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Development of Streams Classification System for Nutrient Criteria in Illinois

by

Momcilo Markus, Lian-Shin Lin, and Amy Russell

Prepared for the
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Illinois State Water Survey
Center for Watershed Science
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

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77 W. Jackson Blvd.
Chicago, IL 60604

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Abstract

This study provides a scientific basis for developing a classification system in support of nutrient criteria development for streams and rivers based on their susceptibility to algal growth. Those streams having high algal biomass as a result of low nutrient concentration are considered susceptible to algal growth. Conversely, streams having low algal biomass and high nutrient concentration are considered less susceptible to algal growth. The process of setting nutrient criteria is complex due to various designated water uses that require different levels of water-quality protection. That complexity is compounded further by the diversity in habitat conditions. Scientists have found that a stream's response to nutrient enrichment depends on various habitat factors such as water velocity, canopy cover along the streambank, and stream width/depth. Habitat conditions may differ considerably from one reach to another and also from season to season. To account for this spatial and temporal variability, monthly aggregated reach-scale habitat conditions were used to develop the classification system.

Algae are either the direct or indirect cause of most problems related to nutrient enrichment. In this study, statistical methods were applied to develop a relationship between algal biomass and nutrients (total nitrogen and total phosphorus). Residuals of the developed relationship were considered to be attributable to stream susceptibility to algal growth. Variability of the residuals (i.e., susceptibility values) then can be explained by habitat conditions. Two sets of monitoring data for Illinois streams and rivers were used to develop the statistical models. The susceptibility-habitat model uses habitat monitoring data to predict stream susceptibility, and classify these streams based on their susceptibility. Eventually, the classification system may be used to develop site-specific nutrient standards based on stream tolerance to nutrients. It also can be used to prioritize streams and rivers for the Total Maximum Daily Load (TMDL) and for watershed management purposes.

This two-stage model approach was tested on two datasets for Illinois. The Fox River dataset included nine locations on the Fox River in Lake, McHenry, Kane, Kendall, and LaSalle Counties. The Illinois Environmental Protection Agency (IEPA) dataset included extensive habitat factors and nutrient data observed at 142 locations on rivers and streams throughout the state. Those data were used to estimate the nonlinear regression model (f_1) for calculating susceptibility based on the habitat factors. Validation entailed comparing predicted susceptibility with "observed" susceptibility calculated as a residual from the nutrients-algal biomass (chlorophyll *a*) nonlinear regression model (f_2). Various combinations of linear or squared inputs were examined for both f_1 and f_2 models, and those models giving the best-fit statistics were identified.

Results show how the proposed two-stage model could be implemented for watershed classification based on stream susceptibility. Longer, more complete datasets will be required in the future to further test the results and to finetune the models, however.

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1. Introduction

Excess nutrients are one of the leading causes of impaired water quality of the nation's streams and rivers (USEPA, 2002). The U.S. Environmental Protection Agency (USEPA) has published recommended nutrient criteria for different types of water bodies and different ecoregions of the country to prevent eutrophication, a condition in an aquatic ecosystem where high nutrient concentrations stimulate blooms of algae (USEPA, 2000a; USEPA, 2000b). The USEPA also is assisting states and Indian tribes in developing numeric water quality standards based on those recommended criteria.

The trophic state of streams and rivers is commonly determined from water-quality variables such as nutrient concentrations, algal biomass, and turbidity. Additional variables such as dissolved oxygen (DO) and pH also are used to develop nutrient criteria. The scientific literature includes many studies that explore relationships between nutrient concentrations and algal biomass for establishing appropriate nutrient levels to protect designated water uses (Van Nieuwenhuyse and Jones, 1996; Dodds et al., 1997; Dodds et al., 1998; Chetelat et al., 1999). Those relationships typically were developed from statistical analyses of nutrient and algal biomass data. Efforts to establish nutrient-algae relationships for streams and rivers, however, often are less successful than those for lakes due to large variances that cannot be explained by the relationships developed. The unexplained variance is attributable to the fact that there are many more factors that help control algal biomass in streams than in lakes (Dodds and Welch, 2000).

From regulatory perspectives, setting nutrient criteria may be driven by the need to ensure full support of designated water uses. Therefore, water bodies with the same designated uses should be subject to the same level of protection. From practical perspectives, nutrient criteria should be based on nutrient forms that better correlate with water-quality impairment. Van Nieuwenhuyse and Jones (1996) showed that summer mean sestonic (particulate) chlorophyll concentrations in temperate streams exhibited a strong curvilinear relationship with summer mean total phosphorus (TP) concentrations. They suggested that TP may provide a reliable basis for predicting chlorophyll in small and large temperate streams worldwide. Dodds et al. (1997) conducted regression analyses on a large dataset of temperate streams and found that total nitrogen (TN) and TP better explain the variation of benthic algal biomass data than dissolved forms of nitrogen and phosphorus.

Dodds and Welch (2000) suggested setting nutrient criteria for both nitrogen and phosphorus. Development of the nutrient criteria also should consider seasonal variations. Cold temperatures in winter may inhibit algal growth so that streams tolerate higher nutrient concentrations without showing adverse effects. In addition, rainfall distribution throughout the year often is not uniform, and flooding frequency is found to be one of the factors influencing stream algal biomass (Biggs et al., 1998a; Biggs et al., 1998b; Biggs, 2000). Development of nutrient criteria also should take into consideration downstream effects. Stream reaches often exhibit a wide range of velocity and mixing characteristics. Receiving waters such as lakes and estuaries can have dramatically different hydraulic and transport characteristics than their upstream waters. These differing hydraulic regimes can lead to significantly different responses to nutrient enrichment.

Various factors have been reported to influence stream response to nutrient enrichment. Scientists have found that stream response to nutrient enrichment generally depends on factors related to stream habitats. Table 1 summarizes different factors examined in some of the studies found in the literature. Table 2 lists conditions of dominant factors that affect algal biomass (USEPA, 2000c).

Algal growth depends on nutrient concentrations, such as TN or TP, and habitat factors, such as water temperature or turbidity. Dodds et al. (1997) studied regression methods to explain variability in algal biomass based on combined nutrients and habitat factors. The present study introduces a new two-stage method that separates the effects of nutrients with those of habitat factors. In the first stage, statistical methods were applied to develop a relationship between algal biomass and nutrients (TN and TP). Next, residuals of the developed relationship were considered to be attributable to stream susceptibility to algal growth. Variability of the residuals (i.e., susceptibility values) then was explained by habitat conditions in the second stage. This study i) separates the effects of nutrients and habitat factors on algal growth, ii) defines stream susceptibility to algal growth as a residual of the relationship between nutrients and algal biomass, and iii) serves as a scientific basis for watershed classification based on their susceptibility. This model for stream classification can be used for nutrient criteria development in Illinois.

This research does not address questions regarding bioavailability and limiting nutrients. It is based on the findings of Dodds et al (1997) and Dodds (2003), which support the use of TN and TP as the best indicators of trophic state.

This study uses two datasets: data collected in the Fox River watershed in Illinois (Appendices A-1, A-2, B-1 and B-2), and a dataset for the entire state of Illinois (Appendices C-1 and C-2). The Fox River and the IEPA databases consist of numerous nutrient, habitat and chlorophyll *a* data. Although those two extensive datasets contain long-term ambient data are incomplete and do not necessarily contain storm-event data, they represent the best currently available datasets for testing the results of this study Illinois. The following sections of this report provide information on these datasets, model details, and analysis results.

Table 1. Habitat Factors Influencing Algal Biomass in Streams and Rivers

Source	*Algal type*	*N*	*C*	*V*	*D*	*T*	*CC*	*TR*	*SB*	*DA*	*FF*	*IG*	*Data*
Munn et al., 1989	Periph	**x**				**x**		**x**					6 streams
Van Nieuwenhuyse and Jones, 1996	Phyto	**x**								**x**			116 streams
Dodds et al., 1997	Periph	**x**											205 streams
Cattaneo et al., 1997	Periph	**x**							**x**				8 streams
Bourassa and Cattaneo, 1998	Periph	**x**		**x**	**x**		**x**					**x**	12 streams
Biggs et al., 1998a	Periph	**x**									**x**	**x**	1 river
Chetelat et al., 1999	Periph	**x**	**x**	**x**									13 rivers
Biggs, 2000	Periph	**x**									**x**		25 streams

Notes: Periph=Periphyton, Phyto=Phytoplankton, N=nutrients, C=conductivity, V=velocity, D=depth, T=temperature, CC=canopy cover, TR=turbidity, SB=substratum size, DA=drainage area, FF=flood frequency, and IG=macroinvertebrate grazing.

Table 2. Conditions of Habitat Factors Affecting Algal Biomass (USEPA, 2000c)

Phytoplankton-dominated systems

High Phytoplankton Biomass
1. low current velocity (< 10 cm/sec)/long detention time (> 10 days) *and*
2. low turbidity/color *and*
3. open canopy *and*
4. greater stream depth *and*
5. great depth to width ratio

Low Phytoplankton Biomass
1. high current velocity (> 10 cm/sec)/short detention time (< 10 days) *and/or*
2. high turbidity/color *and/or*
3. closed canopy *and/or*
4. shallow stream depth

Periphyton-dominated systems

High Periphyton Biomass
1. high current velocity (> 10cm/sec) and
2. low turbidity/color *and*
3. open canopy *and*
4. shallow stream depth *and*
5. minimal scouring *and*
6. limited macroinvertebrate grazing *and*
7. gravel or larger substrata *and*
8. smaller depth to width ratio

Low Periphyton Biomass
1. low current velocity (< 10 cm/sec) *and/or*
2. high turbidity/color *and/or*
3. closed canopy *and/or*
4. greater stream depth *and/or*
5. high scouring *and/or*
6. high macroinvertebrate grazing *and/or*
7. sand or small substrata

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2. Data Description

2.1 Fox River Watershed Data Description

The Illinois State Water Survey (ISWS) has an ongoing project to study water quality and model the Fox River watershed. A product of phase I of the project (funded by the IEPA) is a comprehensive relational database (FoxDB) that stores data from various agencies and organizations. Data sources were identified after extensive review of the literature and related publications on water quality and stream habitat in the Fox River watershed. The identified datasets were imported to the FoxDB and details of the quality assurance/quality control procedures can be found in the report for the phase I study (McConkey et al., 2004).

2.1.1 Data Sources

According to McConkey et al. (2004), the FoxDB is populated primarily with data from regular monitoring programs of the USEPA, IEPA, and U.S. Geological Survey (USGS). Those data usually were acquired from the USEPA Legacy Data Center (formerly STORET), the USGS National Water Information System (NWIS), and the USGS National Ambient Water Quality Assessment (NAWQA) databases. Ambient Water Quality Monitoring Network (AWQMN) data collected after 1998 were acquired directly from the IEPA.

A major portion of data in the FoxDB are from those agencies, but the database also contains records from regular monitoring by some local governments and facilities, such as the Fox River Water Reclamation District (FRWRD), the Fox Metro Water Reclamation District (FMWRD), and the Northeastern Illinois Planning Commission (NIPC). Datasets are also available from a few special studies investigating water-quality-related issues in the Fox River watershed. Those studies include a two-year study by the Max McGraw Wildlife Foundation (MMGWF) and a monitoring program of seven stations on the Fox River mainstem by the Fox River Study Group (FRSG). McConkey et al. (2004) presented additional descriptions of individual data sources, their original structure, attributes, and any special considerations.

2.1.2 Available Data

For the purpose of this study, the FoxDB was inventoried for all available data for Illinois rivers and streams only. Based on the literature, initial queries were made for the following types of data: algal biomass, nutrients, temperature, and turbidity. Temperature data were the most prevalent: more than 23,000 records from 169 stations sampled between 1956 and 2003. Nitrogen data in various forms also were widely available: more than 22,000 records from 192 stations sampled between 1964 and 2003. The inventoried dataset also included more than 10,000 records of total phosphorus (TP) concentrations from 187 stations sampled between 1959 and 2003 and more than 4,000 records of turbidity from 121 stations sampled between 1956 and 2003. However, fewer algal biomass data were available.

Algal Biomass. Data from 68 sites within the Fox River watershed included at least one of 14 different measures of phytoplankton. Examples of the phytoplankton data available in the Fox DB include corrected chlorophyll *a*, uncorrected chlorophyll *a*, uncorrected chlorophyll *b*, and uncorrected chlorophyll *c*. Periphyton data were available for only 20 sites. Most of these sites collected only one or two samples. The original goal of this study with respect to the Fox River watershed data was to obtain detailed long-term information for as many stations as possible, rather than one or two samples per location. The desired dataset for this study would contain results for months or preferably years for a given location. Thus, the analysis included only those sites for which at least 12 samples had been collected for any measure of phytoplankton or periphyton. At least 12 measurements of phytoplankton were available only for 11 sites on the Fox River. Using the same criteria, sufficient periphyton data were not available from any monitoring site in the Fox River watershed. As a result, further data compilation continued for only the 11 sites (listed in Table 3) having sufficient phytoplankton data. It should be noted that the station identification numbers used for the FoxDB provide no information as to the location of a station along the river.

Table 3. List of Fox River Monitoring Sites with Phytoplankton Data, Ordered from Upstream to Downstream

FoxDB Station ID	*Station description*
197	Route 173
184	Johnsburg
23	Route 176
24	Algonquin
240	I-90 Bridge N of Elgin
26	South Elgin
40	Geneva
27	Montgomery
34	Yorkville
30	Dayton
31	Route 71

The two most analyzed measures of phytoplankton at these 11 sites were chlorophyll *a* measured by the fluorometric method with acid correction (STORET Code 32209) and without acid correction (STORET Code 32217), 297 and 357 samples, respectively. To supplement these data, an additional 26 sample results of chlorophyll *a* data (STORET Code 32211) measured by the spectrophotometric method with acid correction (USEPA, 1982) also were included in the corrected dataset. Of the 11 sites on the Fox River, ten stations had information on chlorophyll *a*, corrected, and eight stations had information on chlorophyll *a*, uncorrected. Five monitoring agencies collected corrected chlorophyll *a* data: FRSG (seven stations), NIPC (four stations), USGS (four stations), IEPA (two stations) and MMGWF (one station). The FRSG also collects uncorrected chlorophyll *a* data at their seven stations, and FRWRD collects uncorrected chlorophyll *a* data at stations. Some agencies monitor at independent locations, but two or more monitoring agencies share four of the 11 sites (stations 24, 26, 27, and 34).

After an initial inventory to ascertain whether the necessary corresponding nutrient and habitat data were also available for the 11 sites, two sites were dropped from the analysis. Specific data lacking for those two sites (stations 31 and 240) will be discussed in the paragraphs pertaining to that dataset (Turbidity and Velocity).

Nitrogen. Total nitrogen (TN) data were not available for all 11 sites. More than 400 TN data results were available for only seven sites monitored by FRWRD and IEPA. Because nitrate-nitrogen (NO_3-N) or nitrate-nitrite nitrogen (NO_3+NO_2-N) data and total Kjeldahl nitrogen (TKN) data were available for all 11 sites, TN was calculated from the summation of simultaneous NO_3+NO_2-N and TKN data values. This increased the number of samples available for inclusion in the analysis to more than 1300. Unfortunately, despite the increased dataset, less than 250 of those samples were collected during site visits when chlorophyll *a* data also were collected, severely limiting data usefulness. To increase the usability of the TN data, additional TN data were calculated by the summation of simultaneous NO_3-N and TKN values, under the assumption that the contribution of NO_2-N to TN is negligible. This nearly doubled the number of TN sample results available for analysis.

Phosphorus. Total phosphorus data were available for all 11 sites on the Fox River. The monitoring agencies that collected these data included were FRSG, IEPA, USGS, FRWRD, and MMGWF.

Temperature. Temperature data were available for all 11 sites on the Fox River. The primary monitoring agencies included FRSG, IEPA, USGS, and FRWRD.

Turbidity. Sufficient turbidity data were available only for 10 sites. Station 240 (I-90 bridge north of Elgin) was not included due to a dataset of only eight samples collected in 1964 and 1971, and reported in Jackson candle units. This unit of measurement is no longer in common use; consequently, these data were deemed unacceptable for inclusion in the analysis.

Turbidity data included in the analysis were reported in either formazin turbidity units (FTU) or nephelometric turbidity units (NTU). Primary monitoring agencies responsible for collecting these data included FRSG, IEPA, and USGS. In their chapter of the *USGS National Field Manual for the Collection of Water Quality Data*, Wilde and Gibs (1998) state that turbidity data collected for compliance purposes may require reporting in NTU, but FTU is considered analogous to NTU. Therefore, this study did not distinguish between samples reported in the two different units.

Velocity. Velocity data are an important variable to the data analysis. Unfortunately, measures of stream velocity were extremely limited and available in the FoxDB for only two sites. Thus, in order to calculate stream velocity information, additional gage height and streamflow information were obtained for nearby USGS stations. A stage-discharge relationship from the USGS data then could be determined for seven sites. A cross-sectional area for a given flow was calculated by using that relationship in conjunction with channel geometry data obtained from hydraulic models developed for flood insurance studies throughout the watershed and maintained at the ISWS. Channel geometry data were not available for station 31 (Route 71 northeast Ottawa), and the site was dropped from analysis. For the remaining two sites (stations 40 and 34), previously prepared hydraulic models for the locations of interest were used. Figure 1 identifies the USGS gaging records and the final nine locations used in the analysis.

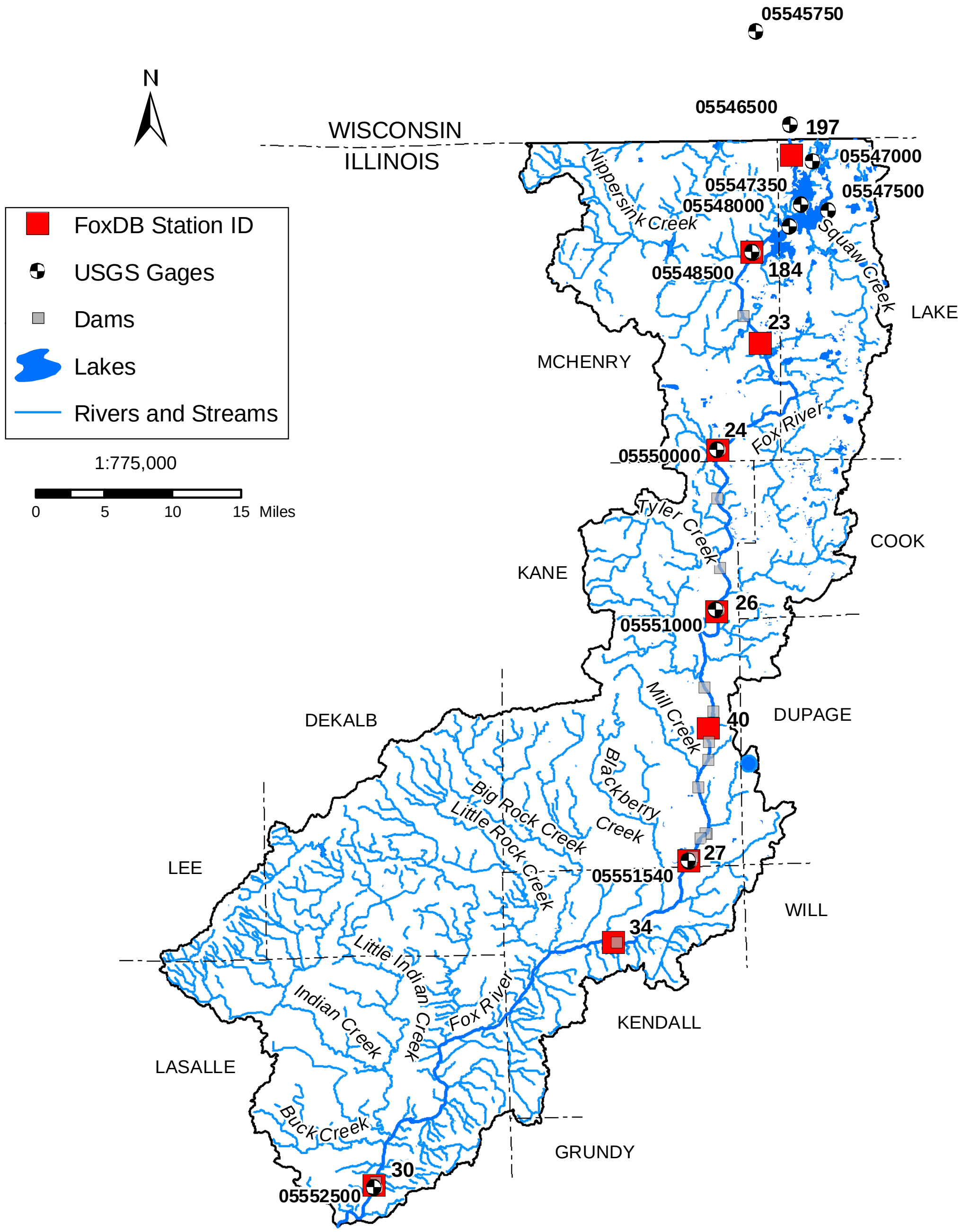

Figure 1. Fox River watershed water-quality stations and USGS gaging stations

It was not possible to determine the flow conditions at all nine sites during the various times of sample collection. Vern Knapp, ISWS, previously developed an Illinois Streamflow Assessment Model (ILSAM) for the Fox River watershed to estimate long-term streamflow conditions for any location in the watershed (Knapp and Myers, 1999; Knapp, 1988). The online version of the model was used to calculate the long-term average monthly flows at the nine locations (ISWS, 2004). These flow values were used as input for the hydraulic models or with the computed cross-sectional area to determine the corresponding mean velocities.

