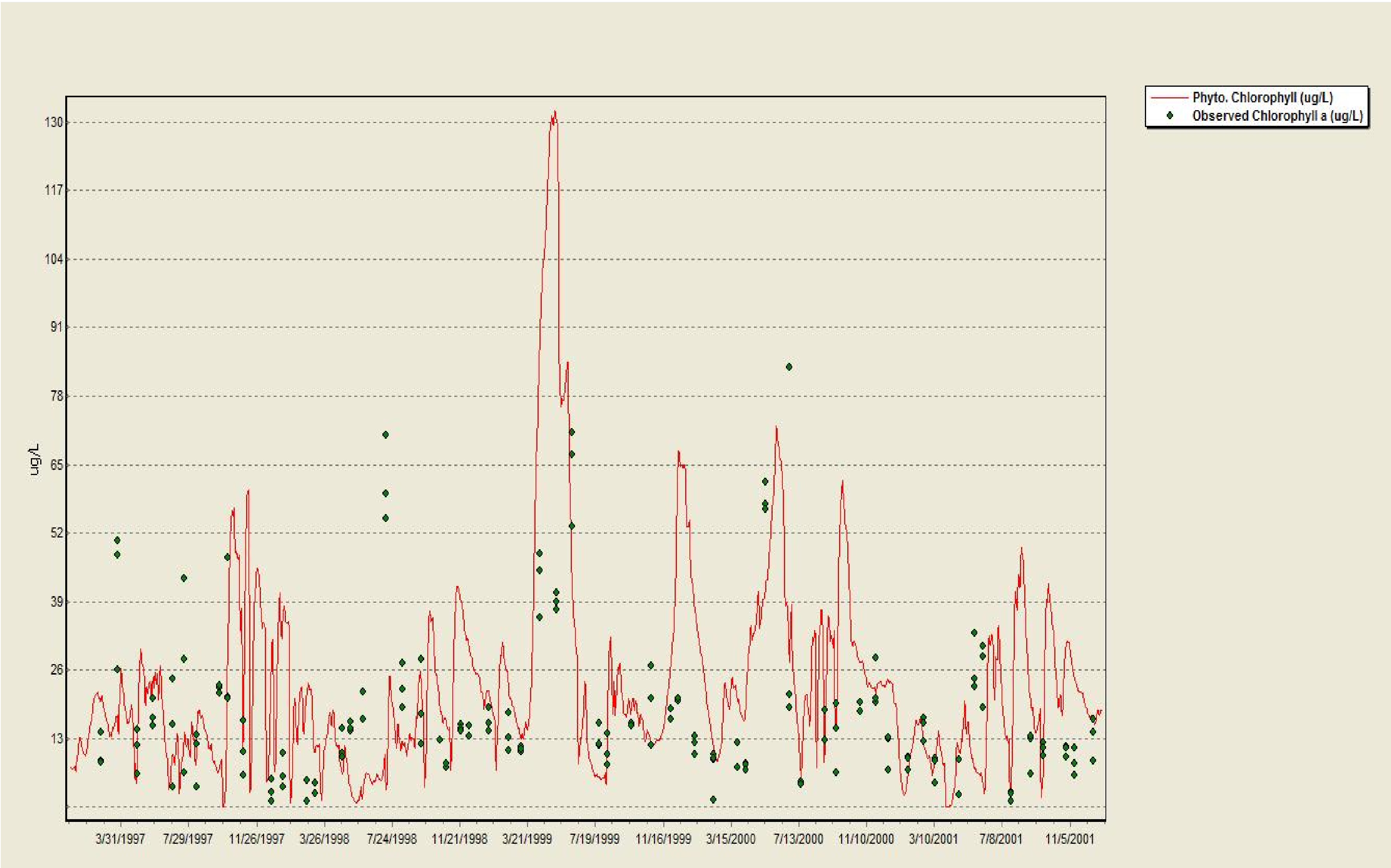

Figure 12. Comparison of predicted (red line) and observed (green points) Chlorophyll *a* for the calibration period (1997-2001).

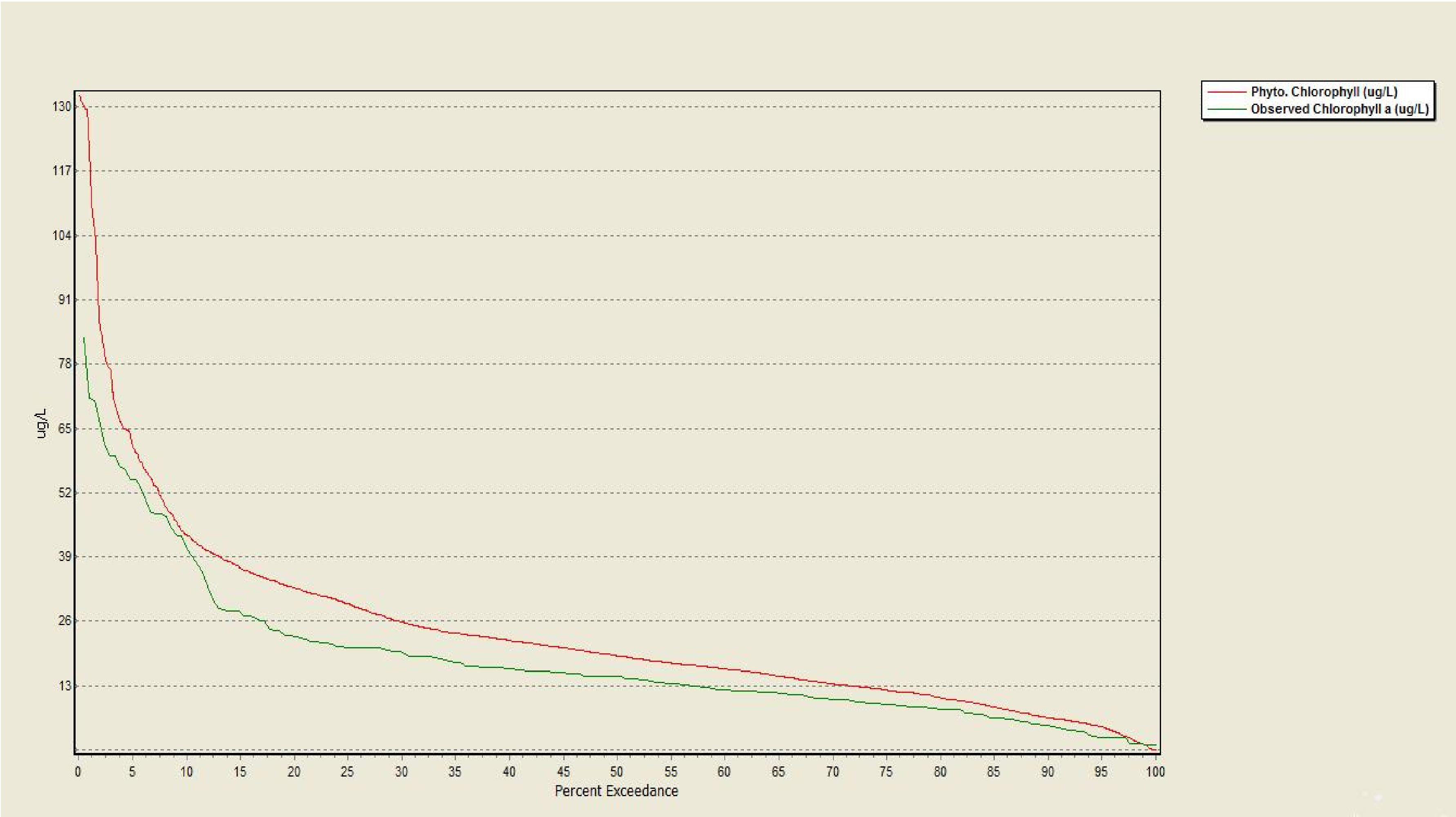

Figure 13. Comparison of predicted (red line) and observed Chlorophyll *a* for the calibration period (1997-2001) using an exceedance graph.

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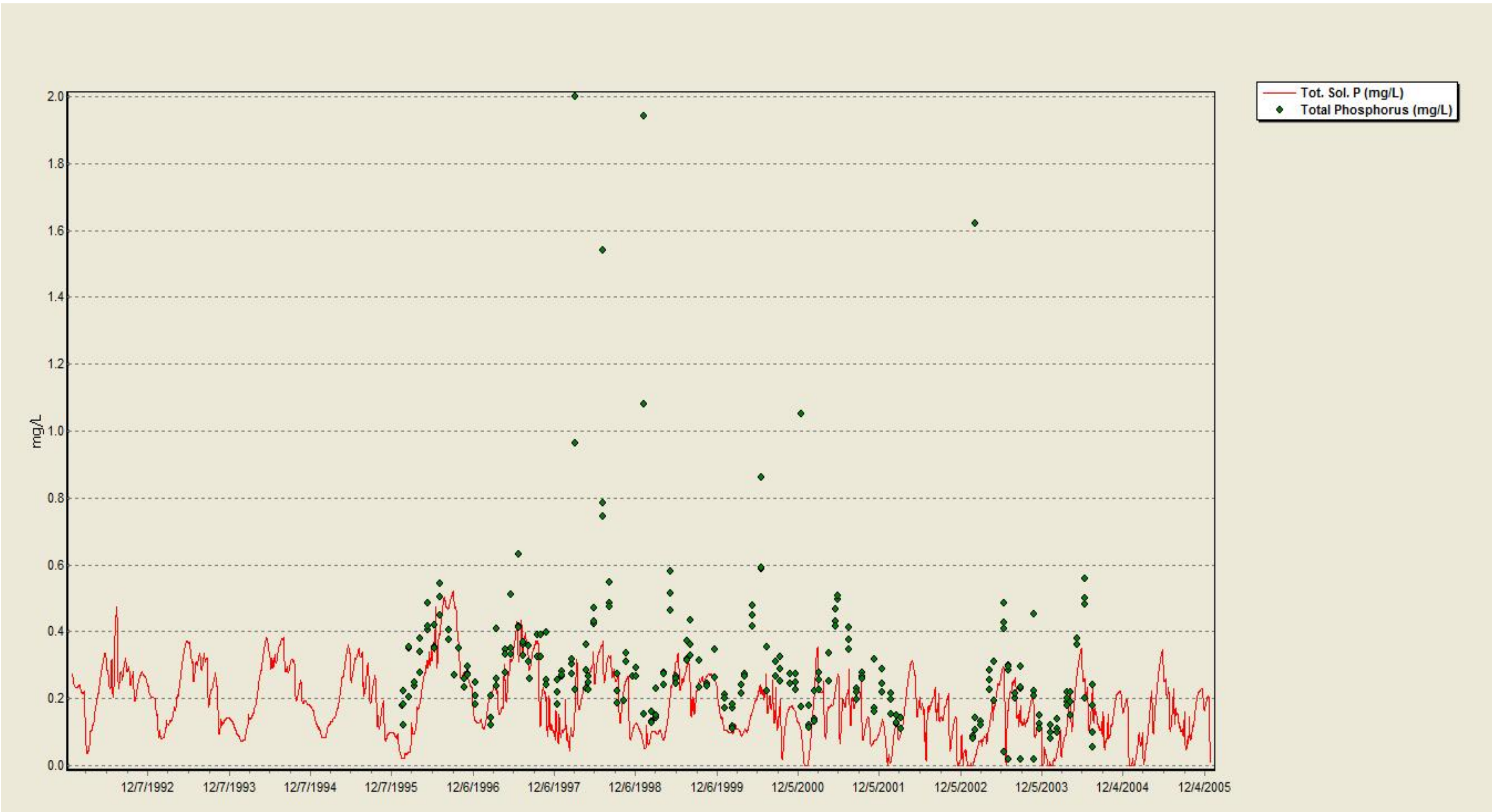