Depth/Width Ratio. The top width and mean depth of the streams also were calculated from the cross-section information for average monthly flow conditions for each of the nine sites. Once these values were determined for each month for each site, the mean depth, measured in feet, was then divided by the top width, measured in feet, to calculate a dimensionless depth/width (DW) ratio.

2.1.3 Data Preparation

The next step in the data analysis involved further preparation and processing of data for the nine locations. For the purpose of analysis, it was critical that the various datasets were collected in similar time frames. Datasets were aggregated to a monthly resolution and thinned to include only data for months when chlorophyll *a* data were available.

In an effort to increase the number of months for which chlorophyll *a* data were available, a relationship was developed based on simultaneous measures of chlorophyll *a* with and without acid correction. A total of 161 samples collected at the FRSG's seven monitoring sites were analyzed for both measures of chlorophyll *a*. These results were used to develop the relationship shown in Figure 2. The best-fit linear relationship is very nearly 1:1, and the regression indicates that the uncorrected chlorophyll *a* values are only about 3.5 percent greater than the corrected values. Using this relationship, the chlorophyll *a* dataset increased to nearly 500 samples.

This process resulted in 176 months of complete records for nine sites. The monthly record was considered complete when it included at least one datapoint for each variable. If there were two or more datapoints in the same month, a simple arithmetic mean was calculated to represent the mean value of the parameter for that month. While some months had dozens of observations, most months typically had from one to three datapoints. Table 4 lists the approximate time frame of data availability.

Contributions of different monitoring agencies to each of the different monthly datasets are listed as percentages (Table 5) but do not total 100 percent for the chlorophyll *a* data. This is due to the datapoints calculated from the relationship described above (Figure 2). Percentages of chlorophyll *a* data calculated using that relationship are 11 percent and 40 percent for chlorophyll *a* corrected and uncorrected, respectively. Because the analysis requires only one measure of algal biomass, and due

Table 4. List of Fox River Monitoring Sites Used in Analysis, Ordered from Upstream to Downstream

FoxDB Station ID	*Station description*	*Years with monthly data*	*Total months with data*
197	Route 173	2000, 2001, 2002	11
184	Johnsburg	2002, 2003	13
23	Route 176	2002, 2003	11
24	Algonquin	1976, 1987, 1988, 1989, 1990, 2002, 2003	42
26	South Elgin	1976, 1988, 1998, 1999, 2000, 2001, 2002, 2003	34
40	Geneva	2002, 2003	12
27	Montgomery	1976, 2002, 2003	14
34	Yorkville	2002, 2003	13
30	Dayton	1987, 1988, 1989, 1990	26

Table 5. List of Monitoring Agencies and Datasets Used in Analysis

Data collecting agency	*Chlorophyll a, corrected*	*Chlorophyll a, uncorrected*	*Temperature*	*Nitrogen*	*Phosphorus*	*Turbidity*	*Mean velocity*	*Depth/Width ratio*
Fox River Study Group	50	49	42	46	46	46		
IEPA – AWQMN	6		32	44	32	49		
IEPA			1	< 1	2			
USGS*	31		10	2	14	2	*	*
USGS – NAWQA			6		< 1			
Fox River WRD		11	5	6	6			
Fox Metro WRD			2	1		1		
Max McGraw Wildlife Foundation	< 1		< 1	< 1	< 1	< 1		
Northeastern Illinois Planning Commission	2		1	1		2		
Illinois State Water Survey*							*	*

Note: All numbers given are percentages. *The USGS and ISWS did not directly collect velocity and channel geometry data, but other datasets of these agencies were used to derive velocity and depth/width information.

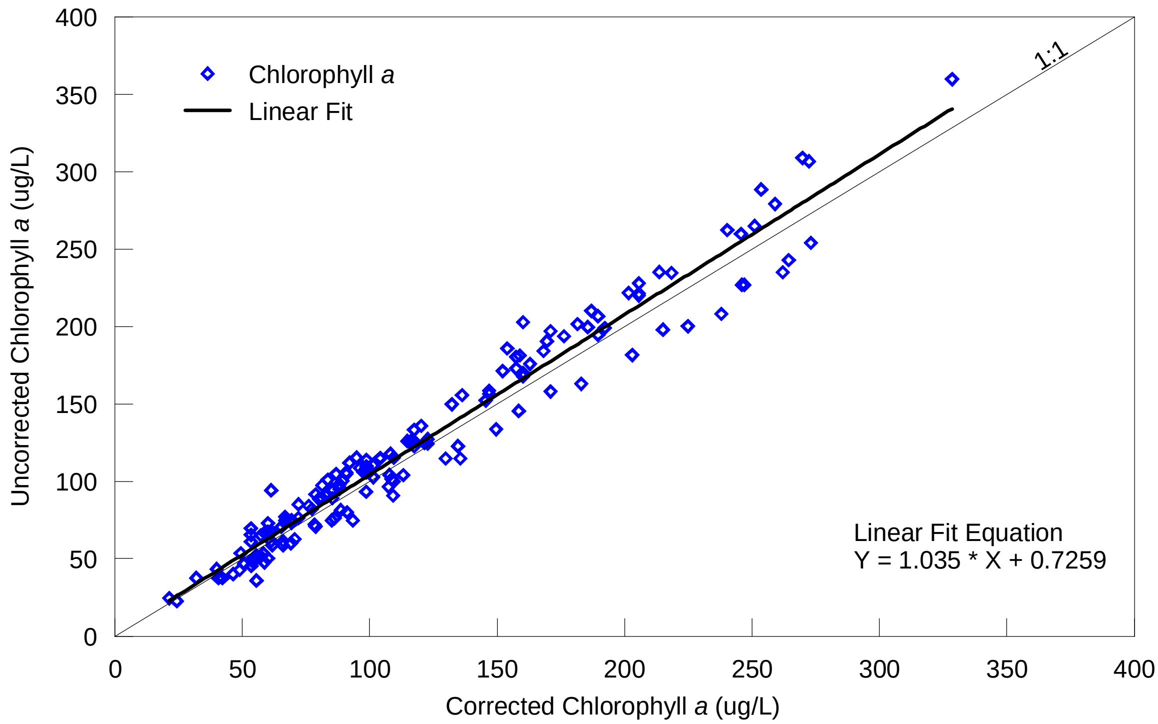

Figure 2. Relationship between chlorophyll *a* samples with and without acid correction.

to the large percentage of calculated chlorophyll *a* uncorrected data, all further analyses in this study used only chlorophyll *a* corrected data.

2.2 Statewide IEPA Data Description

The IEPA has been collecting chlorophyll *a* data at approximately 30 ambient sites since 2000. The IEPA also has been collecting 1-3 chlorophyll *a* samples per site from approximately 100 sites per year, as part of their intensive basin survey programs. Habitat data are also available from the intensive survey sites and some of the smaller ambient sites.

2.2.1 Data Sources

The IEPA grouped their data into two categories. Chemical data include chlorophyll *a*, nutrients, temperature, and turbidity information. Habitat data include velocity, depth/width information, and canopy cover information. Unlike the Fox River watershed, the algal biomass data were the most abundant component of the IEPA dataset.

2.2.2 Available Data

Algal Biomass. Results for 2267 corrected chlorophyll *a* samples from 579 monitoring sites were available from the IEPA. The amount of nutrient and habitat data available for these 579 stations within the same time frame proved to be a major limitation of the analysis. All subsequent data availability will be in reference to the subset of the 579 stations with chlorophyll *a* data.

Nitrogen. Total nitrogen was calculated from the summation of simultaneous nitrate-nitrite nitrogen and TKN data values. Only 678 TN results at 151 sites were available in the same time frame as the 2267 chlorophyll *a* samples collected.

Phosphorus. Total phosphorus data were available for 150 sites. This reduced the total number of samples with chlorophyll *a*, TN, and TP results available from 678 to 673 samples.

Temperature. Temperature data were available for the same 150 sites but not for every month. This reduced the total number of samples with complete information from 673 to 670 samples.

Turbidity. Sufficient turbidity data were only available for 142 sites. This further reduced the total number of samples with chlorophyll *a*, TN, TP, temperature, and turbidity available for analysis to 627 samples.

Velocity, Depth/Width, and Canopy Cover. Habitat data primarily were collected during the summer months, which made it practically impossible to match that habitat information with chlorophyll *a* samples collected throughout the year. Only two samples collected at two different locations had complete records of chlorophyll *a*, TN, TP, temperature, turbidity, velocity, DW ratio, and canopy cover.

2.2.3 Data Preparation

The next step in the data analysis involved further data processing for the various locations. For the purpose of analysis, it was critical that the various datasets were collected in similar time frames. Like the Fox River watershed data, datasets were aggregated to a monthly resolution.

This process resulted in 586 months of “long” records at 142 sites. The monthly record was considered “long” when it included at least one datapoint for each of the following variables: chlorophyll *a*, TN, TP, temperature, and turbidity. Velocity, depth/width ratio, and canopy cover information were dropped from the analysis because only two samples had complete records for all nine variables.

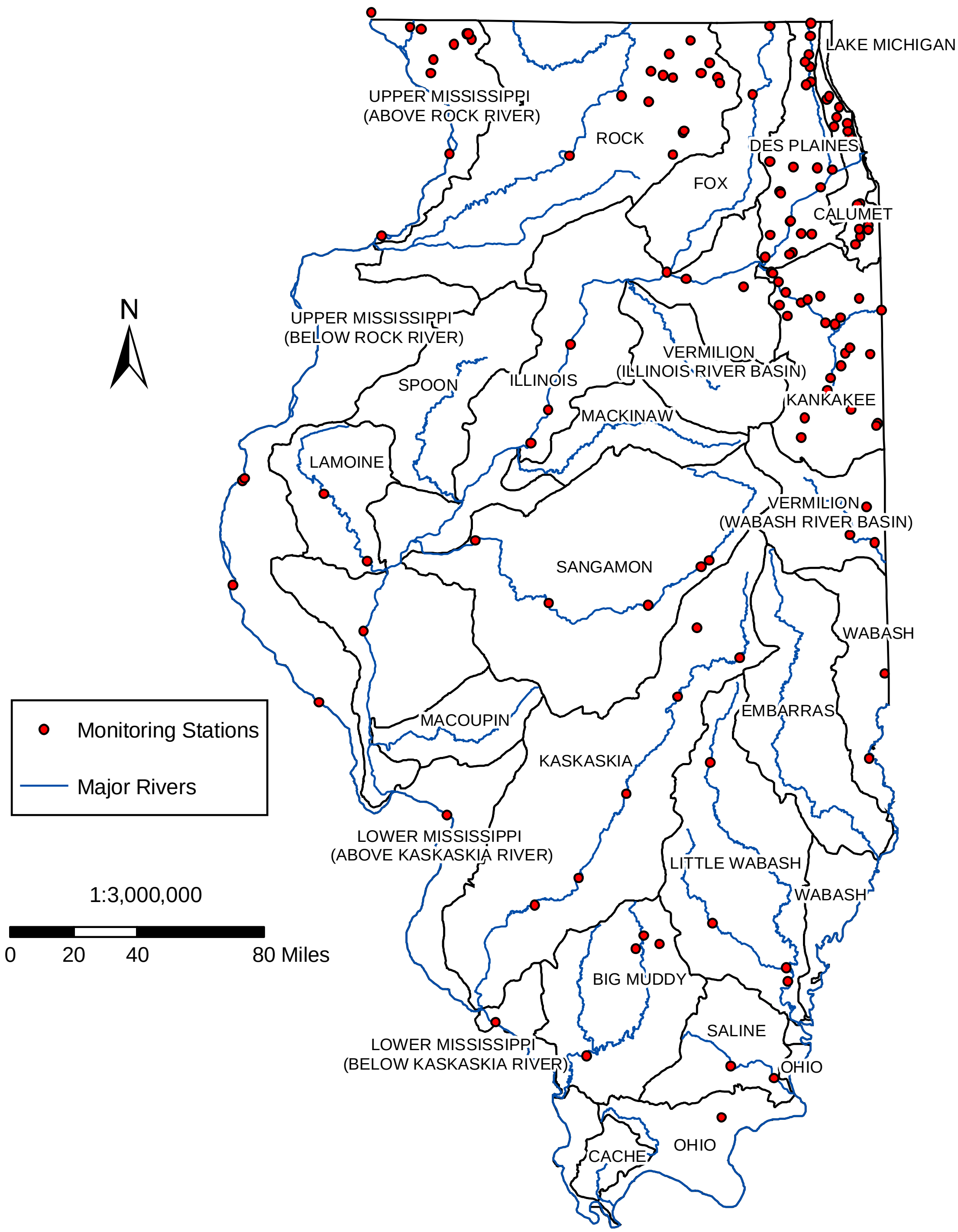

Figure 3. Location of IEPA water-quality stations within major drainage basins

If there were two or more datapoints in the same month, a simple arithmetic mean was calculated to represent the mean value of the parameter for that month. Most months typically had only one datapoint. Figure 3 identifies the locations of IEPA monitoring stations used in the analysis, including three stations in the Fox River watershed. Only two of those three stations had sufficient data for inclusion in the Fox River watershed study, for a total of 12 datapoints common to both investigations.

3. Model and Statistical Analysis

3.1 Model Description

The modeling framework is based on a unique pattern recognition and classification approach that combines hydrologic, chemical, and biological data from various sources. Two groups of variables generally affect algal biomass: stream habitat conditions and nutrients. Habitat conditions largely control stream susceptibility to algal growth. Therefore, a high nutrient level does not always result in high algal biomass and vice versa. The modeling framework consists of two components to elucidate the cause-effect relationship between nutrient levels and algal biomass using susceptibility values. Figure 4 illustrates the model structure.

The first component, denoted as f_1, calculates the susceptibility as a function of habitat factors. The second component, denoted as f_2, represents algal biomass (AB) as a function of nutrients (N).

Model development for this approach starts with the second component, i.e., with the calculation of algal biomass based on nutrients:

$$AB = f_2(N) + \varepsilon_2 \tag{1}$$

The residual (ε_2) is the unexplained variability attributable to a stream susceptibility (S) to algal growth, and ε_2 is assumed to be equal to S. The next step in this approach is to characterize S by conditions of the habitat factors (HF):

$$\varepsilon_2 = S = f_1(HF) + \varepsilon_1 \tag{2}$$

where $f_1(HF)$ denotes predicted susceptibility ($\hat{S}$), and $\varepsilon_1 = S - \hat{S}$ is the residual. The function f_1 in the above equation is the first component of the proposed model.

Combining Equations 1 and 2 yields:

$$AB = f_2(N) + f_1(HF) + \varepsilon_1 \tag{3}$$

The structures of f_1 and f_2 were defined through an analysis of regression between simultaneously observed model inputs and model outputs (as detailed in Section 2 of this report). Parameters of both functions are optimized through minimization of the residuals. Function f_2 is a linear or nonlinear multiple input-single output (MISO) function as its inputs are nutrients (TN and TP), and output is algal biomass; the “observed” susceptibility value (S) is the prediction error, the difference between the observed and computed algal biomass (AB). Function f_1 is a linear MISO function. Inputs are conditions of the habitat factors, and the output is the predicted susceptibility.

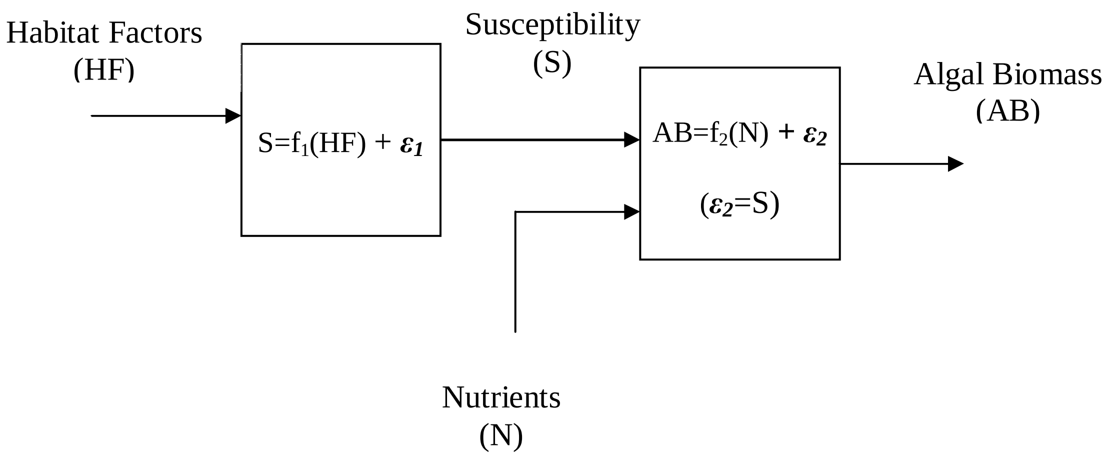

Figure 4. Model structure for quantifying susceptibility and cause-effect relationship between nutrients and algal biomass

Modeling in this study has two major steps: model building and model validation. In model building, several linear and nonlinear models for functions f_1 and f_2 were compared. Each model was evaluated using the adjusted squared correlation coefficient (R^2) and root-mean-square-error (RMSE). Model validation includes an uncertainty analysis for the chosen models. The entire dataset is divided into two datasets: training and testing. Only the training dataset is used in model building, while both training and testing datasets are used in model validation. The direction of model building is opposite to that of model validation. Model building starts with function f_2 and ends with function f_1, but the validation process first uses the function f_1 to predict stream susceptibility, and then the function f_2 to predict algal biomass.

3.1.1 Model Building

The steps in model building (Figure 5) are summarized as follows:

1. In the first stage, all the available physical, chemical, biological, and hydrologic data were inventoried. This stage was important in model design, as the data availability dictates the model input selection. Data availability, completeness, and accuracy were critical in developing various test models. Based on the inventoried data, the preliminary computational units and time increments were defined. Three monthly datasets, Fox River watershed monthly data, Fox River watershed summer monthly data, and the IEPA monthly data, as described in Section 2, were prepared, processed, aggregated, and normalized using a logarithmic transformation.

2. Various linear and nonlinear f_2 models were tested. Models having the minimum RMSE and the maximum R^2 were selected for future calculations. It was assumed that residuals from f_2 models explain the degree of susceptibility to algal growth based on nutrient enrichment for each model. This susceptibility, calculated as a residual of model f_2, is the observed susceptibility (S).

3. Observed susceptibility (S) and the habitat factors (HF) then were used to estimate the corresponding f_1 models. Various f_1 model structures also were tested, to find the model producing the minimum error. If the number of the f_2 models is denoted as M, and the number of f_1 models is denoted as N, the total number of models tested would be M·N. Models were also evaluated using R^2 and RMSE.

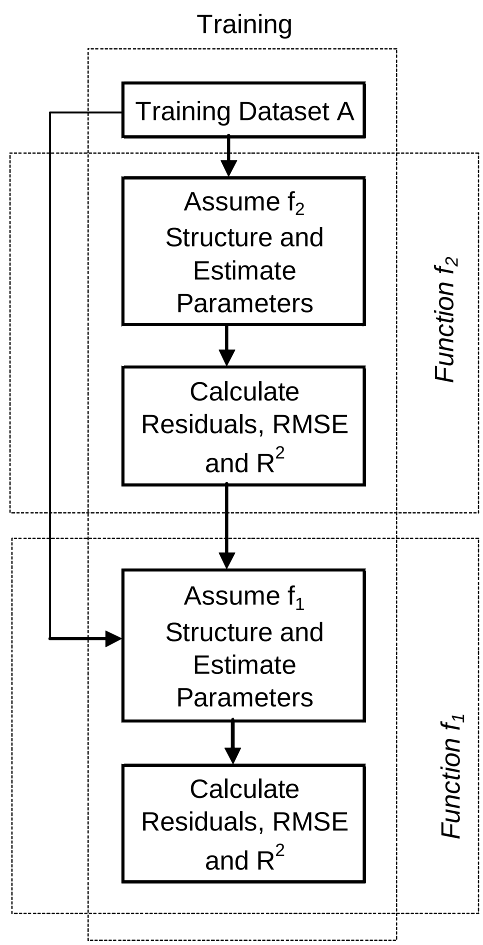

Figure 5. Schematic of model building steps

3.1.2 Model Validation

The model validation stage (Figures 6-7) includes uncertainty estimation for models constructed in the model building stage. Although models were constructed using only training datasets, the models were validated for both training and testing stages. Figures 6 and 7 show the validation procedure for calculations of S and AB, respectively. These figures are valid for both training and testing stages.