Figure 14. Comparison of observed (green points) and predicted total phosphorus (red line) for the period 1992 through 2005.

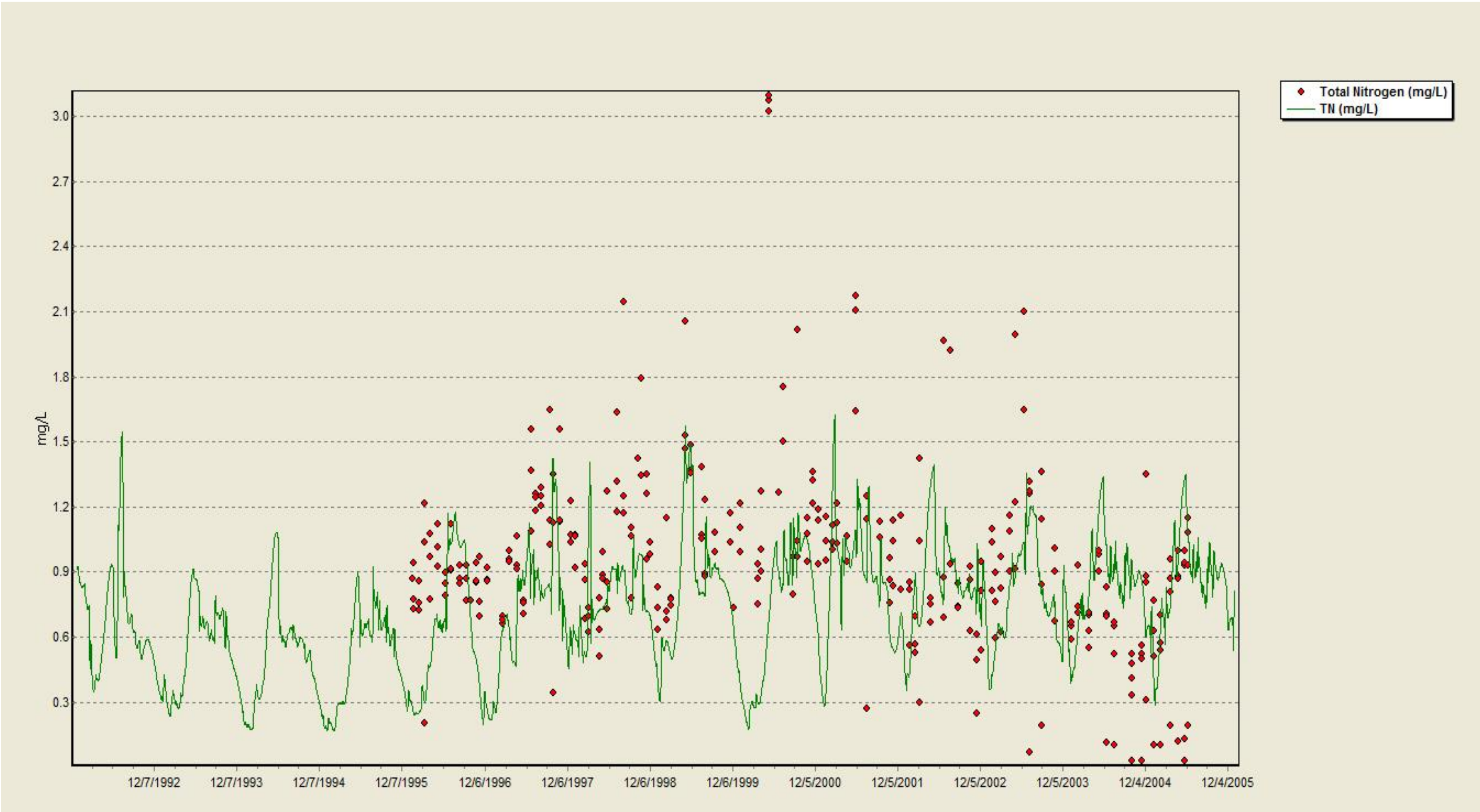

Figure 15. Comparison of observed (red points) and predicted total nitrogen (green line) for the period 1992 through 2005.

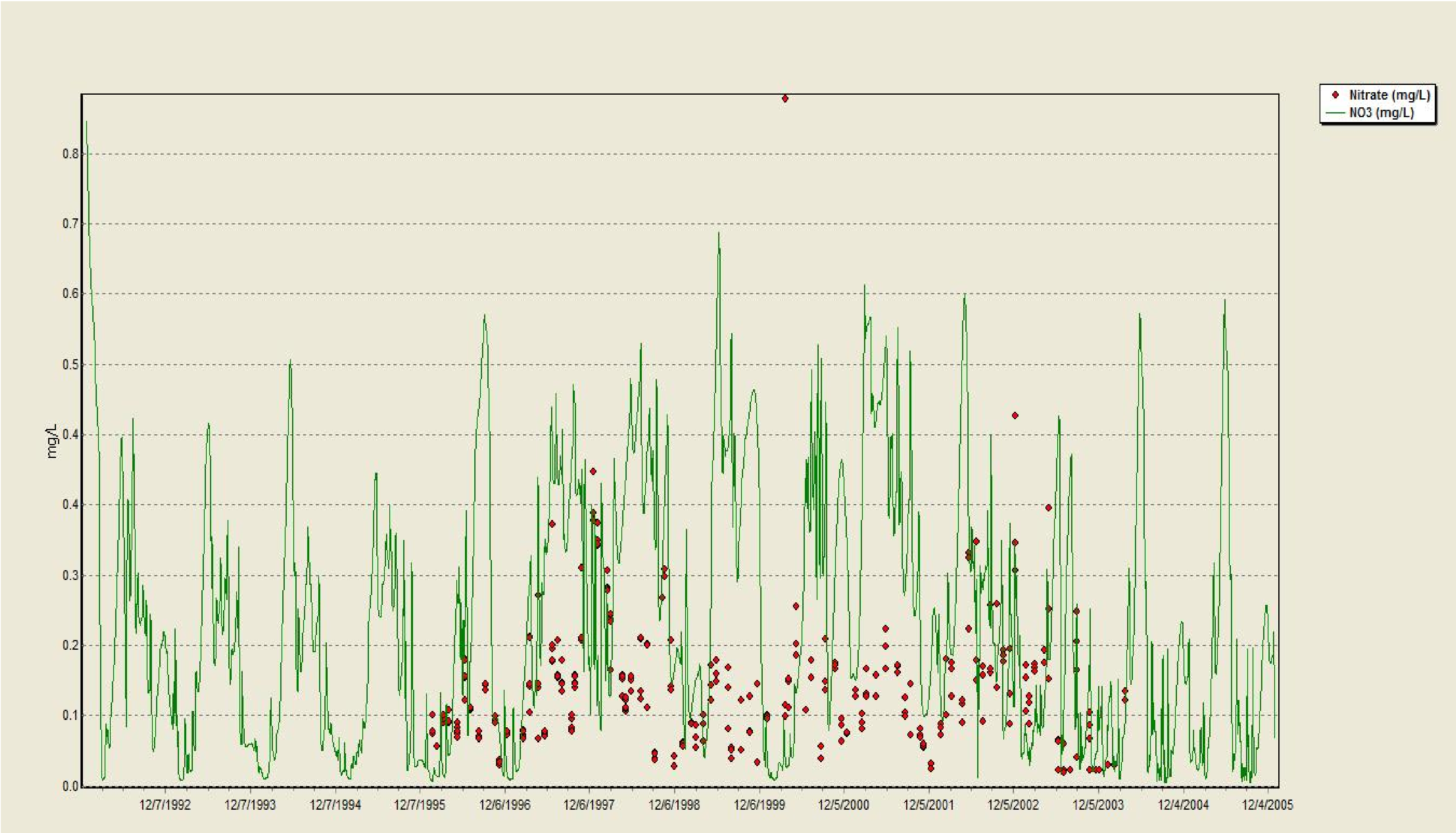

Figure 16. Comparison of observed and predicted nitrate nitrogen for the period 1992 through 2005.