Figure 6 shows the method used to validate the models for susceptibility prediction. Using the observed nutrients and algal biomass as respective f_2 model inputs and output, the model residuals were calculated. These residuals were considered the "observed" susceptibility. Using the observed habitat factors and known f_1 model, a predicted susceptibility was calculated. Comparing the observed and the predicted susceptibility is the first component of the validation process.

Figure 7 shows the method used to validate the models for algal biomass prediction. The comparison between the observed and calculated algal biomass is used to further validate the methods developed in this study. The calculated algal biomass is a result of the f_2 model using inputs of observed nutrients and susceptibility predicted by the f_1 model.

The cross-validation approach was applied to all the models selected in the model building to further refine selection of the most appropriate model. This technique performs the training procedure using a portion of time-series data, while the remaining data are reserved for testing. If the simulation accuracy in the training stage is superior to that of testing stage, it may indicate that training fit the noise, and that the model structure is inadequate. Models (linear and nonlinear regression equations) were validated through RMSE, adjusted R^2, classification success rate, and entropy.

The classification success rate is expressed as a percentage of successfully classified watershed susceptibility S. If the class of the calculated S coincided with the class of the observed S, the classification was considered successful. A normal distribution was fitted to all data, and the class limits were equal to the 0.333 and 0.667 quartiles for three categories (low, medium, and high). In addition, the class limits were equal to the three quartiles of the fitted normal distribution for four categories (low, medium-low, medium-high, and high). The entropy measure of classification success is described in Section 3.2.

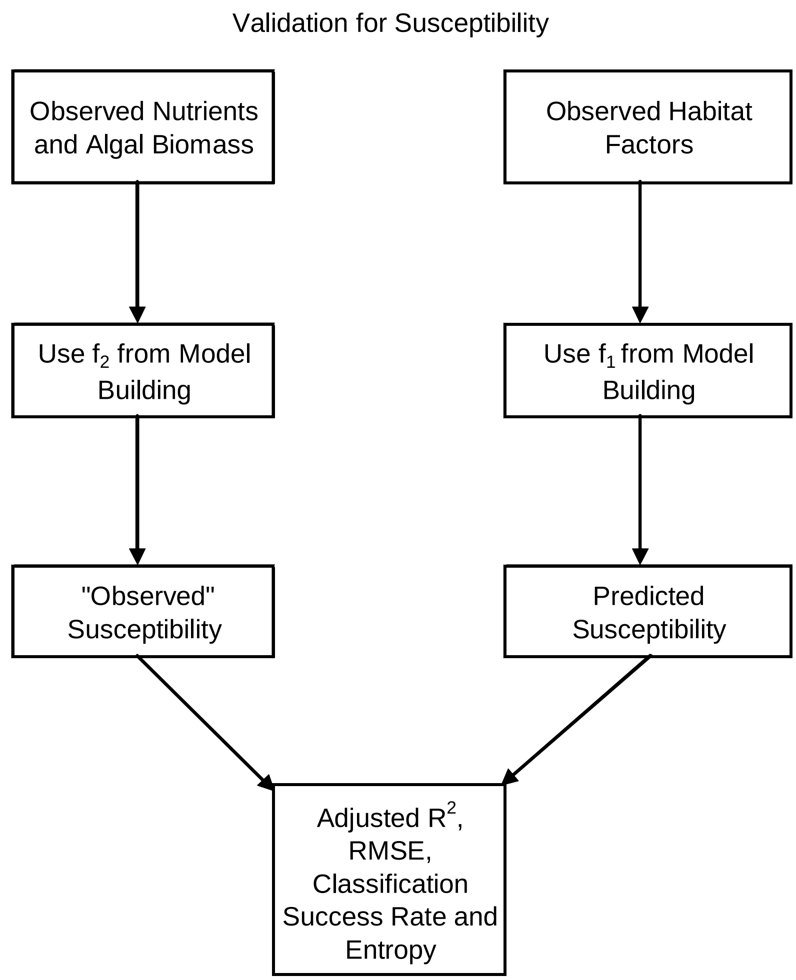

Figure 6. Schematic of steps in model validation for nutrient susceptibility

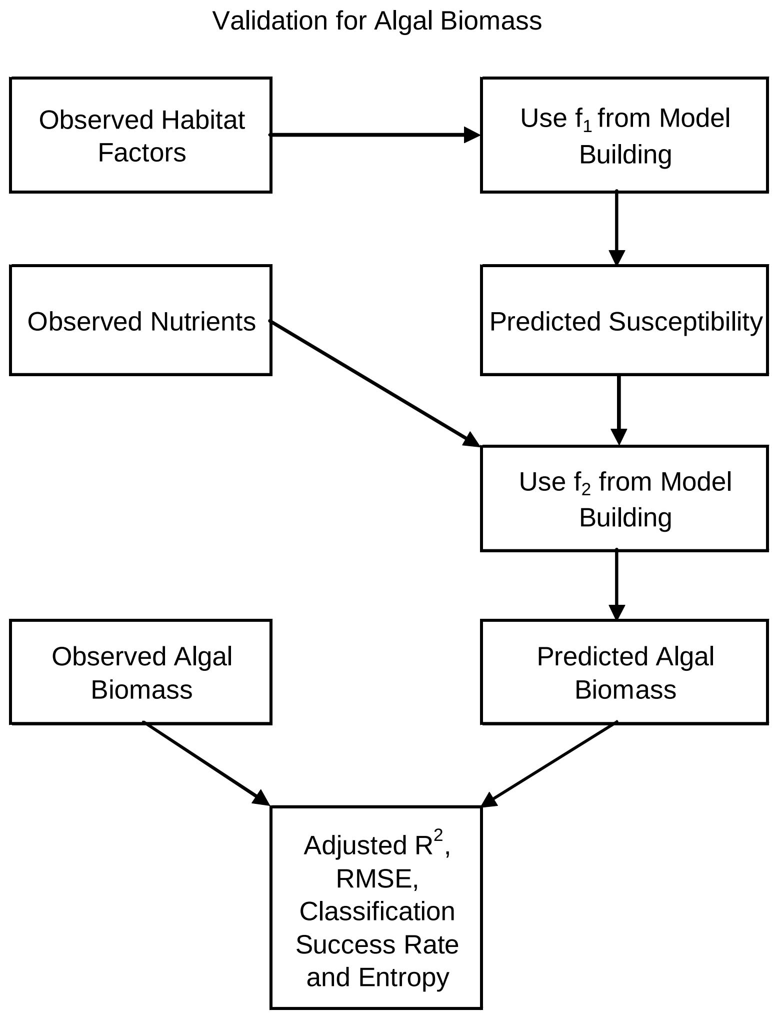

Figure 7. Schematic of steps in model validation for algal biomass

3.2 Entropy

Due to its advantages over traditional validation statistics, the concept of entropy has been very popular in the literature for decades. Entropy, as defined in information theory, is a measure of the uncertainty of a particular outcome in a random process, and provides an objective criterion in selecting the mathematical model. By computing the entropy of a model output from the available input-output data, one can characterize the association between inputs and outputs. Linfoot (1957) demonstrated that the advantage of using informational correlations in physical applications is that they are invariant under transformations, which is not the case with an ordinary correlation. Amorocho and Espildora (1973) and Valdes et al. (1975) were among the first to introduce the basics of entropy in hydrology. Harmancioglu et al. (1986) compared correlation-based and entropy-based measures of information transfer between variables and addressed several ways to improve information transfer between two sets of variables. They also discussed additional advantages and disadvantages of the entropy-based approach, pointing out that the entropy principle does not assume normality or any particular type of functional relationship (linear or nonlinear).

Entropy-based techniques also have been used in various studies for gage network design. Husain (1989) expressed the information-transmitting capabilities of a hydrologic network in terms of entropy and proposed a gage network design method based on entropy. Harmancioglu and Alpaslan (1992) used an entropy-based uncertainty measure in water-quality monitoring network design. Yang and Burn (1994) described an entropy-based approach to design streamgaging networks based on a directional informational transfer (DIT) index, which their study favorably compared with the traditional correlation coefficient approach. Yang and Burn state, "Entropy and mutual information possess advantages relative to other measures of association in that they provide a quantitative measure of: (1) the information at a station; (2) the information transferred and lost during the transmission; (3) a description of the relationships among stations according to their information transmission characteristics" (p. 308). Knapp and Markus (2003) and Markus et al. (2003) successfully applied a modified DIT approach to evaluate the Illinois streamflow gaging network.

Entropy as a measure of the degree of uncertainty of a particular outcome in a process can be expressed as follows (Valdes et al., 1975):

$$H(X) = \int f(x) \log[f(x)] dx \tag{4}$$

where f(x) represents a probability density function of variable X. Entropy H(X) is also called marginal entropy of a single variable X. Uncertainty of two variables, X and Y, is described by joint entropy H(X,Y):

$$H(X,Y) = \iint f(x,y) \log[f(x,y)] dxdy \tag{5}$$

where f(x,y) represents the joint probability density function of variables X and Y. A discrete version of Equation 4 was used to compute entropy for various models (Press et al., 1995):

$$H(X) = \sum_{k=1}^{K} p(x_i) \log \frac{1}{p(x_i)} \tag{6}$$

where k denotes a discrete data interval for variable X, x_k is an outcome corresponding to interval k, and $p(x_k)$ is the probability of x_k. The probability $p(x_k)$ is based on the empirical frequency of variable X. Entropy is expressed in napiers because the base of the logarithm was equal to exponential constant *e* (Amorocho and Espildora, 1973). It was assumed that variable X has a finite number of possible outcomes (K). A discrete version of Equation 5 (Press et al., 1995) was used to calculate joint entropy:

$$H(X,Y) = \sum_{k=1}^{K} \sum_{l=1}^{L} p(x_k, y_l) \log \frac{1}{p(x_k, y_l)} \tag{7}$$

where k denotes a discrete data interval for variable X, l denotes a discrete data interval for variable Y, $p(x_{k,}y_l)$ is the probability of an outcome corresponding to interval k for X and interval l for Y, K and L are the numbers of possible outcomes for X and Y, respectively. In all computations of this research, it was assumed that K=L. For the number of classes, two classification schemes were used: K=3 (low, medium, and high), and K=4 (low, medium-low, medium-high, and high).

4. Model Application

This study uses two databases: the Fox River watershed database (Section 2.1) and the IEPA database (Section 2.2). The following three datasets were created based on these databases (Figure 8) and described in this section: the Fox River watershed monthly data (Section 4.1), the Fox River watershed summer monthly data (Section 4.2), and the IEPA monthly data (Section 4.3).

4.1 Analysis of Fox River Watershed Monthly Data

4.1.1 Model Building Step 1 (Model Inputs)

The Fox River watershed dataset consists of 176 average monthly values for the following parameters: chlorophyll *a*, TN, TP, temperature, turbidity, velocity, and DW ratio (see Appendix A).

All seven parameters were tested for skewness using SAS (SAS, 2003). Regression models require homoscedastic data, meaning that regression residuals are similarly distributed across various points of the range of independent variable. Highly skewed data are often heteroscedastic for which those regression models cannot be applied. To eliminate this problem all the input and output datasets were transformed using the equations presented in Table 6. For more explanation on data transformation, see Helsel and Hirsch (1991, p. 229). Both TN and TP were log-transformed using the equation ln(x) where x is the nutrient concentration. chlorophyll *a*, temperature, turbidity, and velocity data were all still significantly skewed after log-transformation, so the data were transformed using the equation ln(x+c), where x is the parameter value and c is a constant selected such that skewness of the dataset approximated zero. Constants selected for each parameter are displayed (Table 6).

Table 6. Transformation of Model Inputs and Output

Parameter	*Transformed?*	*Equation*	*Constant (c)*
Chlorophyll *a*	Yes	ln(x + c)	61.15
Total nitrogen	Yes	ln(x)	
Total phosphorus	Yes	ln(x)	
Temperature	Yes	ln(x + c)	46.76
Turbidity	Yes	ln(x + c)	4.93
Velocity	Yes	ln(x + c)	-0.17
Depth/Width ratio	No		

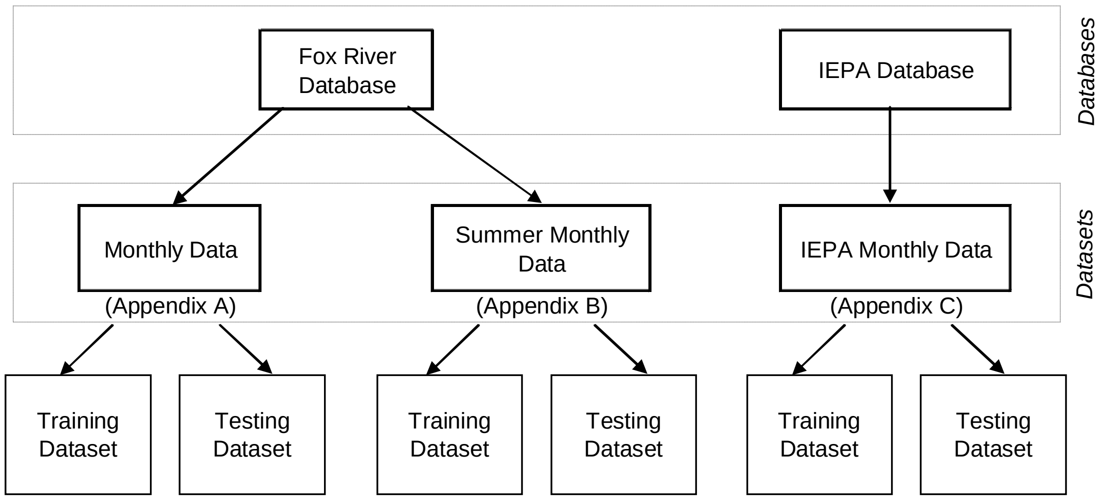

Figure 8. Databases and datasets in this study

Data were divided into separate datasets for training (dataset A) and testing (dataset B). To accomplish this, the total dataset first was sorted by station ID and date in ascending order. Dataset A consisted of odd-numbered observations and dataset B consisted of even-numbered observations.

4.1.2 Model Building Step 2 (Development of f_2 Model)

Using the 88 observations in dataset A, a regression analysis was performed for the dependent variable logarithm of chlorophyll *a* (lnChla) using all possible combinations of the following four independent variables: lnTN, $(\text{lnTN})^2$, lnTP, and $(\text{lnTP})^2$. The 15 possible combinations follow.

lnTN
$(\text{lnTN})^2$
lnTP
$(\text{lnTP})^2$
lnTN, $(\text{lnTN})^2$
lnTN, lnTP
lnTN, $(\text{lnTP})^2$
lnTP, $(\text{lnTP})^2$
lnTP, $(\text{lnTN})^2$
$(\text{lnTP})^2$, $(\text{lnTN})^2$
lnTN, $(\text{lnTN})^2$, lnTP
lnTN, $(\text{lnTN})^2$, $(\text{lnTP})^2$
lnTN, lnTP, $(\text{lnTP})^2$
lnTP, $(\text{lnTP})^2$, $(\text{lnTN})^2$
lnTN, $(\text{lnTN})^2$, lnTP, $(\text{lnTP})^2$

Of these 15 different models, the following seven were selected for further analysis. All seven models use lnChla (the natural logarithm of chlorophyll *a*).

Model 1: lnChla = f(lnTP)
Model 2: lnChla = $f(\text{lnTP})^2$
Model 3: lnChla = f(lnTP, $(\text{lnTP})^2$)
Model 4: lnChla = f($(\text{lnTN})^2$, $(\text{lnTP})^2$)
Model 5: lnChla = f(lnTN, $(\text{lnTN})^2$, $(\text{lnTP})^2$)
Model 6: lnChla = f(lnTN, lnTP)
Model 7: lnChla = f(lnTN, $(\text{lnTN})^2$, lnTP, $(\text{lnTP})^2$)

These seven models were chosen for various reasons. Models 1 and 3 were chosen based on their use by Dodds et al. (1997), and because the relationship between chlorophyll *a* and phosphorus seemed much stronger than the relationship between chlorophyll *a* and nitrogen. Model 2 was chosen because it had the highest R^2 and lowest MSE of all the models with a single independent variable. Model 4 was chosen because it had the highest R^2 and lowest MSE of all the models with two independent variables. Model 5 was chosen because it had the highest R^2 and lowest MSE of all the models with three independent variables. Model 6 was chosen for further analysis because it contained both TN and TP. Model 7 was chosen because it contained all four independent variables. A scatter plot of predicted vs. observed chlorophyll *a* for Model 1 is shown (Figure 9).

The parameter coefficients estimated for these seven models are listed (Table 7). The statistical significance for each variable is indicated.

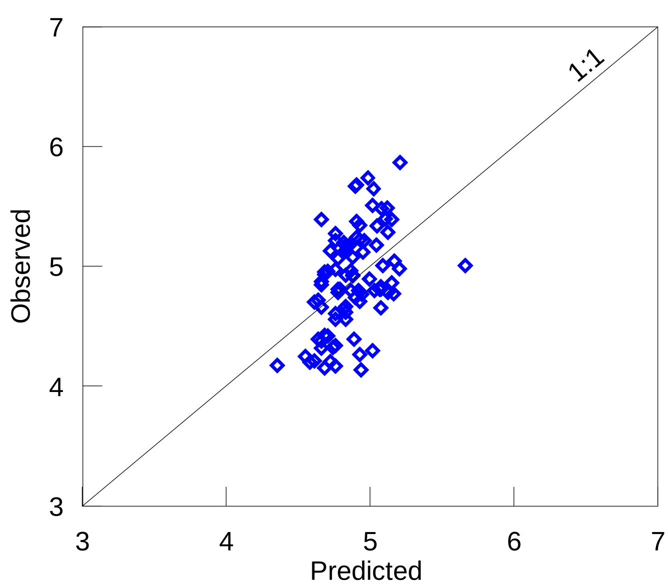

Figure 9. Observed and predicted algal biomass (f_2 model) for Model 1, Fox River watershed monthly training dataset

Table 7. Parameter Coefficients for the Seven f_2 Models

Model	*R^2*	*RMSE*	*Intercept*	*lnTP*	*$(lnTP)^2$*	*$(lnTN)^2$*	*lnTN*
1	0.2074	0.37029	5.25431^d	0.27848^d			
2	0.2513	0.35989	5.14713^d		-0.11685^d		
3	0.2446	0.36149	5.17946^d	0.05522	-0.09849^b		
4	0.2862	0.35138	5.32638^d		-0.11387^d	-0.12625^b	
5	0.3104	0.34540	4.23875^d		-0.10880^d	-0.81853^b	1.7705^b
6	0.2514	0.35985	5.68350^d	0.28713^d			-0.3526^b
7	0.3062	0.34645	4.34527^d	0.07749	-0.08311^c	-0.79338^b	1.68768^c

Notes: $^aP < 0.20$, $^bP < 0.05$, $^cP < 0.01$, $^dP < 0.001$. lnChla is a dependent variable

4.1.3 Model Building Step 3 (Development of f_1 Model)

Residuals from these seven models then were used as the dependent variable (susceptibility) in several multiple linear regression models for all possible combinations of the following four independent variables: log-transformed temperature (lnTemp), log-transformed turbidity (lnTurb), log-transformed velocity (lnVel), and depth-width (DW) ratio. These independent variable combinations are displayed (Table 8).

With each of the seven f_2 models, the f_1 regression model using the combination of lnTemp, lnTurb, and DW had the highest R^2 and the lowest MSE of all the 15 f_1 model combinations. Therefore, that combination of habitat factors was selected as the best model to use and designated in bold (Table 8).

Using the following f_1 model: S=f(lnTemp, lnTurb, DW), parameter coefficients were estimated for these models and are listed (Table 9), while the statistical significance for each variable is also indicated.

4.1.4 Model Validation

Standardization of Susceptibility

The predicted susceptibility ($\hat{S}$) was calculated using habitat factors and model f_1, and standardized by subtracting the observed mean (μ) and dividing the difference by the observed standard deviation (σ) for each datapoint in the training dataset. The observed mean and standard deviation were obtained based on the "observed" S, calculated using nutrients and function f_2. Equations 8-9 describe the standardization of $\hat{S}$.

$$z_{\hat{S}} = \frac{\hat{S} - \mu_{\hat{S}}}{\sigma_{\hat{S}}} \tag{8}$$

Next, the adjusted susceptibility was calculated based on the standardized predicted susceptibility and mean and standard deviation of the observed susceptibility:

$$\text{Adjusted } \hat{S} = \mu + \sigma z_{\hat{S}} \tag{9}$$

The mean and standard deviation for observed susceptibility and predicted susceptibility for dataset A were used for standardization throughout the validation process. The scatter plot of predicted vs. observed susceptibility for Model 1 for the training dataset is shown (Figure 10).

Predicted algal biomass was then computed using the adjusted predicted susceptibility as the residual term in Equation 1 and the observed nutrients as the input for the f_2 models.

$$\hat{AB} = f_2(N) + \text{Adjusted } \hat{S} \tag{10}$$

A sample scatter plot of predicted vs. observed algal biomass (chlorophyll *a*) for Model 1 is shown (Figure 11).

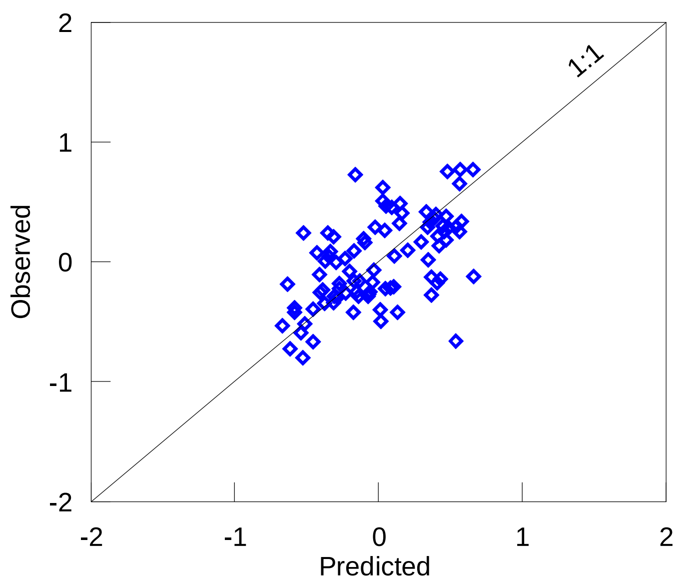

Figure 10. Observed and predicted susceptibility (f_1 model) for Model 1, Fox River watershed monthly training dataset

Table 8. Fox Monthly Data, Parameter Combinations for Chosen Models

Variable	*lnTP*	*$(lnTP)^2$*	*lnTP, $(lnTP)^2$*	*$(lnTP)^2$, $(lnTN)^2$*	*lnTN, $(lnTN)^2$, $(lnTP)^2$*	*lnTN, lnTP*	*lnTN, $(lnTN)^2$, lnTP, $(lnTP)^2$*
lnTemp	x	x	x	x	x	x	x
lnTurb	x	x	x	x	x	x	x
lnVel	x	x	x	x	x	x	x
DW	x	x	x	x	x	x	x
lnTemp, lnTurb	x	x	x	x	x	x	x
lnTemp, lnVel	x	x	x	x	x	x	x
lnTemp, DW	x	x	x	x	x	x	x
lnTurb, lnVel	x	x	x	x	x	x	x
lnTurb, DW	x	x	x	x	x	x	x
lnVel, DW	x	x	x	x	x	x	x
lnTemp, lnTurb, lnVel	x	x	x	x	x	x	x
lnTemp, lnTurb, DW	**x**	**x**	**x**	**x**	**x**	**x**	**x**
lnTemp, lnVel, DW	x	x	x	x	x	x	x
lnTurb, lnVel, DW	x	x	x	x	x	x	x
lnTemp, lnTurb, lnVel, DW	x	x	x	x	x	x	x

Note: Bold x signifies the model with the highest R^2 and the lowest MSE

Table 9. Parameter Coefficients for the Seven f_1 Models

Model	*R^2*	*RMSE*	*Intercept*	*lnTemp*	*lnTurb*	*DW*
1	0.2892	0.31039	-3.25446[c]	0.68206[b]	0.19555[b]	-6.98602
2	0.2740	0.30487	-3.27309[c]	0.70807[b]	0.16679[b]	-7.12271[a]
3	0.2724	0.30478	-3.25727[c]	0.70175[b]	0.16821[b]	-6.74108
4	0.2245	0.30587	-2.90178[c]	0.64017[b]	0.13931[a]	-8.01274[a]
5	0.2398	0.29591	-3.39117[d]	0.78177[c]	0.10305[a]	-6.66115
6	0.2271	0.31271	-2.73615[b]	0.57749[a]	0.16845[b]	-7.79039[a]
7	0.2333	0.29629	-3.32480[c]	0.76239[c]	0.10517[a]	-6.23986

Notes: [a]$P < 0.20$, [b]$P < 0.05$, [c]$P < 0.01$, [d]$P < 0.001$. Susceptibility is dependent variable

4.1.5 Cross Validation

Seven (f_1,f_2) model combinations (each of the seven selected f_2 models coupled with the one selected f_1 model) were applied to the testing dataset (dataset B) with nutrients (TN and TP) and habitat factors (temperature, turbidity, and depth-width ratio) as model inputs. Using the testing dataset, the observed algal biomass (AB) then was compared to the algal biomass calculated from the seven f_2 models. A scatter plot of predicted vs. observed chlorophyll *a* for the f_2 Model 1 using the testing data is shown (Figure 12).

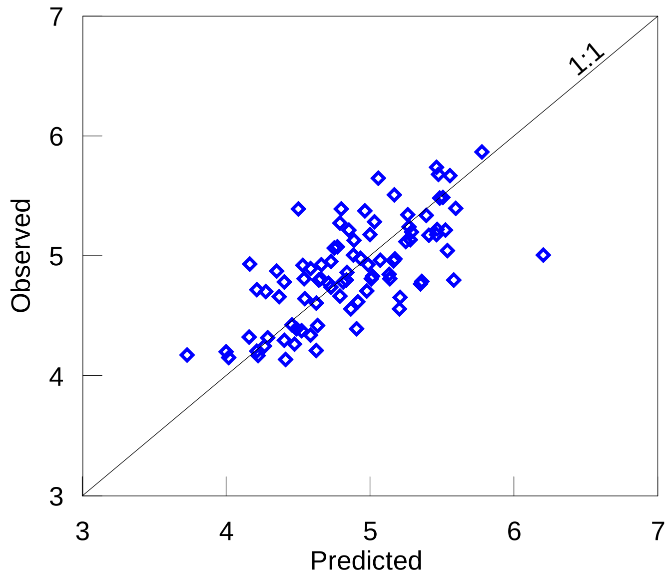

Figure 11. Observed and predicted algal biomass (f_2 + f_1 model) for Model 1, Fox River watershed monthly training dataset

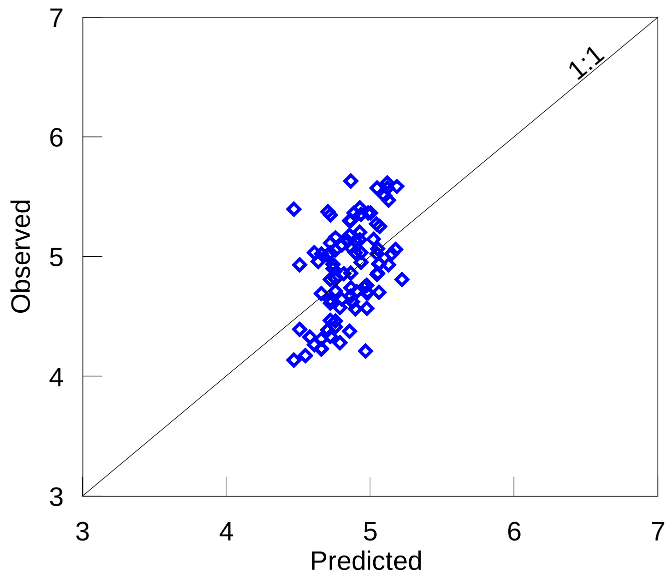

Figure 12. Observed and predicted algal biomass (f_2 model) for Model 1, Fox River watershed monthly testing dataset

The adjusted predicted susceptibility (Adjusted $\hat{S}$) also was calculated for the seven models using the regression equations for f_1 Models 1-7 along with the adjustments described in Equations 8 and 9. A sample scatter plot of predicted vs. observed susceptibility for the testing dataset is shown for Model 1 (Figure 13). The RMSE and adjusted R^2 between the predicted and observed susceptibility, calculated for both training and testing datasets are shown (Table 10).

The observed algal biomass was used to validate the seven f_2 and f_1 models. The observed algal biomass was compared to the algal biomass predicted from the summation of f_2 and f_1 models $(\hat{AB})$. The scatter plot of predicted vs. observed chlorophyll *a* for Model 1 is shown in Figure 14 for dataset B. The RMSE and adjusted R^2 for algal biomass were calculated for both training and testing stages and are shown (Table 11).

Table 10. R^2 and RMSE for f_1 Models

	Training (Dataset A)		*Testing (Dataset B)*	
Model	R^2	*RMSE*	R^2	*RMSE*
1	0.5153	0.35143	0.4882	0.35817
2	0.5076	0.34666	0.4406	0.37743
3	0.5068	0.34671	0.4443	0.37473
4	0.4828	0.35305	0.4374	0.36658
5	0.4904	0.33990	0.4261	0.35986
6	0.4841	0.36064	0.4780	0.35228
7	0.4872	0.34103	0.4301	0.35683

Note: Susceptibility is dependent variable

Table 11. R^2 and RMSE for the Summation of Models f_1 and f_2

	Training (Dataset A)		*Testing (Dataset B)*	
Model	R^2	*RMSE*	R^2	*RMSE*
1	0.6405	0.34732	0.6022	0.35398
2	0.6533	0.34260	0.6013	0.37301
3	0.6494	0.34467	0.5984	0.37252
4	0.6554	0.35096	0.6249	0.36442
5	0.6631	0.33990	0.6249	0.35986
6	0.6441	0.35852	0.6300	0.35021
7	0.6591	0.34308	0.6241	0.35897

Note: Dependent variable is algal biomass

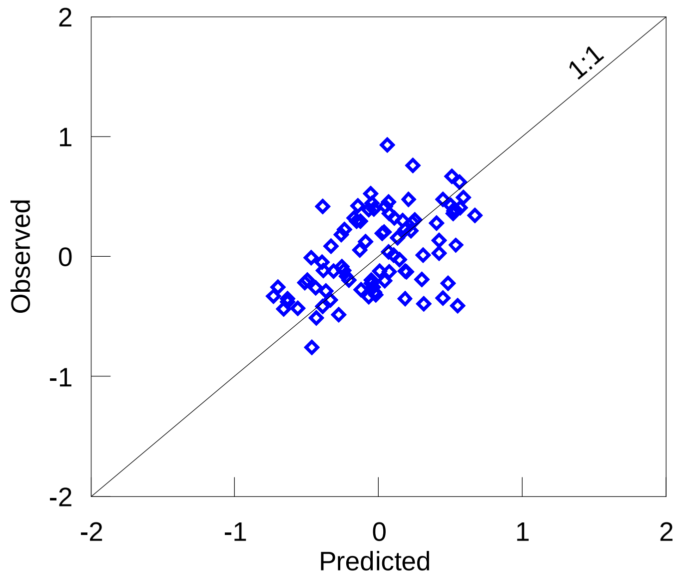

Figure 13. Observed and predicted susceptibility (f_1 model) for Model 1, Fox River watershed monthly testing dataset

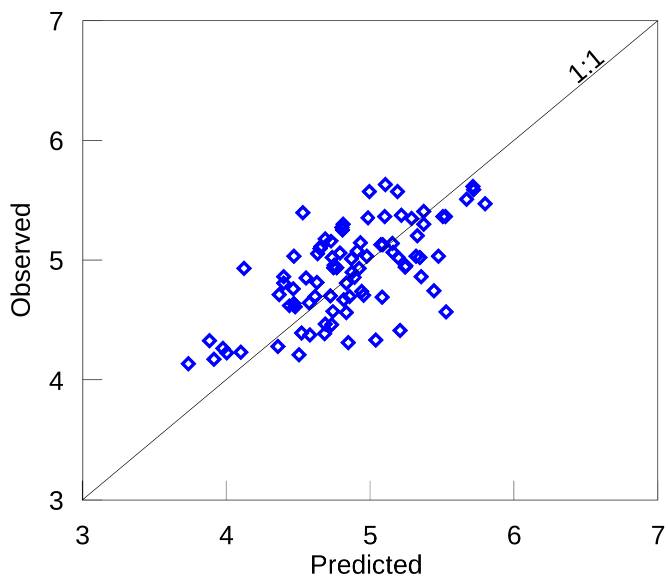

Figure 14. Observed and predicted algal biomass (f_2 + f_1 model) for Model 1, Fox River watershed monthly testing dataset

4.1.6 Susceptibility Classification Success Rates

The observed susceptibilities were divided into three categories (high, medium, and low) using the following procedure. The preliminary analysis indicated that the observed susceptibilities have a normal distribution. The mean (μ) and standard deviation (σ) based on each training sample for the particular model were calculated. Next, lower (s_L) and upper (s_U) limits were determined such that susceptibility was high for $S \geq s_U$; medium for $s_L < S < s_U$; and low for $S \leq s_L$, where s_L was estimated as $\mu - 0.435\sigma$ and s_U as $\mu + 0.435\sigma$.

To further test the classification system, observed susceptibilities also were divided into four categories (high, medium-high, medium-low, and low) using a similar procedure. Lower (s_L) and upper (s_U) limits were established such that susceptibility is high for $S \geq s_U$ and low for $S \leq s_L$ where s_L was estimated as $\mu - 0.67\sigma$, and s_U was estimated as $\mu + 0.67\sigma$. The medium values below average and above the lower limit are medium-low, such that $s_L < S \leq \mu$. The medium values above average and below the upper limit are medium-high, such that $\mu < S < s_U$.

After classification, the following success rates were computed for each model (Table 12). Example matrices for Model 1 for both the training and testing stages are shown (Figures 15 and 16, respectively).

Table 12. Success Rates for 3 x 3 and 4 x 4 Classification Matrices

	3 x 3 matrices		*4 x 4 matrices*	
Model	*Training (Dataset A)*	*Testing (Dataset B)*	*Training (Dataset A)*	*Testing (Dataset B)*
1	0.5113636	0.4886364	0.4204545	0.4204545
2	0.4545455	0.4431818	0.4090909	0.3522727
3	0.4772727	0.4431818	0.4204545	0.3522727
4	0.4772727	0.4318182	0.3863636	0.3181818
5	0.4659091	0.4318182	0.3295455	0.3522727
6	0.5000000	0.4659091	0.4431818	0.3977273
7	0.4772727	0.4318182	0.3295455	0.3409091

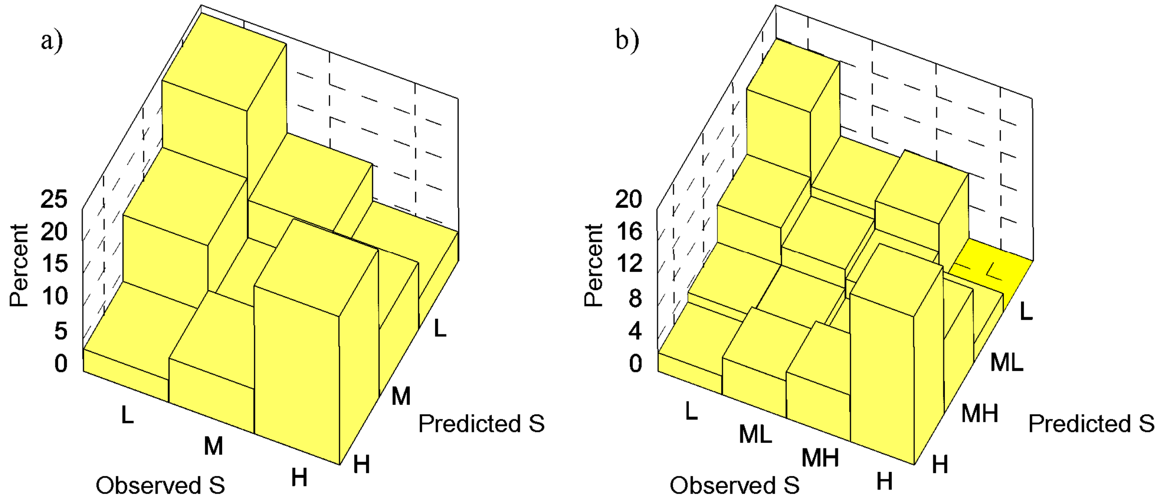

Figure 15. Model 1 classification matrices for Fox River watershed monthly training dataset for susceptibility categories: a) low, medium, and high and b) low, medium-low, medium-high, and high

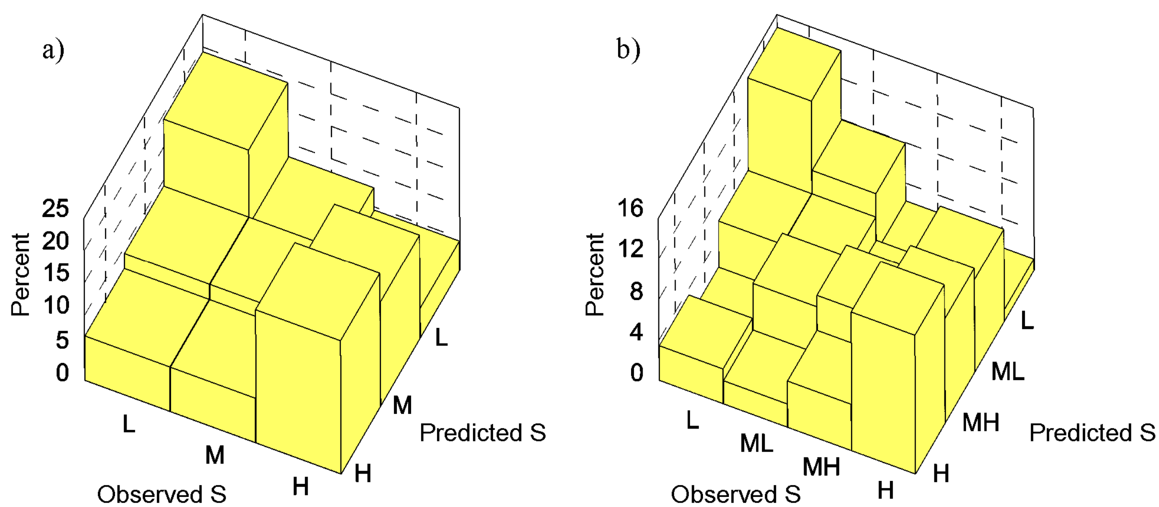

Figure 16. Model 1 classification matrices for Fox River watershed monthly testing dataset for susceptibility categories: a) low, medium, and high and b) low, medium-low, medium-high, and high

4.1.7 Entropy

Entropy was calculated for all seven models and the computed values are displayed (Tables 13-14). Further analysis is provided in Section 5.

Table 13. Entropy Values for a 3 x 3 Classification Matrix

Model	*Training (Dataset A)*	*Testing (Dataset B)*
1	1.9960267	2.0787363
2	2.0329504	2.1071196
3	2.0360281	2.0838672
4	2.0460427	2.0868092
5	2.0828733	2.1266582
6	2.0013420	2.0764467
7	2.0689196	2.1297113

Table 14. Entropy Values for a 4 x 4 Classification Matrix

Model	*Training (Dataset A)*	*Testing (Dataset B)*
1	2.5015147	2.5617585
2	2.5381821	2.6060559
3	2.5361178	2.6011000
4	2.5901225	2.6402741
5	2.5496698	2.6337449
6	2.5320529	2.6269242
7	2.5554732	2.6435307

4.2 Summary of Analysis of Fox Watershed Summer Monthly Data

Because algal biomass levels are primarily a concern during summer months, further analysis focused on data collected during that time. Dodds et al. (1997) defined summer as approximately mid-June through mid-September, and this study deemed summer monthly data as those collected during June, July, August, or September. Model building and validation procedures followed were identical to those used with the Fox River watershed monthly dataset, and additional models investigated are described in the appropriate section.

4.2.1 Model Building Step 1 (Model Inputs)

The Fox River watershed dataset used consisted of 55 average monthly values for the summer months of June, July, August, and September for the following parameters: chlorophyll *a*, TN, TP, temperature, turbidity, velocity, and depth/width ratio (see Appendix B). The transformations performed and constants selected for each parameter are displayed (Table 15).

4.2.2 Model Building Step 2 (Development of f_2 Model)

Using the 28 observations in dataset A, a regression analysis was performed for the dependent variable, lnChla using the same 15 possible combinations of model inputs as in Section 4.1.2. Of these 15 different models, eight were selected for further analysis using the summer monthly dataset.

Model 1: lnChla = f(lnTP)
Model 2: lnChla = $f(\ln TP)^2$
Model 3: lnChla = $f(\ln TP, (\ln TP)^2)$
Model 4: lnChla = $f((\ln TN)^2, (\ln TP)^2)$
Model 5: lnChla = $f(\ln TN, (\ln TN)^2, (\ln TP)^2)$
Model 6: lnChla = f(lnTN, lnTP)
Model 7: lnChla = $f(\ln TN, (\ln TN)^2, \ln TP, (\ln TP)^2)$
Model 8: lnChla = $f(\ln TN, (\ln TN)^2)$

Models 1-7 were used in the monthly data analysis and in the summer monthly data analysis. Model 8 was added to the analysis because, for the summer monthly dataset, it had the highest R^2 and lowest MSE of all models with two independent variables. Using summer monthly data, there appeared to be a stronger relationship between chlorophyll *a* and TN than was previously seen using the entire monthly dataset. A scatter plot of predicted vs. observed chlorophyll *a* for Model 1 is shown (Figure 17).

Parameter coefficients estimated for these models are listed (Table 16), and the statistical significance for each variable is indicated.