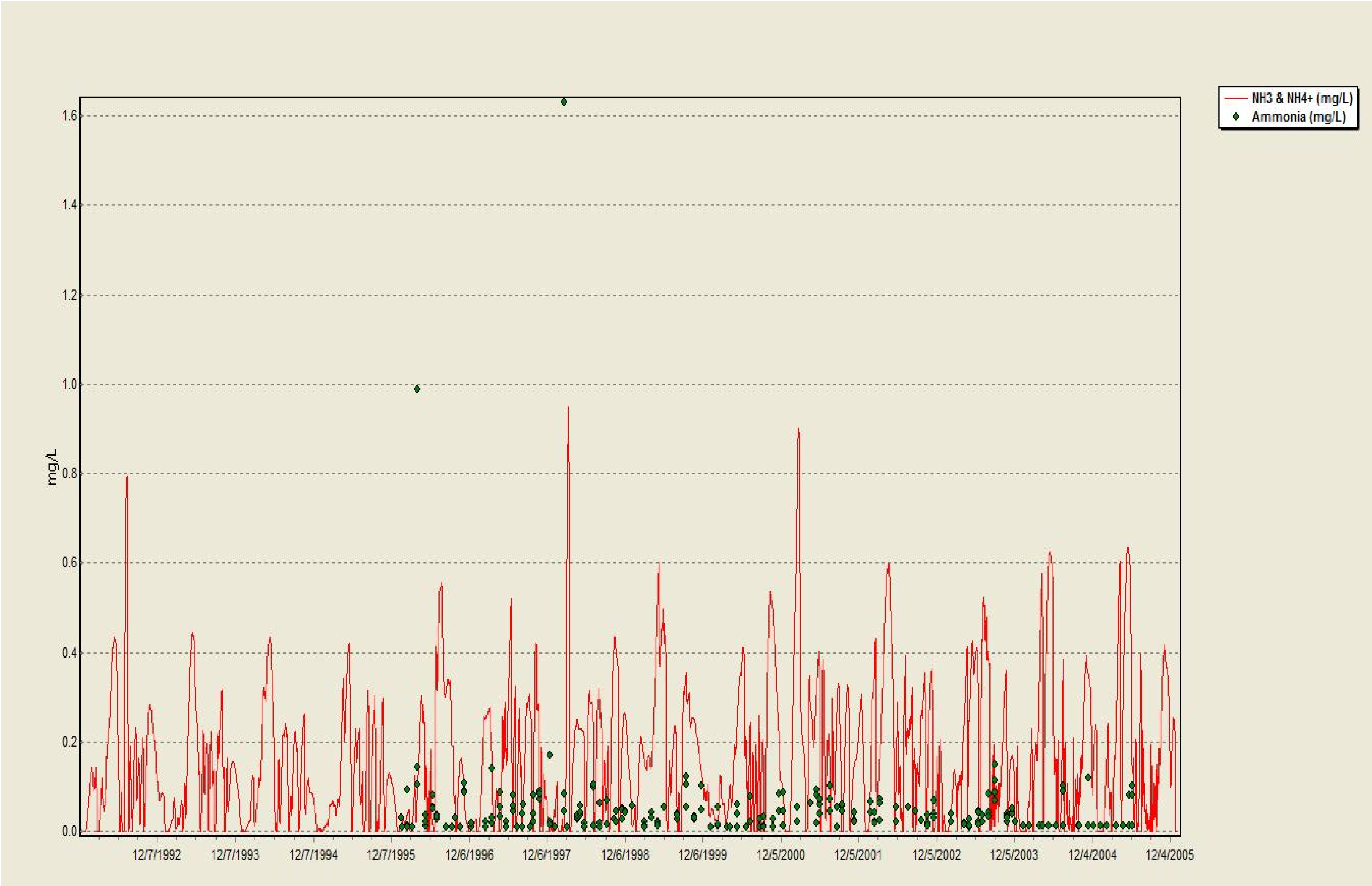

Figure 17. Comparison of observed and predicted ammonia nitrogen for the period 1992 through 2005.

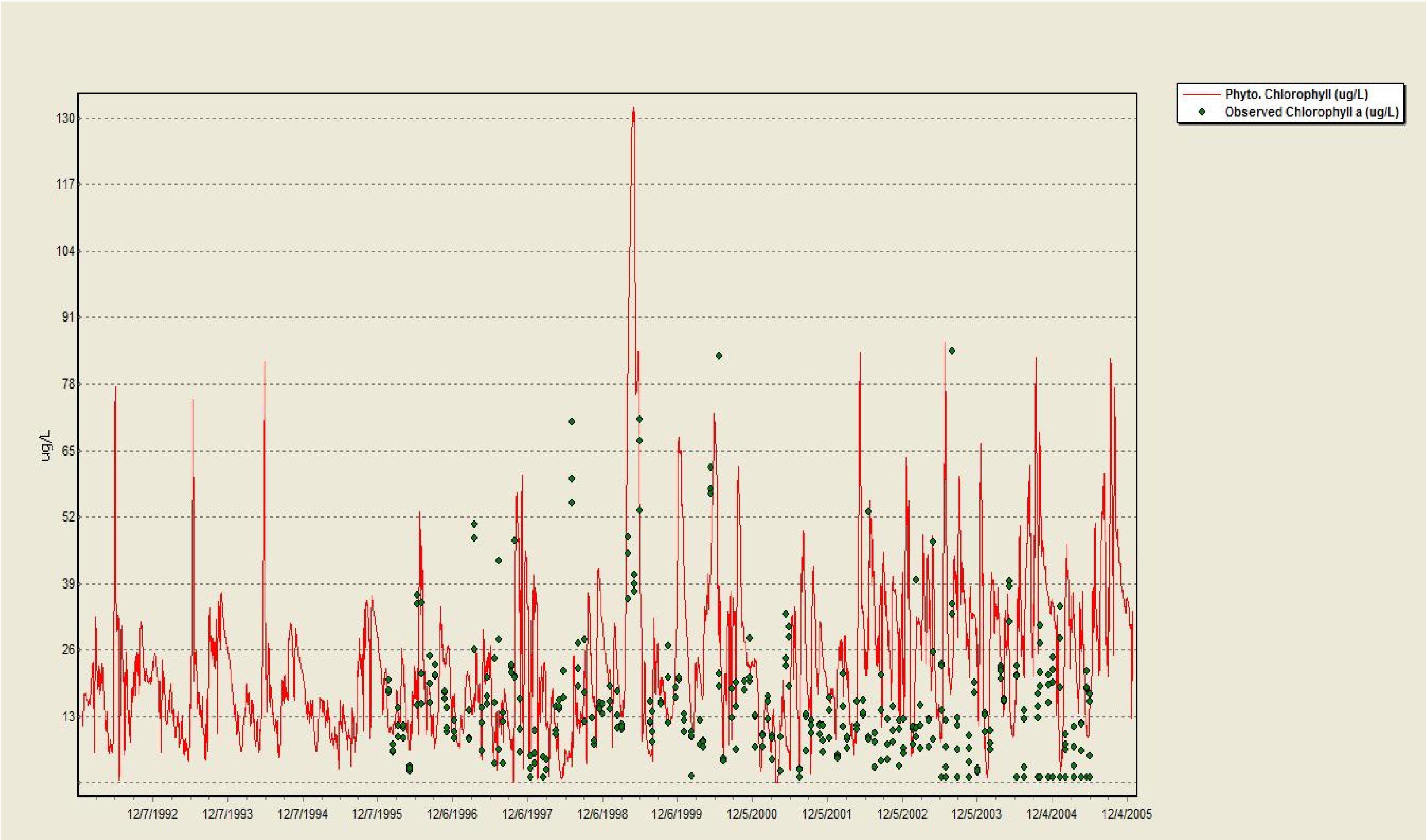

Figure 18. Comparison of observed and predicted Chlorophyll a for the period 1992 through 2005.