Table 15. Transformations of Model Inputs and Output

Parameter	*Transformed?*	*Equation*	*Constant (c)*
Chlorophyll *a*	Yes	ln(x + c)	135.38
Total nitrogen	Yes	ln(x + c)	-1.34
Total phosphorus	Yes	ln(x + c)	-0.04
Temperature	No		
Turbidity	Yes	ln(x + c)	94.59
Velocity	Yes	ln(x + c)	-0.21
Depth/Width ratio	No		

Table 16. Parameter Coefficients for the Eight f_2 Models

Model	R^2	*RMSE*	*Intercept*	*lnTP*	*(lnTP)*^{2}	*(lnTN)*^{2}	*lnTN*
1	0.0747	0.26075	5.68051^d	0.11406^a			
2	0.0040	0.27053	5.56159^d		-0.01764		
3	0.1982	0.24273	6.00163^d	0.54694^b	0.11433^b		
4	0.0818	0.25975	5.62118^d		-0.01510	-0.10329^a	
5	0.1836	0.24493	5.46496^d		-0.00419	-0.30397^b	0.40097^a
6	0.0541	0.26364	5.72786^d	0.11706^a			-0.06739
7	0.2962	0.22741	5.83009^d	0.43128^b	0.09731^a	-0.24590^b	0.32481^a
8	0.2140	0.24032	5.44883^d			-0.31368^c	0.41804^b

Notes: $^a P < 0.20$, $^b P < 0.05$, $^c P < 0.01$, $^d P < 0.001$. lnChla is a dependent variable

4.2.3 Model Building Step 3 (Development of f_1 Model)

Residuals from the eight f_2 models were used as the dependent variable (Susceptibility) in several multiple linear regression models using 15 different combinations of four independent habitat variables: Temp, lnTurb, lnVel, and DW ratio. These combinations are displayed (Table 17).

For each of the eight f_2 models the regression model using lnTurb as the sole input had the highest R^2 and the lowest MSE of all the 15 combinations of habitat factors. Therefore this variable was selected as the best f_1 model to use and is designated in bold in Table 17. The parameter coefficients estimated for these models are listed in Table 18, and the statistical significance for each variable is indicated.

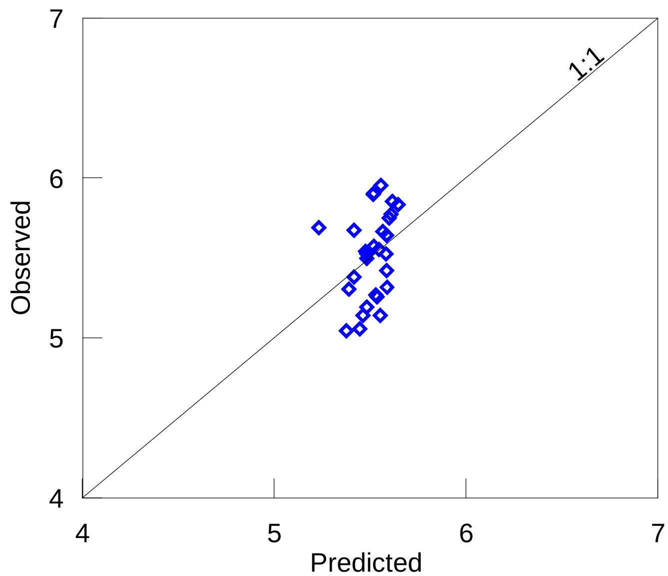

Figure 17. Observed and predicted algal biomass (f_2 model) for Model 1, Fox River watershed summer monthly training dataset

4.2.4 Model Validation

Susceptibility computed from f_1 was standardized using the training dataset according to the procedures described in the earlier section for the Fox River watershed monthly dataset. The mean and standard deviation for observed and predicted susceptibility for the Fox River watershed summer monthly dataset A were used for standardization throughout the validation process. A scatter plot of predicted vs. observed susceptibility for Model 1 is shown (Figure 18); the scatter plot of predicted vs. observed chlorophyll *a* for this model also is shown (Figure 19).

4.2.5 Cross Validation

The scatter plot of predicted vs. observed chlorophyll *a* for Model 1 applied to the testing data is shown (Figure 20). Adjusted predicted susceptibility (adjusted $\hat{S}$) also was calculated for the eight models using the regression equations for f_1 Models 1-8. A scatter plot of predicted vs. observed susceptibility for Model 1 using the testing dataset is shown (Figure 21). The RMSE and R^2 calculated for training and testing stages for susceptibility also are presented (Table 19).

As with the Fox River watershed monthly data, the observed algal biomass was used to further validate the f_2 and f_1 models. A scatter plot of predicted vs. observed chlorophyll *a* for Model 1, using the testing dataset shown (Figure 22). The RMSE and R^2 calculated for training and testing stages for algal biomass also are shown (Table 20).

Table 17. Fox River Watershed Summer Monthly Data: Parameter Combinations for Chosen Models

Variable	*(1)* *lnTP*	*(2)* *$(lnTP)^2$*	*(3)* *lnTP, $(lnTP)^2$*	*(4)* *$(lnTP)^2$, $(lnTN)^2$*	*(5)* *lnTN, $(lnTN)^2$, $(lnTP)^2$*	*(6)* *lnTN, lnTP*	*(7)* *lnTN, $(lnTN)^2$, lnTP, $(lnTP)^2$*	*(8)* *lnTN, $(lnTN)^2$*
Temp	x	x	x	x	x	x	x	x
lnTurb	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
lnVel	x	x	x	x	x	x	x	x
DW	x	x	x	x	x	x	x	x
Temp, lnTurb	x	x	x	x	x	x	x	x
Temp, lnVel	x	x	x	x	x	x	x	x
Temp, DW	x	x	x	x	x	x	x	x
lnTurb, lnVel	x	x	x	x	x	x	x	x
lnTurb, DW	x	x	x	x	x	x	x	x
lnVel, DW	x	x	x	x	x	x	x	x
Temp, lnTurb, lnVel	x	x	x	x	x	x	x	x
Temp, lnTurb, DW	x	x	x	x	x	x	x	x
Temp, lnVel, DW	x	x	x	x	x	x	x	x
lnTurb, lnVel, DW	x	x	x	x	x	x	x	x
Temp, lnTurb, lnVel, DW	x	x	x	x	x	x	x	x

Note: Bold x signifies the model with the highest R^2 and the lowest MSE

4.2.6 Susceptibility Classification Success Rates

The procedure for determining the categories for classification of susceptibility was described earlier in the discussion of the Fox River watershed monthly data. The following classification success rates were computed for each model (Table 21). Matrices for Model 1 for both training and testing stages are shown (Figures 23 and 24, respectively).

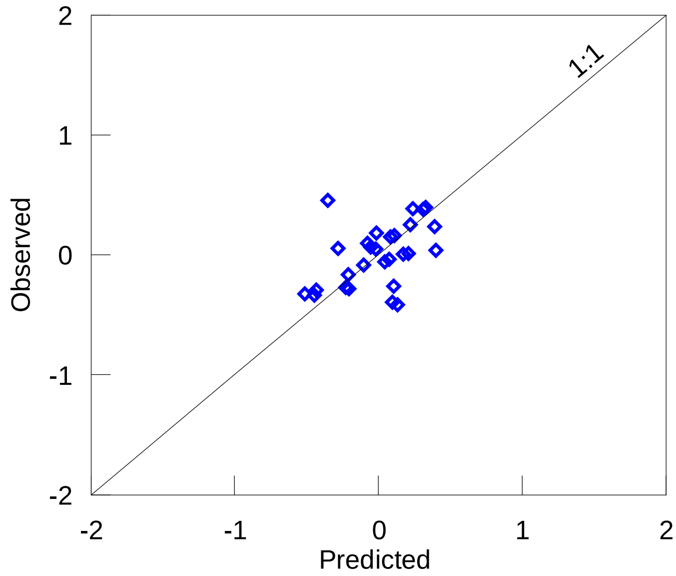

Figure 18. Observed and predicted susceptibility (f_1 model) for Model 1, Fox River watershed summer monthly training dataset

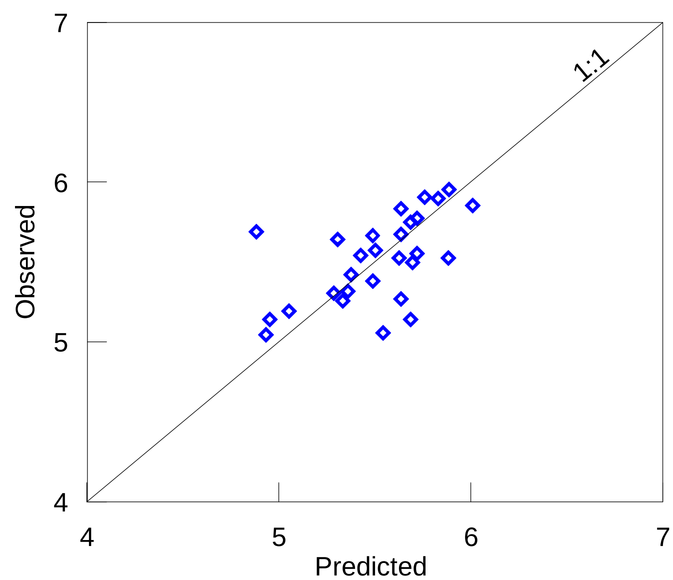

Figure 19. Observed and predicted algal biomass ($f_2 + f_1$ model) for Model 1, Fox River watershed summer monthly training dataset

Table 18. Parameter Coefficients for the Eight f_1 Models

Model	R^2	*RMSE*	*Intercept*	*lnTurb*
1	0.1883	0.23052	-5.20302[b]	1.08064[b]
2	0.2032	0.23697	-5.57222[c]	1.15732[c]
3	0.3209	0.19248	-5.97875[d]	1.24176[d]
4	0.0954	0.23772	-3.90486[a]	0.81102[a]
5	0.0998	0.21909	-3.66690[a]	0.76160[a]
6	0.1509	0.23376	-4.71370[b]	0.97901[b]
7	0.1976	0.18801	-4.35485[b]	0.90448[b]
8	0.1102	0.21813	-3.80757[b]	0.79081[b]

Notes: [a]$P < 0.20$, [b]$P < 0.05$, [c]$P < 0.01$, [d]$P < 0.001$. Susceptibility is dependent variable

Table 19. R^2 and RMSE for f_1 Models.

	Training (Dataset A)		*Testing (Dataset B)*	
Model	R^2	*RMSE*	R^2	*RMSE*
1	0.4643	0.26913	0.3649	0.32775
2	0.4718	0.27526	0.3657	0.33485
3	0.5310	0.21599	0.2167	0.44034
4	0.4166	0.28838	0.3692	0.31936
5	0.4190	0.26521	0.3340	0.31103
6	0.4455	0.27674	0.3659	0.32822
7	0.4690	0.21879	0.2213	0.38765
8	0.4245	0.26275	0.3279	0.31480

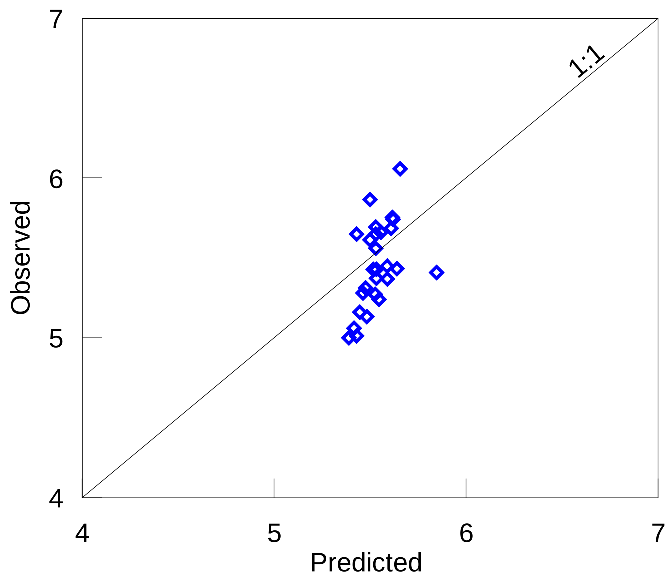

Figure 20. Observed and predicted algal biomass (f_2 model) for Model 1, Fox River watershed summer monthly testing dataset

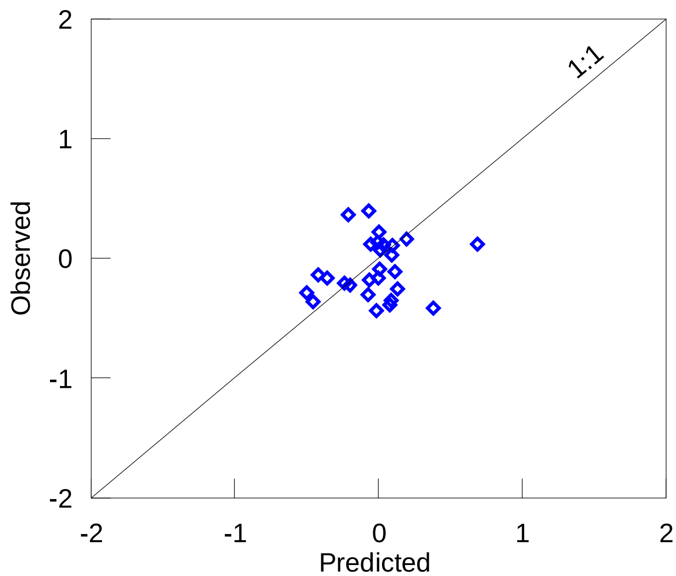

Figure 21. Observed and predicted susceptibility (f_1 model) for Model 1, Fox River watershed summer monthly testing dataset

Table 20. R^2 and RMSE for the Summation of Models f_1 and f_2.

Model	*Training (Dataset A)* R^2	*Training (Dataset A)* *RMSE*	*Testing (Dataset B)* R^2	*Testing (Dataset B)* *RMSE*
1	0.5389	0.26913	0.4119	0.32775
2	0.5153	0.27526	0.3761	0.33485
3	0.6047	0.22026	0.4510	0.44942
4	0.5249	0.29409	0.3380	0.32594
5	0.5519	0.27604	0.3684	0.32427
6	0.5222	0.28222	0.3787	0.33499
7	0.6111	0.23262	0.4122	0.41324
8	0.5709	0.26795	0.3916	0.32129

Table 21. Success Rates for 3 x 3 and 4 x 4 Classification Matrices

	3 x 3 matrices		*4 x 4 matrices*	
Model	*Training (Dataset A)*	*Testing (Dataset B)*	*Training (Dataset A)*	*Testing (Dataset B)*
1	0.6428	0.4444	0.4642	0.2962
2	0.5714	0.4074	0.3928	0.4074
3	0.6428	0.4074	0.5357	0.3333
4	0.4642	0.4444	0.3571	0.4444
5	0.5357	0.5185	0.3571	0.2222
6	0.6428	0.4074	0.5000	0.3333
7	0.5357	0.4074	0.3928	0.3333
8	0.5357	0.5185	0.3571	0.2592

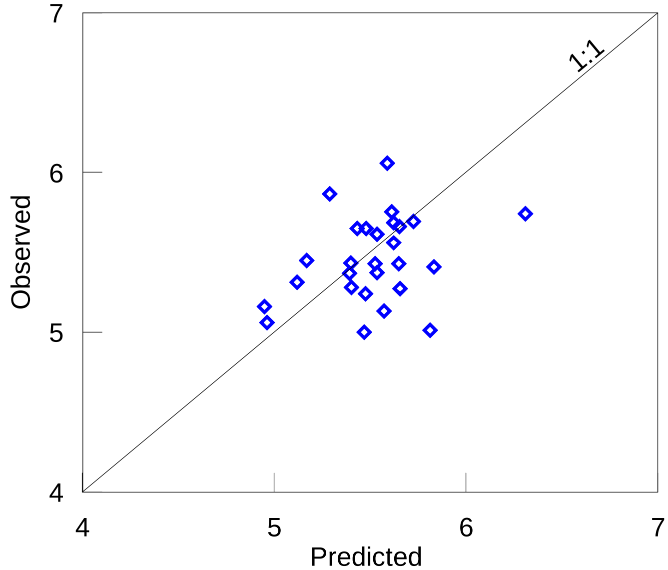

Figure 22. Observed and predicted algal biomass ($f_2 + f_1$ model) for Model 1, Fox River watershed summer monthly testing dataset

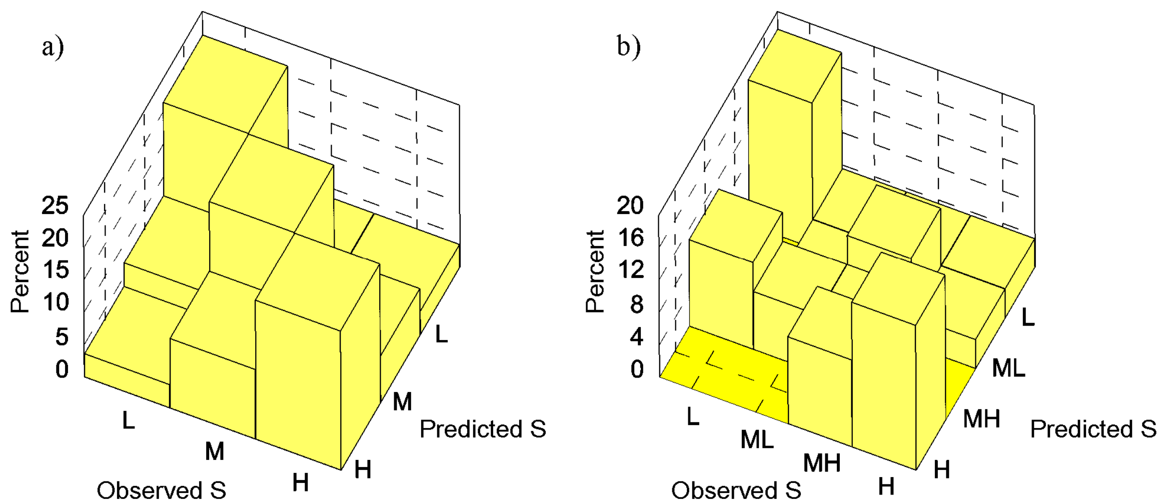

Figure 23. Model 1 classification matrices for Fox River watershed summer monthly training dataset for susceptibility categories: a) low, medium, and high and b) low, medium-low, medium-high, and high

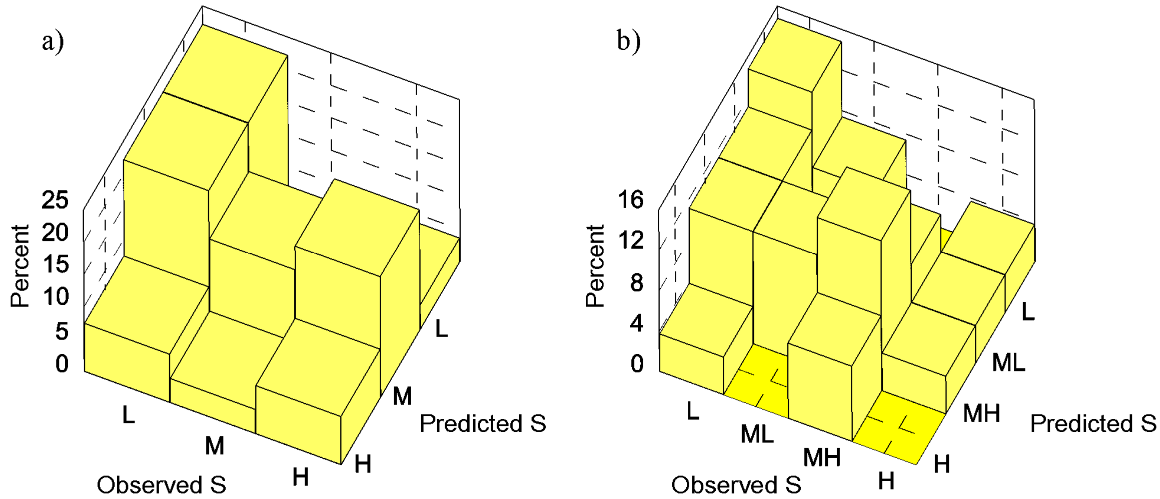

Figure 24. Model 1 classification matrices for Fox River watershed summer monthly testing dataset for susceptibility categories: a) low, medium, and high and b) low, medium-low, medium-high, and high

4.2.7 Entropy

The computed entropy values are displayed in Tables 22 and 23. Further analysis is provided later in Section 5.

Table 22. Entropy Values for a 3 x 3 Classification Matrix

Model	*Training (Data Set A)*	*Testing (Data Set B)*
1	1.9636	1.8933
2	2.0131	1.9935
3	1.9141	2.0009
4	2.1000	1.9227
5	2.0788	1.8058
6	1.9636	1.8058
7	1.9490	1.9815
8	2.0788	1.8058

Table 23. Entropy Values for a 4 x 4 Classification Matrix

Model	*Training (Data Set A)*	*Testing (Data Set B)*
1	2.3052	2.3648
2	2.3734	2.3942
3	2.1000	2.4649
4	2.4531	2.3403
5	2.3759	2.3648
6	2.2087	2.3109
7	2.2647	2.3942
8	2.3759	2.4161

4.3 Summary of Analysis of IEPA Monthly Data

4.3.1 Model Building Step 1 (Model Inputs)

The IEPA statewide dataset consists of 586 average monthly values for the following parameters: chlorophyll *a*, TN, TP, temperature, and turbidity (see Appendix C). Transformations and constants selected for each parameter also are displayed (Table 24). Data were subdivided into two separate datasets for training (dataset A) and testing (dataset B) using the procedure described for the Fox River watershed monthly dataset (Section 4.2).

4.3.2 Model Building Step 2 (Development of f_2 Model)

Using the 293 observations in dataset A, regression analysis was performed for the dependent variable (lnChla) using the 15 combinations of nutrient inputs displayed in Section 4.2.1. Of these 15 models, the following nine were selected for further analysis:

Model 1: lnChla = f(lnTP)
Model 2: lnChla = $f(\ln TP)^2$
Model 3: lnChla = $f(\ln TP, (\ln TP)^2)$
Model 4: lnChla = $f((\ln TN)^2, (\ln TP)^2)$
Model 5: lnChla = $f(\ln TN, (\ln TN)^2, (\ln TP)^2)$
Model 6: lnChla = f(lnTN, lnTP)
Model 7: lnChla = $f(\ln TN, (\ln TN)^2, \ln TP, (\ln TP)^2)$
Model 8: lnChla = $f(\ln TN, (\ln TN)^2)$
Model 9: lnChla = $f((\ln TN)^2, \ln TP, (\ln TP)^2)$

Models 1-8 were used in the Fox River watershed summer monthly data analysis and continued to be used for analysis of IEPA data. Model 9 was added to the analysis because, for the IEPA monthly data, it had the highest R^2 and lowest MSE of all the models with three independent variables. The scatter plot of predicted vs. observed chlorphyll *a* for Model 1 also is shown (Figure 25).

Table 24. Transformations of Model Inputs and Output

Parameter	*Transformed?*	*Equation*	*Constant (c)*
Chlorophyll *a*	Yes	ln(x + c)	0.45
Total nitrogen	Yes	ln(x + c)	2.8
Total phosphorus	Yes	ln(x + c)	0.016
Temperature	No		
Turbidity	Yes	ln(x + c)	1.31

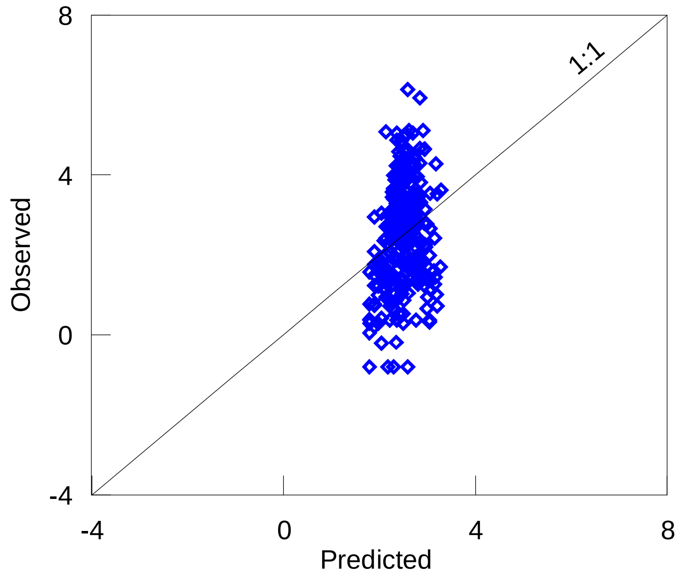

Figure 25. Observed and predicted algal biomass (f_2 model) for Model 1, IEPA monthly training dataset

The parameter coefficients estimated for these models are listed (Table 25), and the statistical significance for each variable also is indicated.

4.3.3 Model Building Step 3 (Development of f_1 Model)

Residuals from these nine models then were used as the dependent variable (susceptibility) for the following three options for dependent variables in linear regression models: (1) temperature (Temp), (2) log-turbidity (lnTurb), and (3) Temp and lnTurb. The model using the combination of Temp and lnTurb had the highest R^2 and the lowest MSE. The use of both of these habitat factors was selected as the best f_1 model. The parameter coefficients estimated for these nine models are listed (Table 26).

4.3.4 Model Validation

Susceptibility computed from f_1 was standardized using the IEPA training dataset according to the procedures described in the earlier section for the Fox River watershed monthly data. The mean and standard deviation for observed and predicted susceptibility for IEPA dataset A were used for standardization throughout the validation process. A scatter plot of predicted vs. observed susceptibility for Model 1 is shown (Figure 26), and the scatter plot of predicted vs. observed chlorophyll *a* for dataset A for this model also is shown (Figure 27).

Table 25. Parameter Coefficients for the f_2 Models

Model	R^2	*RMSE*	*Intercept*	*lnTP*	*lnTP2*	*lnTN2*	*lnTN*
1	0.0584	1.26489	2.95432^d	0.31820^d			
2	0.1416	1.20771	2.97589^d		-0.15590^d		
3	0.1951	1.16943	2.58627^d	-0.73462^d	-0.36987^d		
4	0.1658	1.19057	3.56795^d		-0.17832^d	-0.13133^c	
5	0.1789	1.18117	-0.12311		-0.14510^d	-1.05292^c	3.72841^b
6	0.0659	1.25983	3.68936^d	0.37496^d			-0.33591^a
7	0.2165	1.15379	0.15364	-0.63213^d	-0.33139^d	-0.84573^b	2.99370^a
8	0.0991	1.23725	-5.06570^d			-2.08420^d	8.15047^d
9	0.2091	1.15927	3.08947^d	-0.67124^d	-0.36919^d	-0.10417^b	

Notes: $^a P < 0.20$, $^b P < 0.05$, $^c P < 0.01$, $^d P < 0.001$. lnChla is a dependent variable

Table 26. Parameter Coefficients for the f_1 Models

Model	R^2	*RMSE*	*Intercept*	*Temp*	*lTurb*
1	0.1348	1.17455	-1.75561^d	0.02656^c	0.39823^d
2	0.0856	1.15286	-1.31577^d	0.02793^d	0.25990^d
3	0.0839	1.11546	-1.16199^d	0.03356^d	0.18685^c
4	0.0797	1.13821	-1.27125^d	0.02420^c	0.26447^d
5	0.0934	1.11885	-1.34745^d	0.02687^c	0.27450^d
6	0.1329	1.16912	-1.73622^d	0.02353^c	0.40693^d
7	0.0887	1.09385	-1.20878^d	0.03191^d	0.20878^c
8	0.1912	1.10885	-2.02041^d	0.03337^d	0.44479^d
9	0.0771	1.10795	-1.13995^d	0.03011^d	0.19678^c

Notes: $^a P < 0.20$, $^b P < 0.05$, $^c P < 0.01$, $^d P < 0.001$. Susceptibility is a dependent variable

4.3.5 Cross Validation

The nine f_2 and f_1 models were applied to the validation dataset (dataset B) with nutrients (TN and TP) and habitat factors (Temp, lnTurb) as model inputs. Using the testing dataset, the observed algal biomass (AB) then was compared to the algal biomass calculated from the nine f_2 models. A scatter plot of predicted vs. observed chlorophyll *a* for Model 1, using the testing data is shown (Figure 28). The adjusted predicted susceptibility (Adjusted $\hat{S}$) also was calculated for the nine models using the regression equations for f_1. The scatter plot of predicted vs. observed susceptibility for Model 1 for the testing dataset is shown (Figure 29). The RMSE and R^2 calculated for training and testing stages for susceptibility also are presented (Table 27).

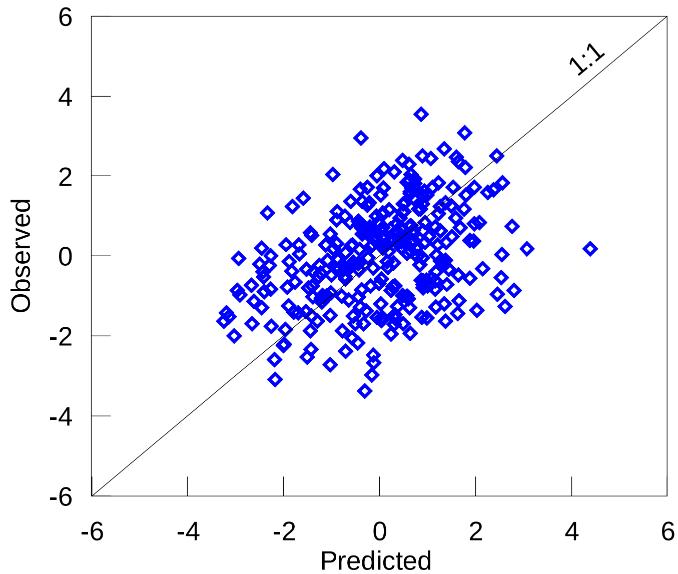

Figure 26. Observed and predicted susceptibility (f_1 model) for Model 1, IEPA monthly training dataset

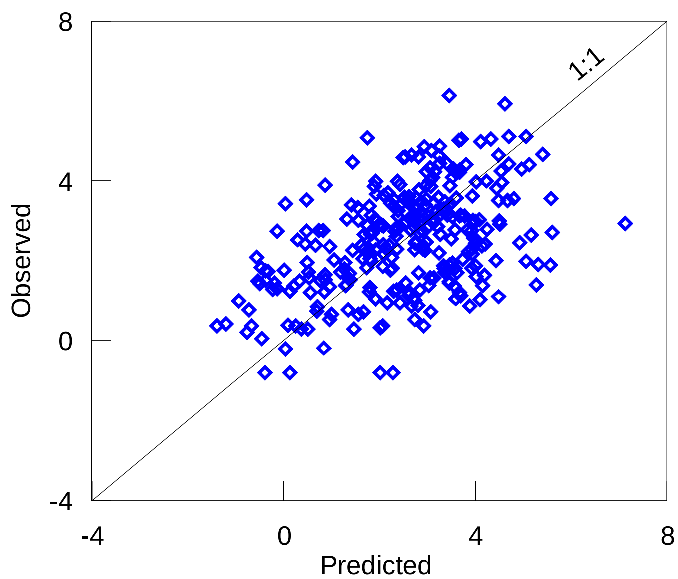

Figure 27. Observed and predicted algal biomass ($f_2 + f_1$ model) for Model 1, IEPA monthly training dataset

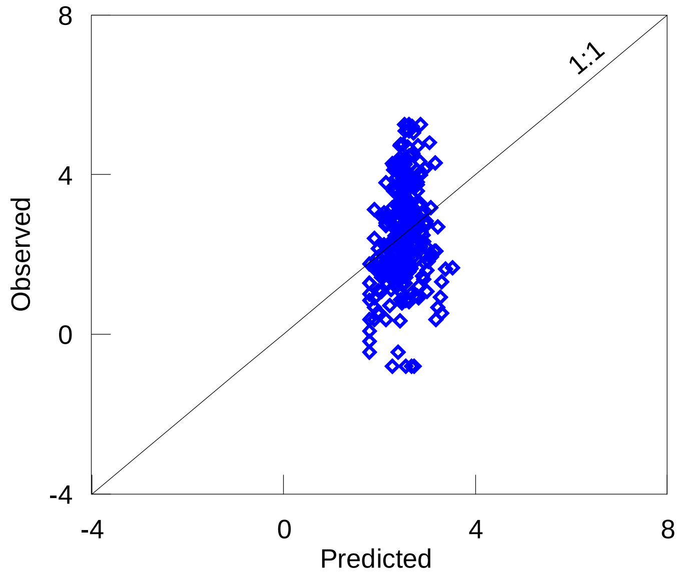

Figure 28. Observed and predicted algal biomass (f_2 model) for Model 1, IEPA monthly testing dataset

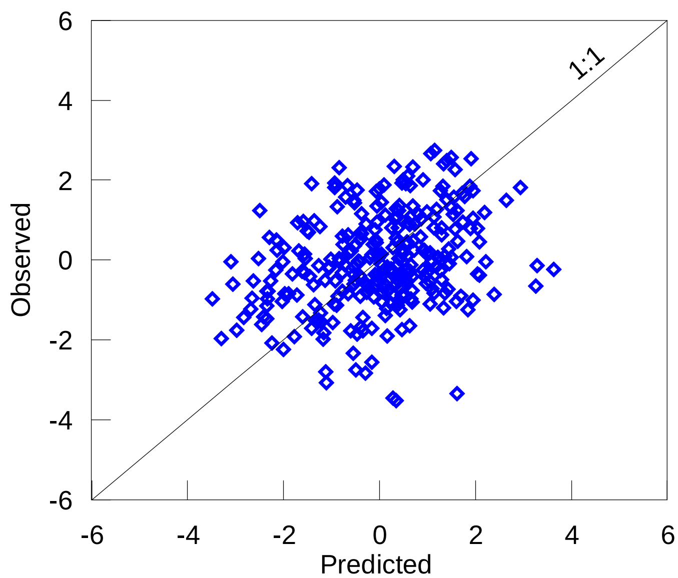

Figure 29. Observed and predicted susceptibility (f_1 model) for Model 1, IEPA monthly testing dataset

The observed algal biomass then was used to validate the nine f_2 and f_1 models. The observed algal biomass (AB) was compared to the algal biomass calculated from the summation of f_1 and f_2 models $(\hat{AB})$. A sample scatter plot of predicted vs. observed algal biomass for Model 1 is shown (Figure 30) for dataset B. The RMSE and R^2 calculated for training and testing stages for algal biomass also are displayed in Table 28.

4.3.6 Susceptibility Classification Success Rates

The procedure for determining the categories for classification of susceptibility was described earlier in the discussion of the Fox River watershed monthly data. After classification, the following success rates were computed for each model (Table 29). Matrices for Model 1 for both training and testing stages are shown (Figures 31 and 32, respectively).

Table 27. Adjusted R-squared and RMSE for f_1 Models.

	Training (Dataset A)		*Testing (Dataset B)*	
Model	R^2	*RMSE*	R^2	*RMSE*
1	0.4523	1.45258	0.4368	1.47426
2	0.4102	1.41817	0.3995	1.43694
3	0.3941	1.33638	0.3835	1.36943
4	0.4201	1.44555	0.4017	1.48298
5	0.4364	1.43784	0.4183	1.47530
6	0.4590	1.47515	0.4401	1.50519
7	0.4168	1.35602	0.3973	1.40941
8	0.4868	1.35685	0.4675	1.38885
9	0.4007	1.35858	0.3821	1.41034

Note: Susceptibility is a dependent variable

Table 28. Adjusted R-squared and RMSE for the Summation of Models f_1 and f_2

	Training (Dataset A)		*Testing (Dataset B)*	
Model	R^2	*RMSE*	R^2	*RMSE*
1	0.5106	1.45009	0.4959	1.46920
2	0.5202	1.41573	0.5134	1.43201
3	0.5174	1.33638	0.5233	1.36473
4	0.5358	1.44555	0.5258	1.47789
5	0.5435	1.44033	0.5380	1.47024
6	0.5178	1.47515	0.5015	1.50003
7	0.5381	1.36072	0.5423	1.40458
8	0.5287	1.35685	0.5242	1.38409
9	0.5309	1.36093	0.5324	1.40550

Note: Algal biomass is a dependent variable

Table 29. Success Rates for 3 x 3 and 4 x 4 Classification Matrices

Model	*3 x 3 matrices* Training (Data Set A)	*3 x 3 matrices* Testing (Data Set B)	*4 x 4 matrices* Training (Data Set A)	*4 x 4 matrices* Testing (Data Set B)
1	0.4334471	0.4368601	0.3617747	0.3276451
2	0.4129693	0.3924915	0.3481229	0.3208191
3	0.4129693	0.4095563	0.3344710	0.3003413
4	0.4163823	0.3993174	0.3378840	0.2935154
5	0.3959044	0.3993174	0.3447099	0.3071672
6	0.4607509	0.4368601	0.3310580	0.3344710
7	0.4027304	0.3924915	0.3344710	0.3105802
8	0.4505119	0.4266212	0.3617747	0.3242321
9	0.4027304	0.4027304	0.3344710	0.3003413

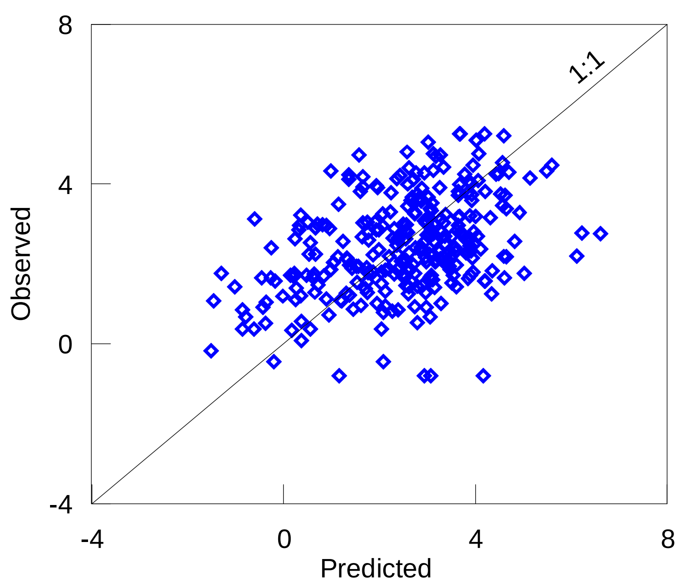

Figure 30. Observed and predicted algal biomass ($f_2 + f_1$ model) for Model 1, IEPA monthly testing dataset

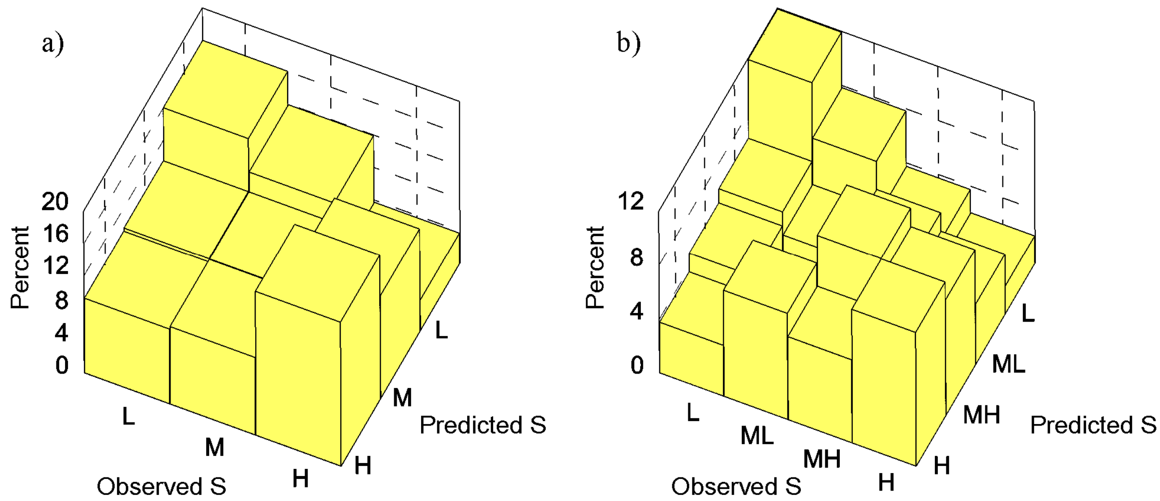

Figure 31. Model 1 classification matrices for IEPA monthly training dataset for susceptibility categories: a) low, medium, and high and b) low, medium-low, medium-high, and high

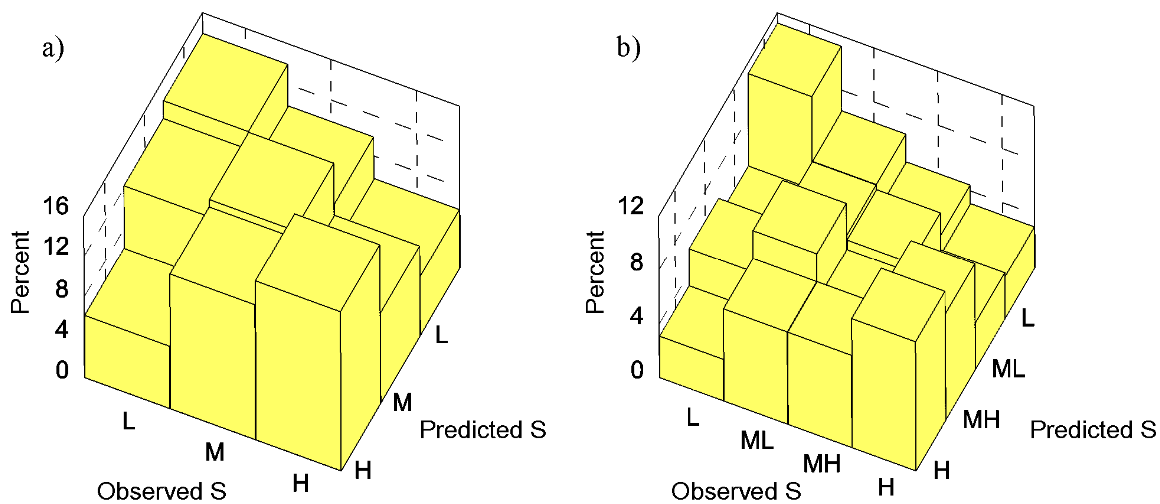

Figure 32. Model 1 classification matrices for IEPA monthly testing dataset for susceptibility categories: a) low, medium, and high and b) low, medium-low, medium-high, and high

4.3.7 Entropy

The computed entropy values are displayed in Tables 30 and 31. Further analysis is provided later in Section 5.