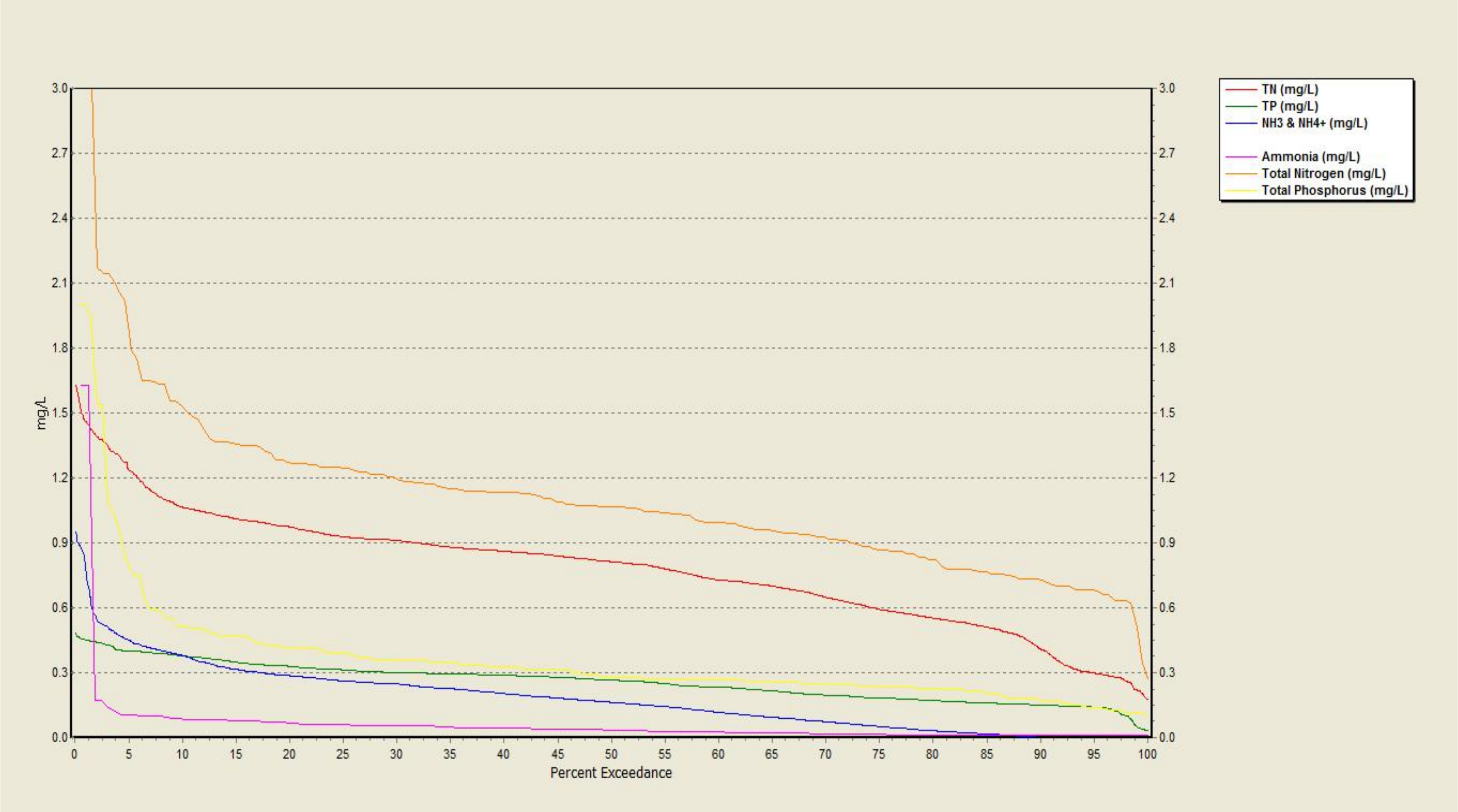

Figure 19. Exceedance graph for simulated (red green and blue lines) and observed (purple, orange and yellow lines) nutrients over the entire time period. Correspondence of respective lines for ammonia, total phosphorus and total nitrogen indicates a reasonable verification of the AQUATOX model.

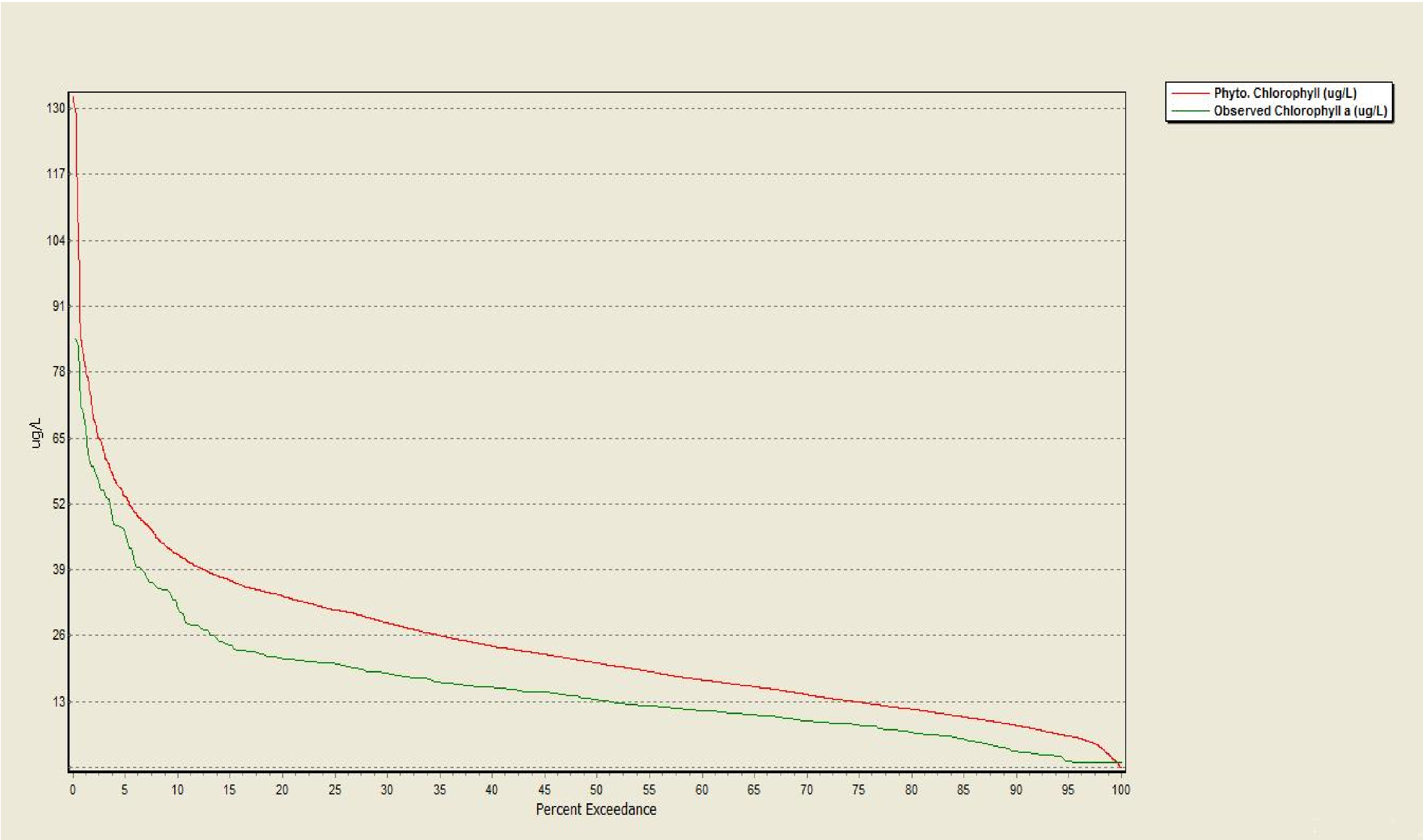

Figure 20. Exceedance graph for Chlorophyll a in the Evers Reservoir for the full simulation period, 1992 through 2005.

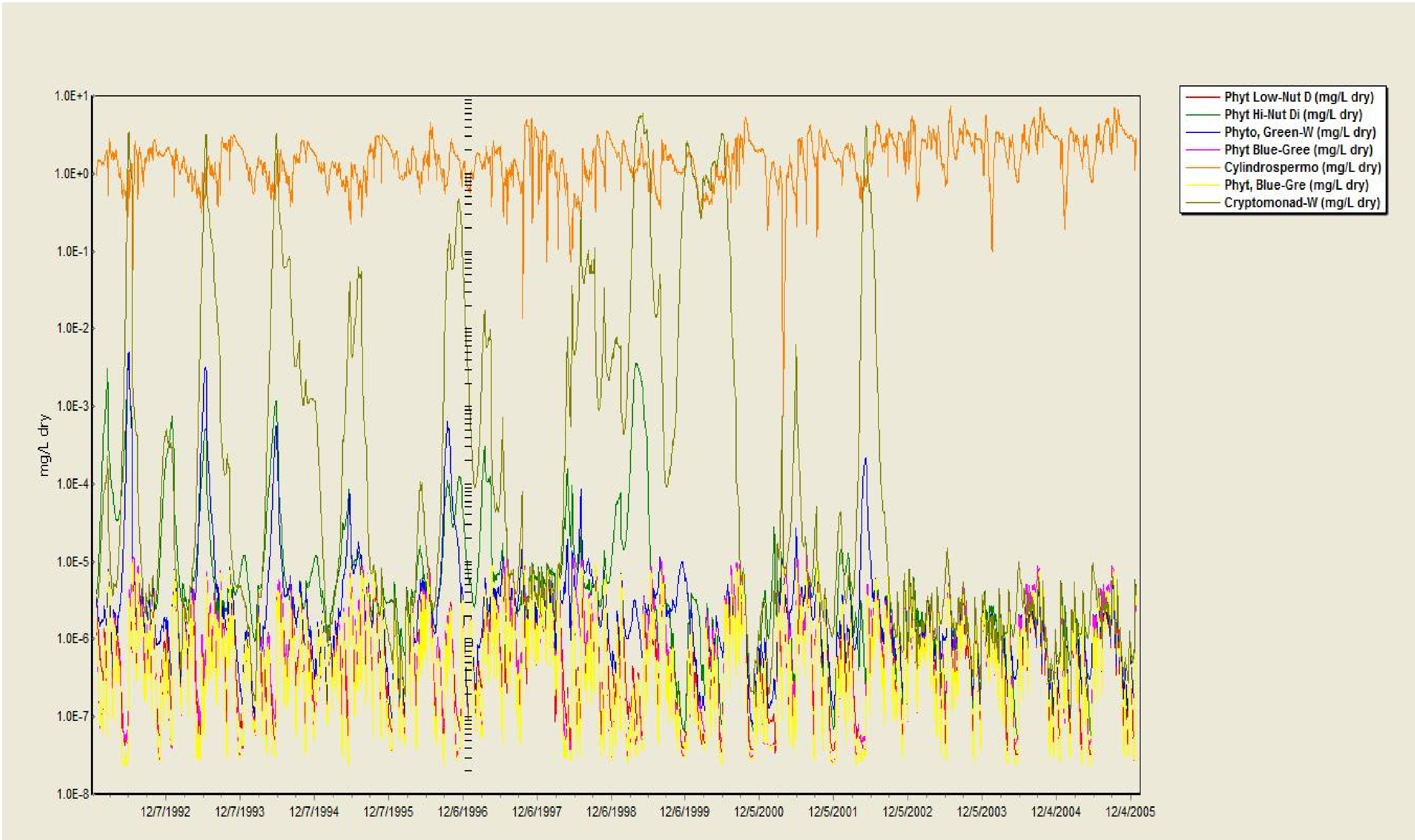

Figure 21. Major algal taxa as simulated by AQUATOX during the period 1992 through 2001

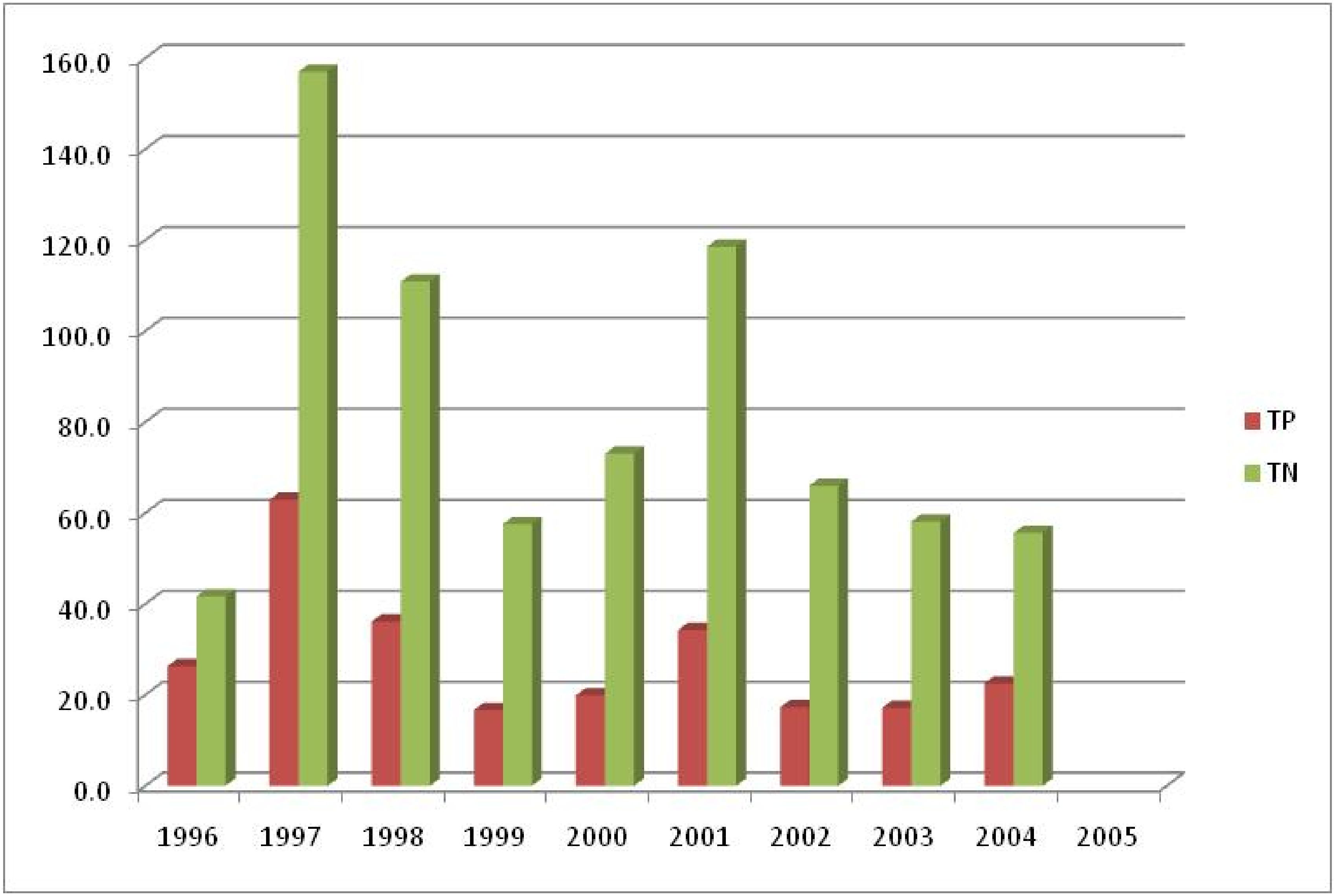

Figure 22. Calculated annual loadings to Evers Reservoir, 1992 through 2005.

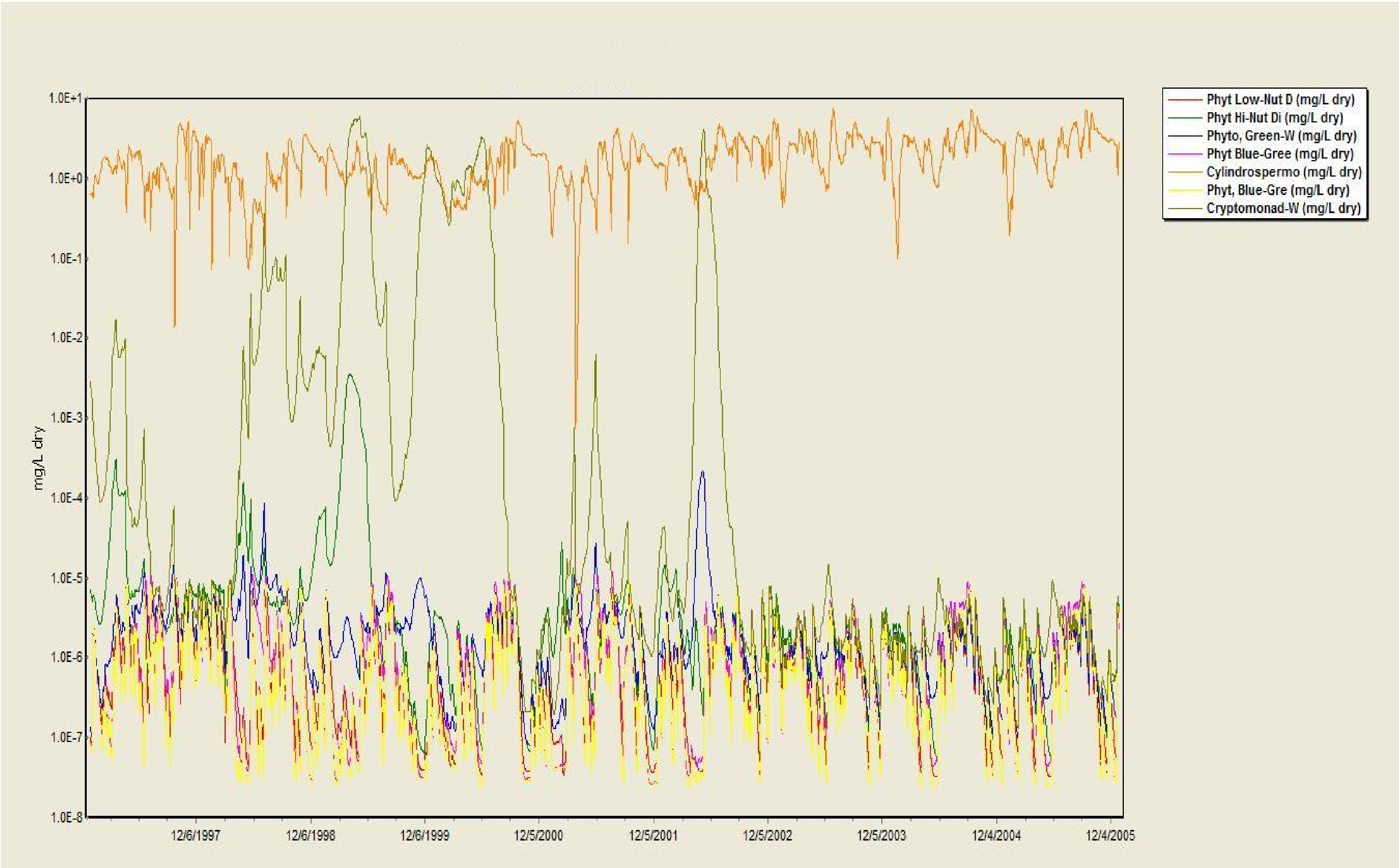

Figure 23. Major algal taxa biomass (dry weight) as simulated by AQUATOX during the period 1997 through 2005