Table 30. Entropy values for a 3 x 3 Classification Matrix

Model	*Training (Data Set A)*	*Testing (Data Set B)*
1	2.1315979	2.1475125
2	2.1681089	2.1628678
3	2.1754190	2.1645803
4	2.1671089	2.1665461
5	2.1708772	2.1664608
6	2.1281189	2.1577796
7	2.1663289	2.1707475
8	2.1103162	2.1432449
9	2.1672676	2.1645147

Table 31. Entropy Values for a 4 x 4 Classification Matrix

Model	*Training (Data Set A)*	*Testing (Data Set B)*
1	2.6730121	2.7073104
2	2.7132669	2.7397108
3	2.7256355	2.7309672
4	2.7268546	2.7171269
5	2.7031262	2.7167642
6	2.6850155	2.7007096
7	2.7341155	2.7182372
8	2.6589267	2.6842914
9	2.7373737	2.7267577

5. Discussion

Some streams are more susceptible to nutrient enrichment-based algal growth than others. Streams with high algal biomass and low nutrient concentrations are considered more susceptible to building algal biomass than those having low algal biomass and high nutrient concentrations. This susceptibility (S) is defined as a residual of a nonlinear relationship which explains algal biomass as a function of nutrient concentration (model f_2, Figure 4). The nutrients used in model f_2 are total nitrogen (TN) and total phosphorus (TP), while algal biomass was represented by the concentration of chlorophyll *a*, which serves as a measure of phytoplankton. In addition, the study attempts to explain the variability in stream susceptibility, calculated in model f_2, by habitat factors, such as stream turbidity, temperature, and velocity (model f_1). This approach represents a new two-stage conceptual model for stream classification, in support of nutrient criteria development.

Models were tested using monthly and summer monthly datasets for the Fox River watershed in Illinois and using monthly data for the entire state from the IEPA dataset. For each dataset, the data were divided into training and testing datasets. A variety of statistical models were used to explore the relationships between the algal biomass in Illinois streams and the causative factors. For each dataset, several linear and nonlinear regression equations were applied to the training dataset in the model building stage. Model validation was performed on both the training and testing datasets. Results were validated using R^2, RMSE, classification success rate, and entropy.

For the Fox River watershed dataset, chlorophyll *a* data were severely lacking. The IEPA dataset was missing TN data, as well as velocity, DW ratio, and canopy information. Lack of simultaneous observations of all the habitat factors, the nutrients, and the chlorophyll *a*, was a limiting factor in designing models for algal biomass prediction and for susceptibility development. However, the available datasets were sufficient to test various nonlinear regression models.

Several conclusions can be drawn for the susceptibility prediction model f_1:

- The results exhibited significant variability between datasets. The variability between models was less significant for the Fox River watershed monthly and the IEPA datasets than for the Fox River watershed summer monthly dataset. For example, for the Fox River watershed monthly data, the R^2 for model f_1 in the testing stage was between 0.43 and 0.49 (Table 10). Similarly, for the Fox River watershed summer monthly data, the R^2 was between 0.22 and 0.37 (Table 19), and between 0.38 and 0.47 for the IEPA data (Table 27). For a general idea of model accuracy, the average performance for the validation stage is shown (Tables 32-33). For model f_1 in the testing stage, the Fox River

Table 32. Average Validation R^2 (Tables 11, 12, 20, 21, 28, and 29)

Dataset	*Fox*		*Fox Summer*		*IEPA*	
Stage	*Training*	*Testing*	*Training*	*Testing*	*Training*	*Testing*
f_1	0.496	0.449	0.455	0.321	0.431	0.414
f_1+f_2	0.652	0.615	0.555	0.391	0.527	0.522

Table 33. Average Validation RMSE (Tables 5, 6, 14, 15, 27, and 28)

Dataset	*Fox*		*Fox Summer*		*IEPA*	
Stage	*Training*	*Testing*	*Training*	*Testing*	*Training*	*Testing*
f_1	0.348	0.364	0.259	0.346	1.404	1.439
f_1+f_2	0.347	0.362	0.265	0.354	1.405	1.434

watershed dataset had the best correlation, followed by the IEPA dataset (Table 32). The Fox River watershed summer monthly dataset had the lowest correlation. However, the RMSE (Table 33 and Figure 33) for the IEPA dataset was larger than for other cases. That the IEPA dataset had a satisfactory R^2 but an RMSE approximately four times larger then for other cases in the testing stage can be explained by the significantly larger, more diverse area.

- Entropy exhibited significant variability between datasets and insignificant variability between models within the same dataset. The Fox River watershed summer monthly model had minimum entropy, followed by the Fox River watershed monthly model and the IEPA model (Figure 34).

- The median value of the classification success rate (Figure 35) was the highest for the Fox River watershed monthly model, followed by the Fox River watershed summer monthly model and the IEPA model.

- The Fox River watershed summer monthly data had the largest relative difference in RMSE between the training and testing stages (Figure 33). This large uncertainty in the results can be explained by a very small range of input variables.

Conclusions regarding the algal biomass prediction (model f_2) follow:

- The accuracy of predicted algal biomass based on nutrients only was satisfactory. The resulting R^2 for the Fox River watershed data was in a 0.21-0.31 range (Table 7); for the Fox River watershed summer monthly data, in a 0.00-0.30 range (Table 16); and for the IEPA data in a 0.06-0.22 range (Table 25). These results were compared with a similar study (Dodds et al., 1997), that estimated nonlinear regression for 205 streams in New Zealand and North America, in which the R^2 ranged between 0.09 and 0.43. These results also were presented as box-and-whisker plots (Figure 36). Results from the Fox River watershed monthly data, are found to be, on average, more consistent with these of Dodds et al. (1997). However, the Fox River watershed summer monthly data and the IEPA data had generally lower correlation coefficients (Figure 36). This partly can be explained by the difference in the dependent variable between the models. Dodds et al. (1997) used the mean chlorophyll *a* for 2- or 3-month periods, while the present study used a monthly time-step. Perhaps, the longer period could have smoothed out the noise of the monthly data.

- Habitat factors and nutrients together (f_1+f_2) were the best predictors of algal biomass. Results (Figure 37) were obtained by averaging appropriate columns in Tables 11, 20, and 28. When only nutrients were used to predict the algal biomass (f_2), the R^2 between predicted and observed algal biomass was smaller then when habitat factors were added in the equation (f_1 +f_2). For example, the average adjusted R^2 for the nine f_2 models applied to the IEPA dataset (Table 25) was 0.148, and the corresponding R^2 for f_1+f_2 was 0.527 (Table 28). Consequently, the habitat factors greatly improved the prediction capability of the model.

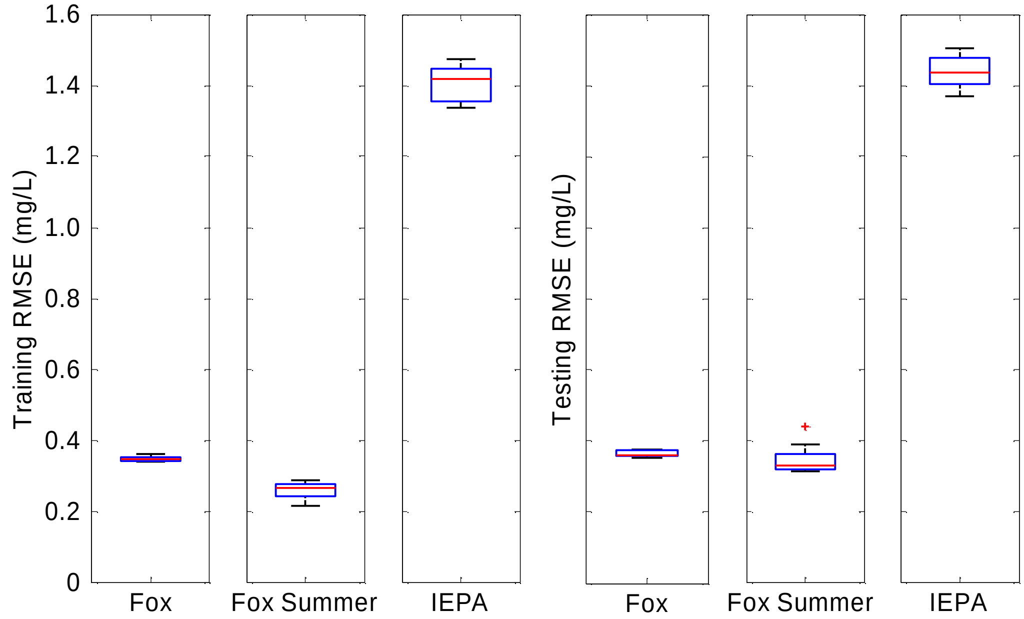

Figure 33. Susceptibility prediction RMSE for Fox River watershed monthly, Fox River watershed summer monthly, and IEPA monthly datasets

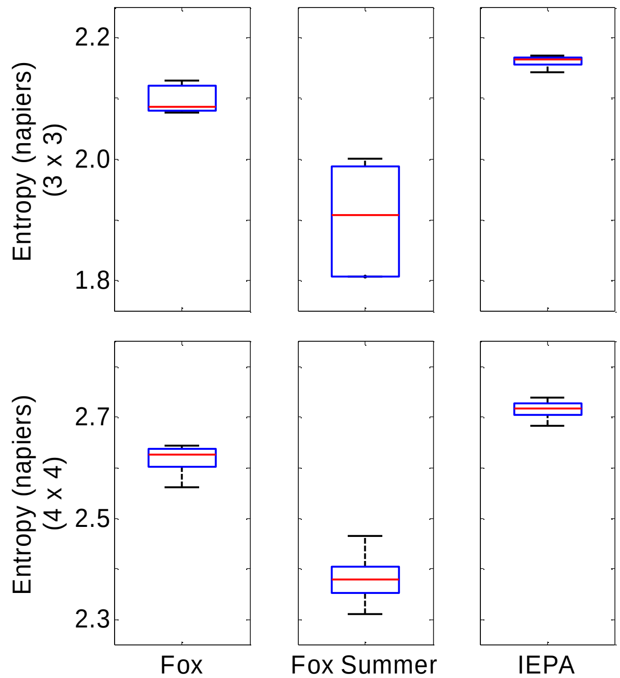

Figure 34. Entropy of susceptibility prediction model in testing stage, Fox River watershed monthly, Fox River watershed summer monthly, and IEPA datasets

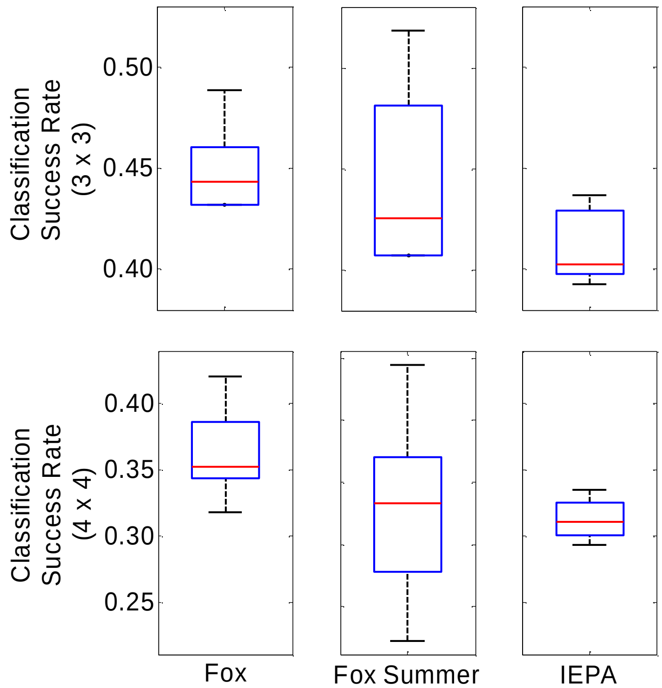

Figure 35. Classification success rate for susceptibility prediction model in testing stage, Fox River watershed monthly, Fox River watershed summer monthly, and IEPA datasets

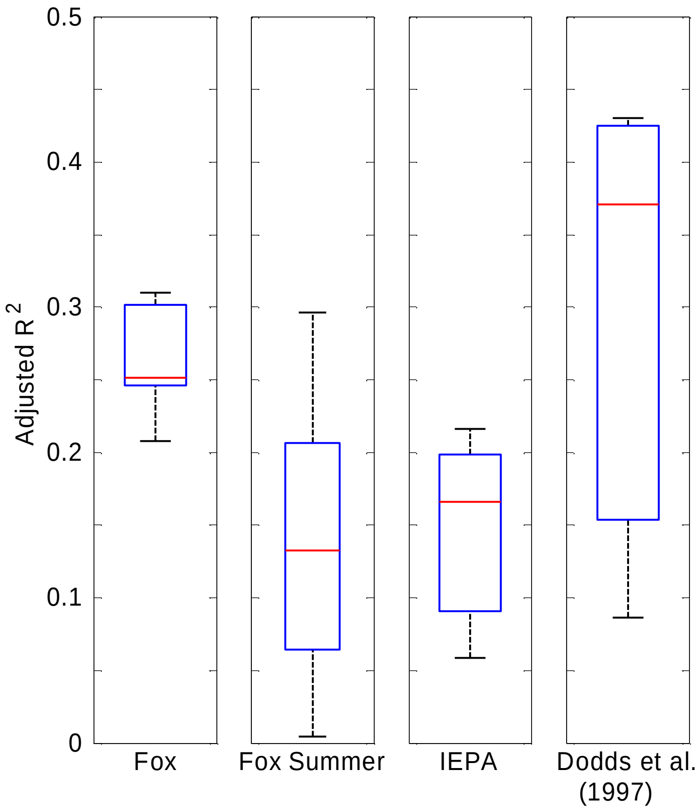

Figure 36. Summary of adjusted correlation coefficients (R^2) between the predicted based on the nutrients and observed chlorophyll *a* for the three cases developed in this study (Fox monthly, Fox summer monthly, and IEPA), and for 205 streams summarized in Dodds et al. (1997)

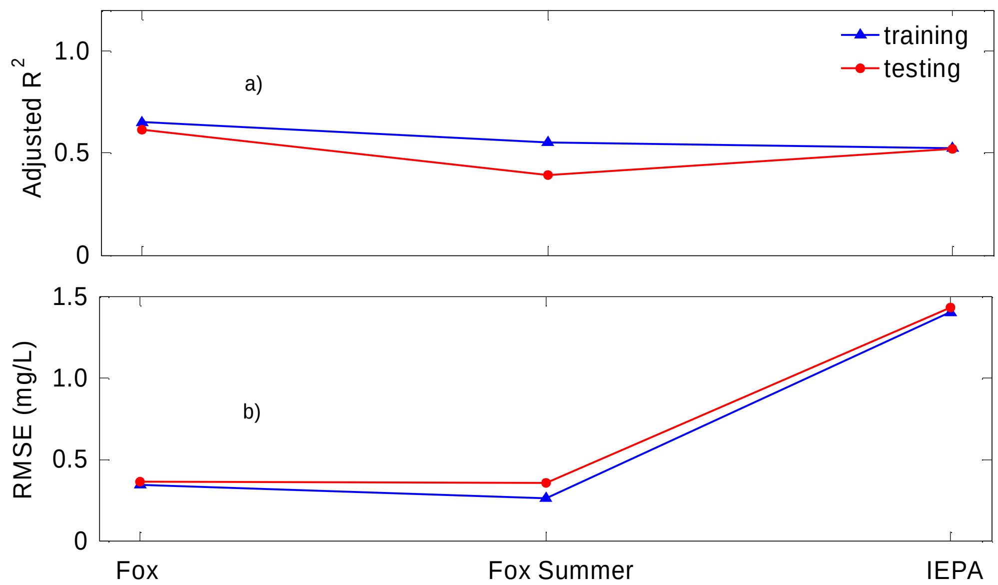

Figure 37. Adjusted R^2 and RMSE for algal biomass (chlorophyll *a*) prediction in the training and testing stages, Fox River watershed monthly, Fox River watershed summer monthly, and IEPA monthly datasets

6. Summary

The study describes a new methodology for stream classification based on stream susceptibility to algal growth. This susceptibility was calculated as a residual of a nonlinear regression between nutrients (TP and TN) and algal biomass (chlorophyll *a*). It also was demonstrated that susceptibility can be predicted using the stream habitat factors. Two large monthly datasets for the Fox River watershed and the IEPA dataset for all of Illinois served for testing the presented approach. The approach was validated by comparing observed and predicted susceptibility using the habitat factors, and also by comparing observed and predicted algal biomass. Algal biomass was predicted based on nutrients and habitat factors. Parameters for all models in the study were estimated from training datasets, and validated using validation datasets. Despite dataset limitations, the models produced accurate predictions of algal biomass. The study suggests that this methodology could be used as a basis for susceptibility-based stream classification.

Future research will examine other data mining/pattern recognition statistical techniques to better validate existing datasets and the presented approach; search for other relevant data types that will improve predictions of algal biomass and more accurately calculate the stream susceptibility to algal growth; and finetune models described in this study. In addition, more complete datasets for other watersheds need to be collected to provide broader spatial and temporal coverage.

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Appendix A-1. Fox River Watershed Monthly Data, Training Dataset A

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*	*Mean Velocity (fps)*	*Depth/Width Ratio (ft/ft)*
23	Apr-02	108.10	2.63	0.15	10.69	30.25	0.83	0.01614
23	Jun-02	81.45	3.24	0.14	22.96	32.67	0.49	0.01346
23	Aug-02	232`.00	3.49	0.29	24.10	42.20	0.33	0.01240
23	Oct-02	76.70	2.25	0.26	13.90	17.13	0.38	0.01275
23	Jan-03	58.30	2.60	0.18	1.40	7.70	0.44	0.01316
23	Apr-03	133.60	2.90	0.17	11.97	17.40	0.83	0.01614
24	Oct-87	77.20	2.06	0.13	12.70	0.30	0.35	0.02112
24	Dec-87	12.30	2.80	0.43	3.50	2.40	0.47	0.02165
24	Apr-88	34.10	2.90	0.17	10.96	33.00	0.90	0.02337
24	Jun-88	44.83	2.70	0.22	22.02	7.70	0.46	0.02158
24	Aug-88	58.75	3.65	0.31	25.99	34.50	0.30	0.02089
24	Nov-88	50.70	3.00	0.11	5.80	5.80	0.47	0.02162
24	Jan-89	5.40	3.85	0.09	0.23	5.15	0.41	0.02139
24	Mar-89	2.50	3.60	0.13	0.55	3.20	0.80	0.02301
24	Jun-89	21.90	2.30	0.14	22.02	6.70	0.46	0.02158
24	Aug-89	34.10	1.75	0.22	22.91	33.50	0.30	0.02089
24	Nov-89	22.40	2.70	0.13	11.38	8.40	0.47	0.02162
24	Jan-90	6.00	3.90	0.15	0.29	7.30	0.41	0.02139
24	Apr-90	13.90	3.40	0.12	5.31	8.80	0.90	0.02337
24	Jun-90	19.60	7.88	0.11	16.85	7.20	0.46	0.02158
24	Apr-02	97.50	2.29	0.18	16.11	14.50	0.90	0.02337
24	Jun-02	108.80	3.32	0.22	24.55	40.50	0.46	0.02158
24	Aug-02	249.65	2.84	0.38	22.86	47.60	0.30	0.02089
24	Oct-02	49.40	2.28	0.31	15.54	17.83	0.35	0.02112
24	Dec-02	76.10	3.55	0.26	3.70	10.70	0.47	0.02165
24	Feb-03	72.45	3.69	0.40	2.60	9.00	0.46	0.02158
24	Apr-03	154.40	2.77	0.29	14.07	22.30	0.90	0.02337
26	Jul-88	147.00	4.90	0.48	26.95	14.60	0.28	0.00967
26	Nov-98	76.71	3.01	0.22	6.38	9.00	0.36	0.00943
26	Mar-99	61.09	3.41	0.18	5.62	6.90	0.66	0.00854
26	Jun-99	119.95	3.12	0.21	24.81	26.00	0.38	0.00938
26	Sep-99	115.93	3.86	0.47	19.37	31.00	0.24	0.00983
26	Dec-99	42.48	2.42	0.21	3.93	7.30	0.36	0.00943
26	Feb-00	9.83	4.41	0.31	1.22	3.90	0.37	0.00941
26	Sep-00	61.27	2.68	0.19	18.46	25.50	0.24	0.00983
26	Mar-01	18.52	2.22	0.12	2.01	15.00	0.66	0.00854
26	Aug-01	122.70	3.46	0.35	23.62	38.33	0.24	0.00985
26	Apr-02	116.10	2.40	0.24	14.93	14.90	0.72	0.00858
26	Jun-02	124.15	3.77	0.31	24.30	33.80	0.38	0.00938
26	Aug-02	158.85	3.09	0.59	24.12	29.40	0.24	0.00985
26	Oct-02	44.10	2.39	0.53	15.23	14.67	0.29	0.00964
26	Dec-02	88.10	3.70	0.55	1.00	13.60	0.36	0.00943
26	Feb-03	68.10	4.82	0.69	0.40	9.25	0.37	0.00941
26	Apr-03	185.47	3.45	0.43	13.67	16.60	0.72	0.00858