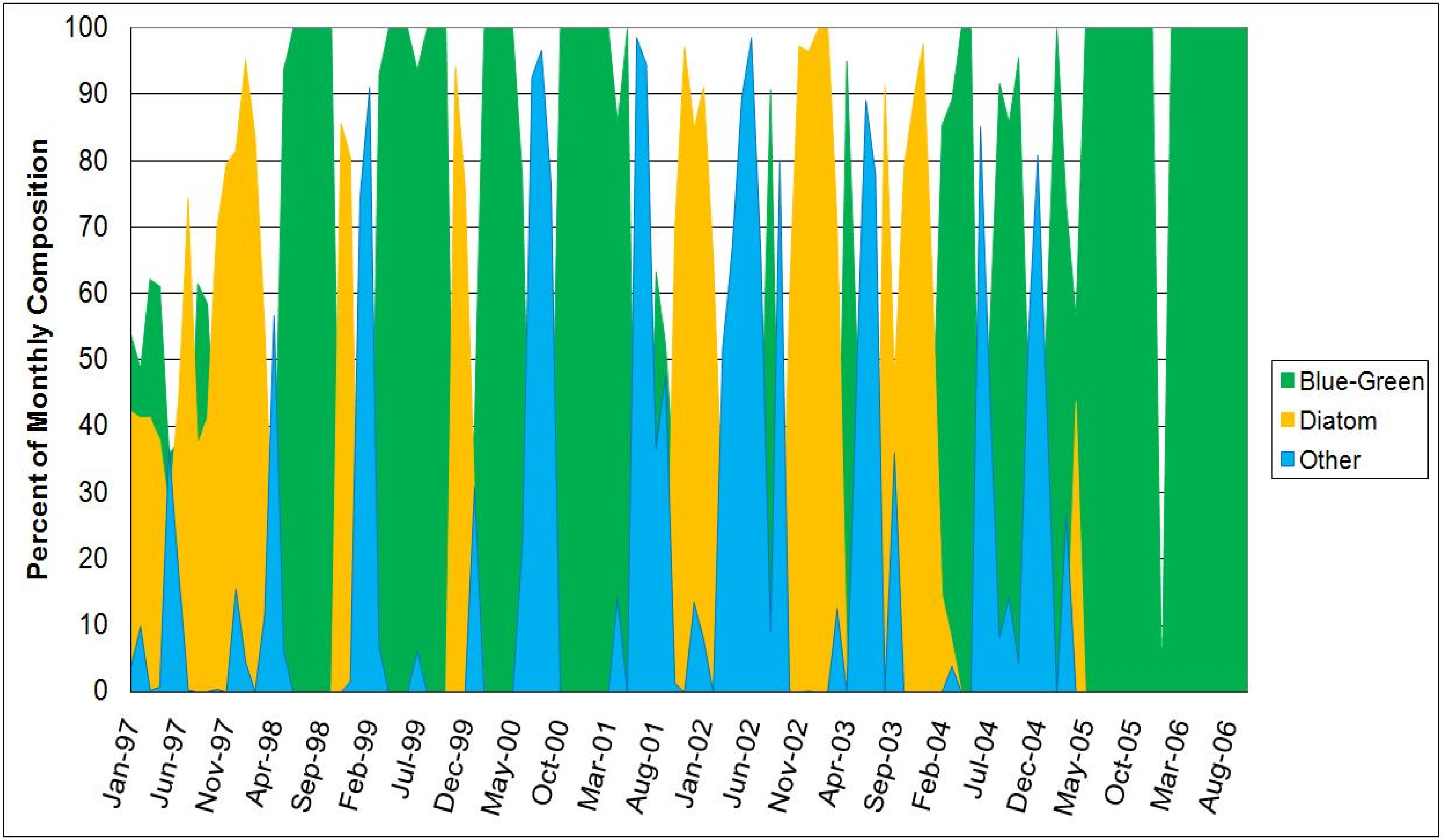

Figure 24. Observed Algal counts for the period 1997 though 2006.

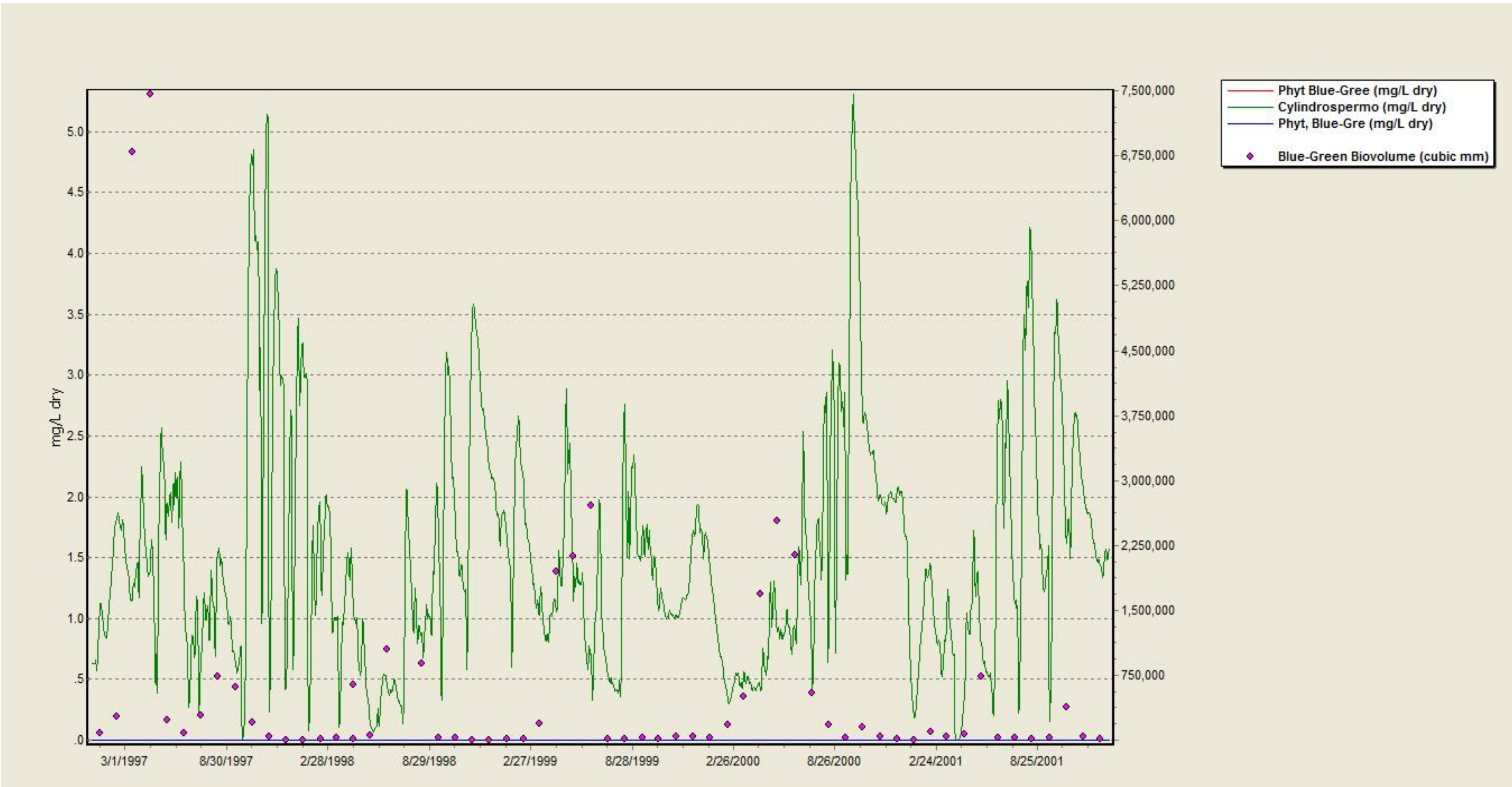

Figure 25. Simulated Blue green algal biomass as compared to estimated blue-green biovolume from City of Bradenton algal counts.

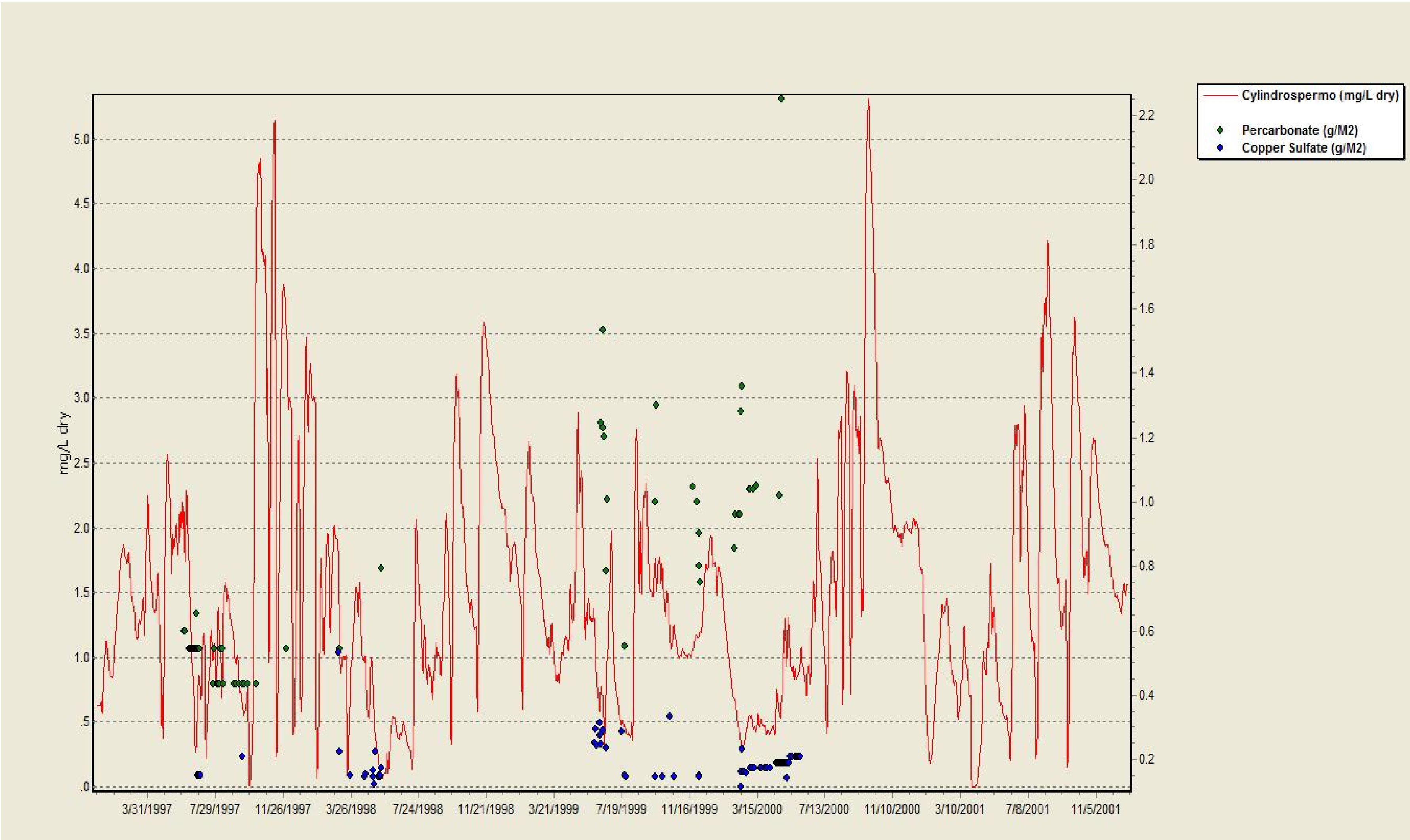

Figure 26. Simulated Blue Green algal response and algaecide loadings for Evers Reservoir.

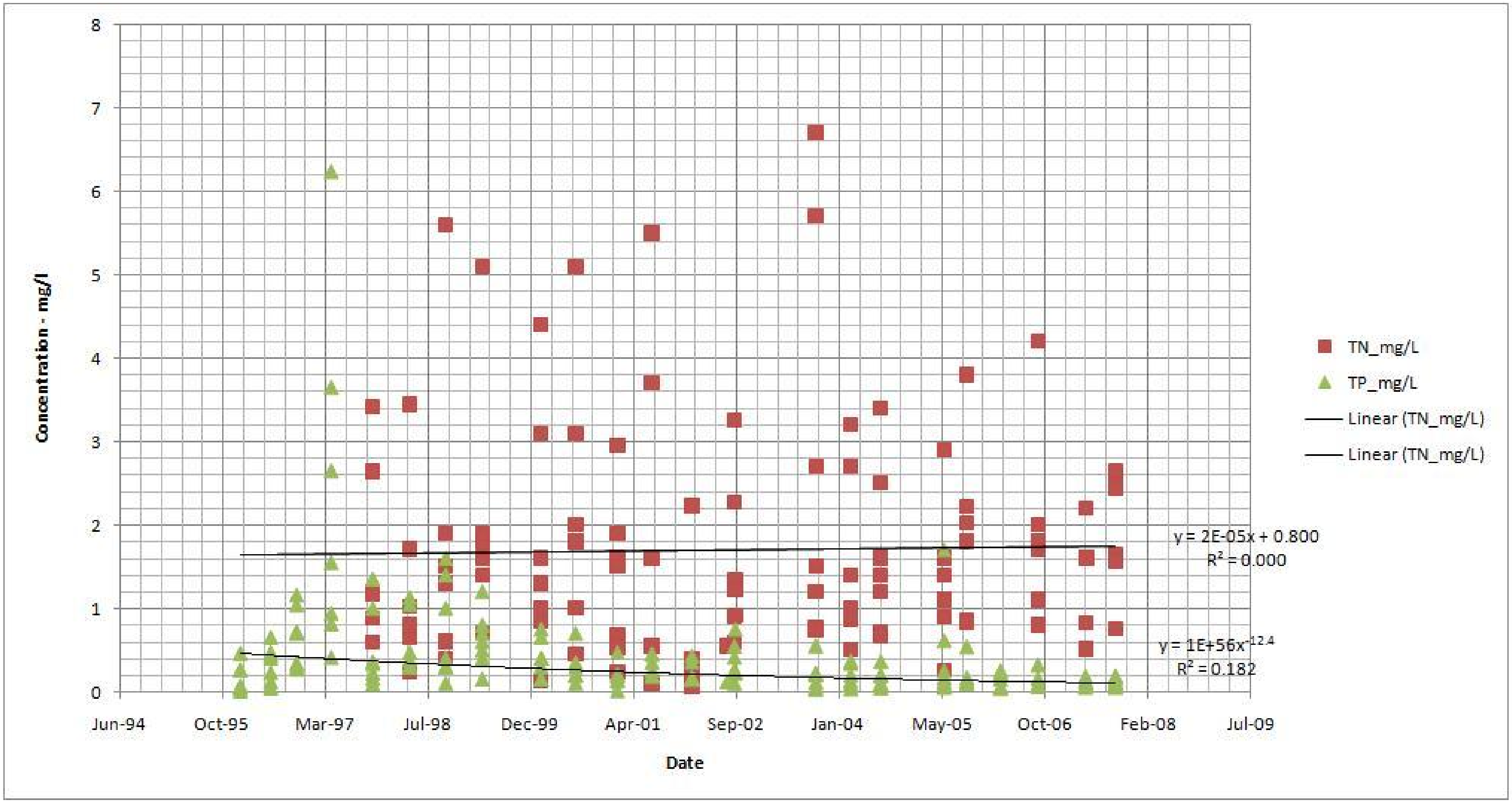

Figure 27. Changes in Groundwater nutrients following land-use conversion in the University Lakes Development, Manatee County.

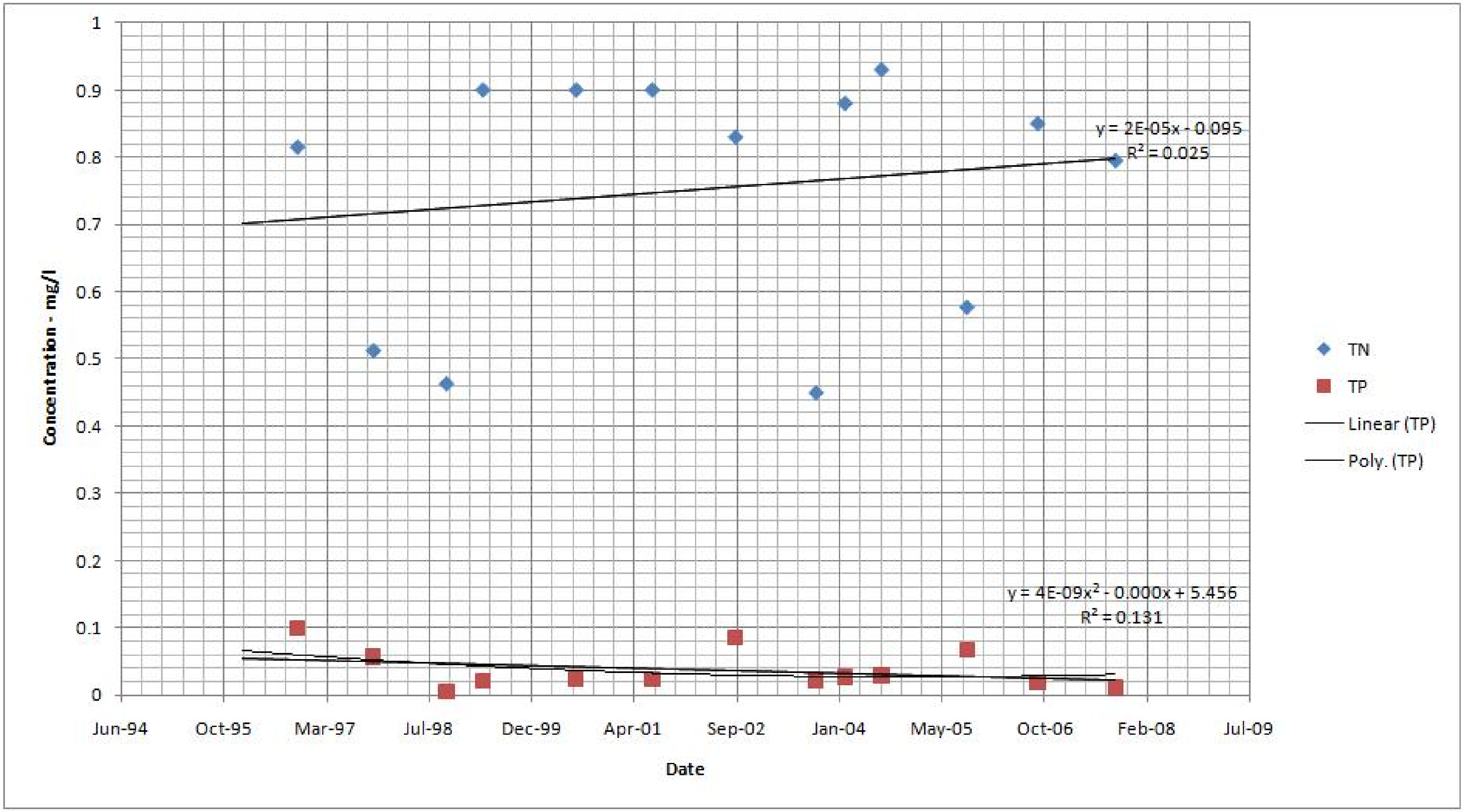

Figure 28. Changes in Surface water nutrients following land-use conversion in the University Lakes Development, Manatee County.

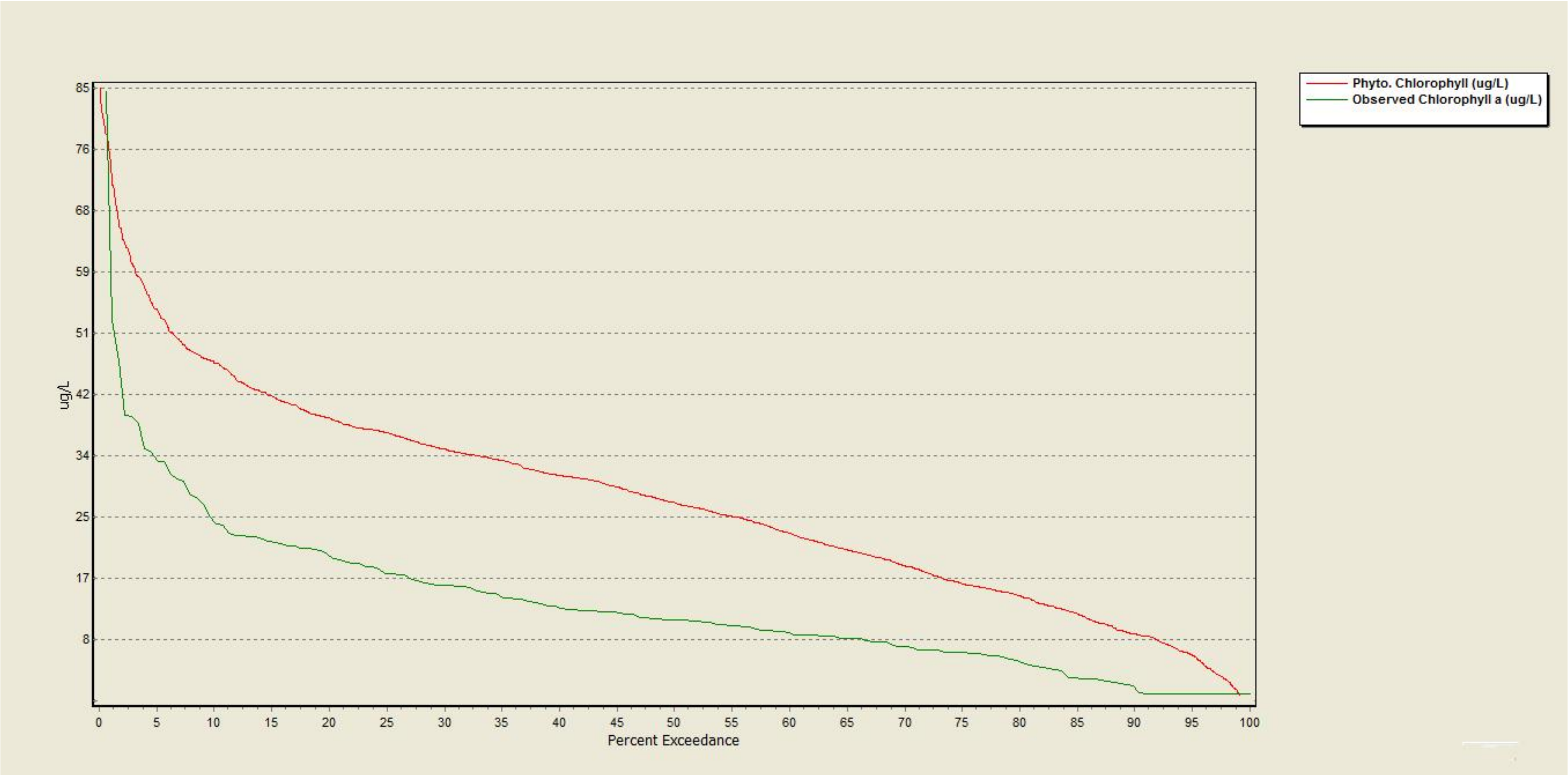

Figure 29. Exceedance chart for chlorophyll *a* simulated by AQUATOX with a 15% decrease in TP loads and 2001-2005 hydrologic conditions. Chlorophyll *a* exceeds 20 ug/l 66% of the time.

Figure 30. Exceedance chart for Chlorophyll *a* simulated by AQUATOX with a 35% decrease in TP loads and 2001-2005 hydrologic conditions. Chlorophyll *a* exceed 20 μg/l about 63% of the time for the simulated condition (red line).

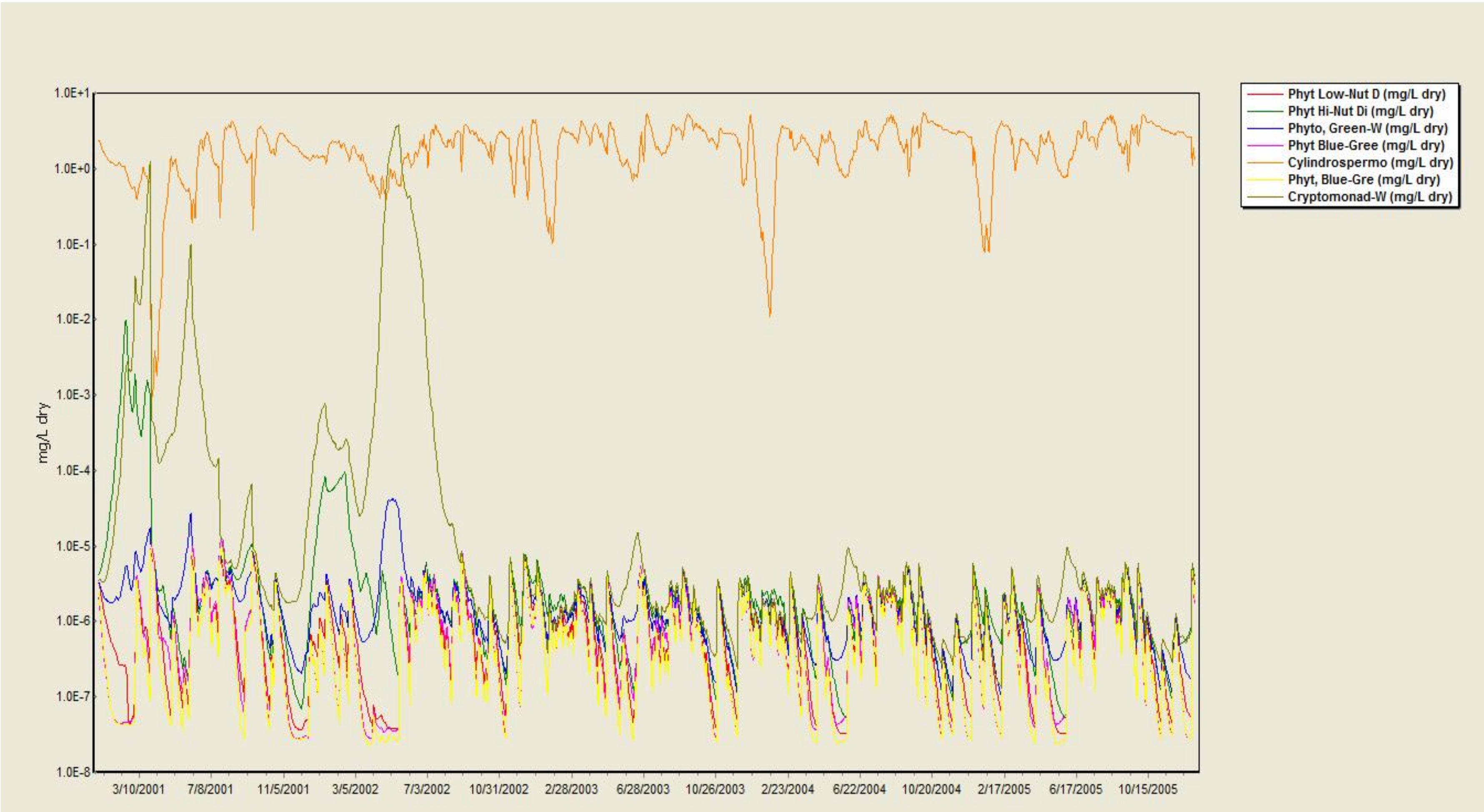

Figure 31. Predicted algal taxa biomass for the 35% decrease in TP loads.

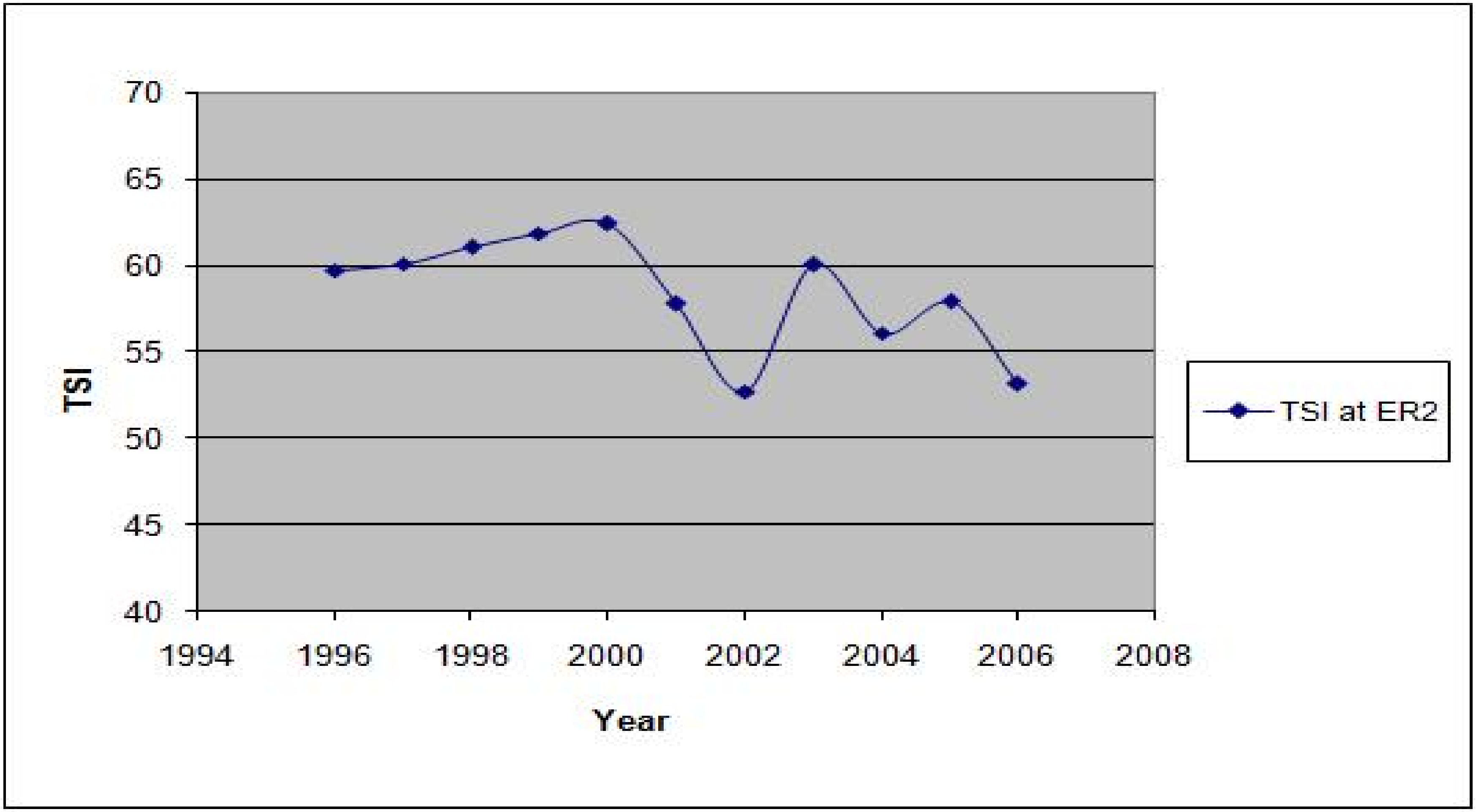

Figure 32. Calculated Trophic State index (TSI) for Evers Reservoir, Station ER1 for the period 1996 through 2005.