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix A-1. concluded

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*	*Mean Velocity (fps)*	*Depth/Width Ratio (ft/ft)*
27	Apr-02	60.10	2.32	0.25	12.10	14.00	1.17	0.01690
27	Jun-02	148.20	3.31	0.31	23.00	26.00	0.65	0.01792
27	Aug-02	180.25	3.92	0.62	25.11	28.47	0.38	0.01862
27	Oct-02	61.40	2.78	0.53	11.93	13.27	0.47	0.01831
27	Dec-02	60.10	4.24	0.45	-0.04	11.00	0.57	0.01807
27	Feb-03	56.85	5.05	0.73	-0.06	8.25	0.61	0.01800
27	Apr-03	222.40	3.04	0.44	13.36	16.17	1.17	0.01690
30	Nov-87	44.50	5.60	0.12	11.50	2.50	1.84	0.01079
30	Mar-88	14.40	4.40	0.16	5.63	0.70	2.89	0.01590
30	May-88	158.00	3.60	0.12	17.20	4.00	2.60	0.01448
30	Aug-88	56.50	3.00	0.33	27.33	18.30	1.65	0.00982
30	Nov-88	53.10	3.20	0.28	5.63	10.40	1.84	0.01079
30	Feb-89	3.40	5.00	0.17	0.28	3.40	2.21	0.01262
30	Apr-89	19.60	4.60	0.27	8.93	21.00	3.01	0.01644
30	Jul-89	59.90	2.30	0.30	31.92	36.00	1.90	0.01109
30	Oct-89	39.93	3.00	0.22	14.13	13.70	1.79	0.01050
30	Jan-90	1.40	4.60	0.32	0.15	3.50	2.00	0.01155
30	Apr-90	15.60	6.50	0.17	6.98	12.00	3.01	0.01644
30	Jun-90	38.80	4.30	0.17	16.38	4.80	2.33	0.01318
30	Sep-90	88.17	3.80	4.38	28.11	28.00	1.70	0.01007
34	May-02	106.15	3.22	0.34	14.55	23.00	2.17	0.00538
34	Jul-02	291.00	3.71	0.86	26.95	25.25	1.78	0.00392
34	Sep-02	93.50	2.75	0.74	21.90	16.65	1.68	0.00352
34	Nov-02	136.20	2.97	0.63	4.87	11.10	1.89	0.00430
34	Jan-03	58.50	4.33	0.63	-0.01	7.15	1.88	0.00426
34	Mar-03	84.30	4.97	0.84	3.53	6.35	2.40	0.00633
40	Apr-02	98.80	2.54	0.26	11.10	15.00	2.14	0.02242
40	Jun-02	128.15	3.30	0.29	25.70	27.75	1.22	0.02092
40	Aug-02	178.90	2.47	0.54	24.33	33.33	0.73	0.02023
40	Oct-02	64.05	2.30	0.53	13.17	13.84	0.91	0.02047
40	Dec-02	61.40	3.68	0.51	0.10	11.50	1.11	0.02074
40	Mar-03	158.50	3.91	0.69	3.68	10.70	2.01	0.02211
184	Apr-02	80.10	2.41	0.13	10.40	14.50	0.73	0.00864
184	Jun-02	66.10	3.22	0.12	26.05	23.30	0.36	0.00841
184	Aug-02	228.30	3.57	0.28	24.55	46.55	0.22	0.00835
184	Oct-02	82.10	2.38	0.25	13.23	20.73	0.27	0.00836
184	Dec-02	69.40	3.28	0.12	1.00	7.15	0.60	0.00623
184	Feb-03	49.00	2.82	0.10	1.00	6.30	0.59	0.00620
184	Apr-03	122.47	2.65	0.17	8.40	20.33	0.73	0.00864
197	Mar-01	8.96	3.66	0.08	4.36	14.00	1.01	0.02336
197	May-01	83.40	2.95	0.17	15.88	63.00	0.67	0.02304
197	Jul-01	115.00	2.64	0.22	27.65	52.00	0.41	0.02161
197	Oct-01	6.30	4.52	0.10	8.52	27.00	0.41	0.02161
197	Jan-02	3.72	4.33	0.04	-0.11	4.00	0.56	0.02113

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix A-2. Fox River Watershed Monthly Data, Testing Dataset B

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*	*Mean Velocity (fps)*	*Depth/Width Ratio (ft/ft)*
23	May-02	90.75	2.11	0.12	14.37	15.83	0.64	0.01455
23	Jul-02	138.85	3.34	0.25	26.40	30.65	0.39	0.01278
23	Sep-02	92.10	2.81	0.28	22.10	29.15	0.33	0.01240
23	Nov-02	102.80	2.44	0.20	5.90	12.65	0.50	0.01351
23	Mar-03	42.30	2.93	0.15	6.80	8.40	0.81	0.01564
24	Apr-76	138.99	3.12	0.24	9.26	22.36	0.90	0.02337
24	Nov-87	77.20	2.92	0.07	11.60	3.40	0.47	0.02162
24	Mar-88	14.74	2.90	0.09	4.18	0.80	0.80	0.02301
24	May-88	92.60	2.63	0.10	17.00	7.80	0.63	0.02231
24	Jul-88	217.00	2.25	0.25	25.99	18.00	0.36	0.02112
24	Oct-88	62.30	3.60	0.17	11.20	12.70	0.35	0.02112
24	Dec-88	9.80	4.00	0.10	1.60	3.00	0.47	0.02165
24	Feb-89	7.30	4.00	0.12	0.50	3.10	0.46	0.02158
24	May-89	25.70	2.70	0.17	12.89	17.30	0.63	0.02231
24	Jul-89	21.40	1.90	0.17	27.33	34.00	0.36	0.02112
24	Oct-89	19.30	1.90	0.14	14.51	14.90	0.35	0.02112
24	Dec-89	7.70	3.10	0.12	0.52	5.70	0.47	0.02165
24	Mar-90	1.55	3.50	0.06	1.33	1.50	0.80	0.02301
24	May-90	26.10	3.04	0.15	16.21	13.00	0.63	0.02231
24	Jul-90	67.45	2.35	0.21	23.60	11.00	0.36	0.02112
24	May-02	112.80	2.14	0.17	15.28	14.27	0.63	0.02231
24	Jul-02	161.55	2.72	0.31	24.54	39.70	0.36	0.02112
24	Sep-02	80.10	2.80	0.32	22.20	28.75	0.30	0.02089
24	Nov-02	116.10	2.44	0.24	7.65	14.97	0.47	0.02162
24	Jan-03	67.90	2.72	0.25	2.60	6.80	0.41	0.02139
24	Mar-03	48.70	3.24	0.38	8.35	6.45	0.80	0.02301
26	Apr-76	153.06	2.74	0.27	9.14	28.85	0.72	0.00858
26	Sep-98	97.42	3.39	0.49	21.14	8.30	0.24	0.00983
26	Dec-98	72.91	3.27	0.16	7.51	26.00	0.36	0.00943
26	Apr-99	95.38	3.21	0.17	11.78	6.10	0.72	0.00858
26	Aug-99	152.51	3.74	0.38	23.53	34.00	0.24	0.00985
26	Oct-99	109.71	3.31	0.31	11.95	26.00	0.29	0.00964
26	Jan-00	48.66	4.39	0.37	14.20	5.10	0.33	0.00952
26	Apr-00	121.11	3.37	0.31	10.43	49.00	0.72	0.00858
26	Nov-00	78.46	3.31	0.16	7.40	18.00	0.36	0.00943
26	Apr-01	91.84	3.12	0.15	12.08	27.00	0.72	0.00858
26	Nov-01	88.62	2.76	0.14	9.50	25.00	0.36	0.00943
26	May-02	107.45	2.64	0.23	15.16	20.67	0.51	0.00905
26	Jul-02	186.25	3.33	0.58	25.64	34.85	0.28	0.00967
26	Sep-02	68.10	2.70	0.49	22.15	17.10	0.24	0.00983
26	Nov-02	110.80	2.38	0.44	5.25	13.95	0.36	0.00943
26	Jan-03	78.55	3.71	0.50	0.55	9.00	0.33	0.00952
26	Mar-03	77.35	4.03	0.64	4.75	8.70	0.66	0.00854

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix A-2. concluded

Station ID	*Date*	*Chl a, Corrected (μg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*	*Mean Velocity (fps)*	*Depth/Width Ratio (ft/ft)*
27	Apr-76	150.71	2.73	0.32	8.93	24.03	1.17	0.01690
27	May-02	107.45	2.74	0.28	15.66	24.67	0.84	0.01753
27	Jul-02	213.15	3.94	0.62	26.26	51.48	0.46	0.01837
27	Sep-02	90.80	2.59	0.48	18.87	18.10	0.38	0.01859
27	Nov-02	133.50	2.45	0.47	5.26	11.95	0.57	0.01809
27	Jan-03	66.75	3.71	0.48	-0.19	7.00	0.54	0.01817
27	Mar-03	96.50	4.39	0.76	3.50	7.05	1.09	0.01702
30	Oct-87	50.30	4.00	0.17	12.60	0.30	1.79	0.01050
30	Dec-87	11.00	8.00	0.19	5.30	2.50	1.87	0.01094
30	Apr-88	42.60	5.90	0.20	12.05	5.80	3.01	0.01644
30	Jul-88	53.50	2.60	0.35	27.48	25.00	1.90	0.01109
30	Oct-88	34.90	3.00	0.28	14.02	7.30	1.79	0.01050
30	Dec-88	40.30	4.30	0.26	2.70	3.90	1.87	0.01094
30	Mar-89	18.23	5.60	0.24	2.19	12.40	2.89	0.01590
30	May-89	49.60	3.40	0.29	15.59	12.80	2.60	0.01448
30	Aug-89	35.10	3.40	0.37	24.09	36.00	1.65	0.00982
30	Dec-89	6.25	4.10	0.36	0.18	4.90	1.87	0.01094
30	Mar-90	3.75	6.00	0.08	1.89	1.40	2.89	0.01590
30	May-90	45.50	4.50	0.25	16.58	7.90	2.60	0.01448
30	Jul-90	35.50	7.70	0.19	20.41	4.30	1.90	0.01109
34	Apr-02	53.40	2.42	0.25	11.20	13.90	2.45	0.00656
34	Jun-02	152.85	3.50	0.41	25.10	24.65	2.00	0.00468
34	Aug-02	205.60	3.32	0.79	22.70	28.10	1.67	0.00350
34	Oct-02	90.75	2.44	0.69	12.95	16.87	1.79	0.00396
34	Dec-02	48.80	4.97	0.50	-0.04	6.45	1.90	0.00432
34	Feb-03	61.30	5.35	0.90	0.00	4.85	1.95	0.00451
34	Apr-03	202.47	3.58	0.62	12.98	11.73	2.45	0.00656
40	May-02	98.80	2.64	0.25	14.85	18.50	1.56	0.02139
40	Jul-02	176.60	3.35	0.64	26.07	71.60	0.89	0.02044
40	Sep-02	78.80	2.47	0.50	21.55	18.60	0.75	0.02023
40	Nov-02	129.50	2.51	0.51	4.55	13.45	1.10	0.02071
40	Jan-03	55.60	2.76	0.37	0.60	6.80	1.04	0.02064
40	Apr-03	202.60	3.36	0.48	13.06	15.43	2.14	0.02242
184	May-02	81.45	2.26	0.11	14.95	13.00	0.51	0.00850
184	Jul-02	148.85	2.84	0.15	27.70	28.95	0.27	0.00836
184	Sep-02	92.10	2.92	0.32	22.85	35.05	0.22	0.00835
184	Nov-02	105.40	2.44	0.15	4.45	14.00	0.60	0.00623
184	Jan-03	61.80	2.58	0.15	1.00	6.50	0.53	0.00610
184	Mar-03	39.30	3.26	0.15	3.15	8.10	0.96	0.00724
197	Aug-00	160.00	2.49	0.06	22.71	11.40	0.37	0.02136
197	Apr-01	47.80	2.94	0.12	11.80	65.00	0.94	0.01668
197	Jun-01	15.00	5.39	0.15	13.76	51.00	0.50	0.02207
197	Sep-01	13.30	3.41	0.12	13.48	33.00	0.36	0.02133
197	Nov-01	19.80	3.29	0.07	10.68	22.00	0.65	0.02103
197	Jul-02	155.00	2.39	0.14	28.11	41.00	0.41	0.02161

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix B-1. Fox River Watershed Summer Monthly Data, Training Dataset A

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*	*Mean Velocity (fps)*	*Depth/Width Ratio (ft/ft)*
23	Jun-02	81.45	3.24	0.14	22.96	32.67	0.49	0.01346
23	Aug-02	232.00	3.49	0.29	24.10	42.20	0.33	0.01240
24	Jun-88	44.83	2.70	0.22	22.02	7.70	0.46	0.02158
24	Aug-88	58.75	3.65	0.31	25.99	34.50	0.30	0.02089
24	Jul-89	21.40	1.90	0.17	27.33	34.00	0.36	0.02112
24	Jun-90	19.60	7.88	0.11	16.85	7.20	0.46	0.02158
24	Jun-02	108.80	3.32	0.22	24.55	40.50	0.46	0.02158
24	Aug-02	249.65	2.84	0.38	22.86	47.60	0.30	0.02089
26	Jul-88	147.00	4.90	0.48	26.95	14.60	0.28	0.00967
26	Jun-99	119.95	3.12	0.21	24.81	26.00	0.38	0.00938
26	Sep-99	115.93	3.86	0.47	19.37	31.00	0.24	0.00983
26	Aug-01	122.70	3.46	0.35	23.62	38.33	0.24	0.00985
26	Jul-02	186.25	3.33	0.58	25.64	34.85	0.28	0.00967
26	Sep-02	68.10	2.70	0.49	22.15	17.10	0.24	0.00983
27	Jul-02	213.15	3.94	0.62	26.26	51.48	0.46	0.01837
27	Sep-02	90.80	2.59	0.48	18.87	18.10	0.38	0.01859
30	Aug-88	56.50	3.00	0.33	27.33	18.30	1.65	0.00982
30	Aug-89	35.10	3.40	0.37	24.09	36.00	1.65	0.00982
30	Jul-90	35.50	7.70	0.19	20.41	4.30	1.90	0.01109
34	Jun-02	152.85	3.50	0.41	25.10	24.65	2.00	0.00468
34	Aug-02	205.60	3.32	0.79	22.70	28.10	1.67	0.00350
40	Jun-02	128.15	3.30	0.29	25.70	27.75	1.22	0.02092
40	Aug-02	178.90	2.47	0.54	24.33	33.33	0.73	0.02023
184	Jun-02	66.10	3.22	0.12	26.05	23.30	0.36	0.00841
184	Aug-02	228.30	3.57	0.28	24.55	46.55	0.22	0.00835
197	Aug-00	160.00	2.49	0.06	22.71	11.40	0.37	0.02136
197	Jul-01	115.00	2.64	0.22	27.65	52.00	0.41	0.02161
197	Jul-02	155.00	2.39	0.14	28.11	41.00	0.41	0.02161

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix B-2. Fox River Watershed Summer Monthly Data, Testing Dataset B

Station ID	*Date*	*Chl a, Corrected (μg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*	*Mean Velocity (fps)*	*Depth/Width Ratio (ft/ft)*
23	Jul-02	138.85	3.34	0.25	26.40	30.65	0.39	0.01278
23	Sep-02	92.10	2.81	0.28	22.10	29.15	0.33	0.01240
24	Jul-88	217.00	2.25	0.25	25.99	18.00	0.36	0.02112
24	Jun-89	21.90	2.30	0.14	22.02	6.70	0.46	0.02158
24	Aug-89	34.10	1.75	0.22	22.91	33.50	0.30	0.02089
24	Jul-90	67.45	2.35	0.21	23.60	11.00	0.36	0.02112
24	Jul-02	161.55	2.72	0.31	24.54	39.70	0.36	0.02112
24	Sep-02	80.10	2.80	0.32	22.20	28.75	0.30	0.02089
26	Sep-98	97.42	3.39	0.49	21.14	8.30	0.24	0.00983
26	Aug-99	152.51	3.74	0.38	23.53	34.00	0.24	0.00985
26	Sep-00	61.27	2.68	0.19	18.46	25.50	0.24	0.00983
26	Jun-02	124.15	3.77	0.31	24.30	33.80	0.38	0.00938
26	Aug-02	158.85	3.09	0.59	24.12	29.40	0.24	0.00985
27	Jun-02	148.20	3.31	0.31	23.00	26.00	0.65	0.01792
27	Aug-02	180.25	3.92	0.62	25.11	28.47	0.38	0.01862
30	Jul-88	53.50	2.60	0.35	27.48	25.00	1.90	0.01109
30	Jul-89	59.90	2.30	0.30	31.92	36.00	1.90	0.01109
30	Jun-90	38.80	4.30	0.17	16.38	4.80	2.33	0.01318
30	Sep-90	88.17	3.80	4.38	28.11	28.00	1.70	0.01007
34	Jul-02	291.00	3.71	0.86	26.95	25.25	1.78	0.00392
34	Sep-02	93.50	2.75	0.74	21.90	16.65	1.68	0.00352
40	Jul-02	176.60	3.35	0.64	26.07	71.60	0.89	0.02044
40	Sep-02	78.80	2.47	0.50	21.55	18.60	0.75	0.02023
184	Jul-02	148.85	2.84	0.15	27.70	28.95	0.27	0.00836
184	Sep-02	92.10	2.92	0.32	22.85	35.05	0.22	0.00835
197	Jun-01	15.00	5.39	0.15	13.76	51.00	0.50	0.02207
197	Sep-01	13.30	3.41	0.12	13.48	33.00	0.36	0.02133

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-1. IEPA Monthly Data, Training Dataset A

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*
AK-02	Nov-00	4.02	0.17	0.02	5.80	5.00
AK-02	Feb-01	0.00	0.26	0.01	6.80	6.00
AK-02	May-01	5.35	0.37	0.02	18.90	3.00
AK-02	Aug-01	1.65	0.28	0.02	23.50	4.50
AK-02	Jan-02	1.00	0.38	0.01	2.00	2.80
AK-02	Apr-02	1.01	0.28	0.01	13.57	5.95
AK-02	Jun-02	4.32	0.54	0.01	25.53	3.53
AK-02	Mar-03	1.72	0.24	0.01	12.70	22.30
AK-02	Aug-03	5.63	0.77	0.03	24.20	19.90
AK-02	Oct-03	3.81	2.37	1.01	11.90	0.90
ATG-03	Nov-00	0.00	4.43	0.30	8.30	34.50
ATG-03	Mar-01	1.89	1.45	0.09	8.60	10.40
ATG-03	Oct-01	17.30	2.24	0.44	16.80	10.00
ATG-03	Jan-02	1.49	2.74	0.11	3.50	19.00
ATG-03	Mar-02	2.90	1.23	0.22	9.60	123.00
ATG-03	Jun-02	6.22	7.87	0.72	21.60	175.00
ATG-03	Jul-03	11.40	1.19	0.16	25.90	23.00
B-06	Sep-00	117.00	2.65	0.20	16.50	46.00
B-06	Jan-01	15.20	4.68	0.47	2.60	200.00
B-06	May-01	5.63	4.25	0.18	22.90	39.00
B-06	Jan-02	10.40	5.05	0.13	5.90	11.00
B-06	Apr-02	6.94	7.36	0.27	18.20	130.00
B-06	Jun-02	13.60	7.92	0.32	22.90	175.00
B-06	Jul-03	146.00	4.51	0.23	28.60	50.00
B-06	Nov-03	38.40	2.67	0.11	16.10	19.00
BM-02	Nov-01	5.27	3.24	0.31	8.21	2.00
BM-02	Feb-02	36.20	6.15	0.25	5.38	60.00
BP-08	Oct-01	2.41	11.86	0.31	10.90	95.00
BP-08	Jan-02	1.00	10.00	0.14	0.24	4.00
BP-08	Mar-02	2.94	11.11	0.09	6.45	14.00
BP-08	May-02	6.19	11.69	0.53	13.50	411.00
BP-08	Jul-02	59.47	7.61	0.32	28.87	25.83
BP-08	Jun-03	6.50	12.65	0.26	21.82	44.90
BPG-09	Aug-01	20.30	1.86	0.27	20.80	21.00
BPG-09	Apr-02	5.06	11.59	0.04	13.30	7.30
BPG-09	Jun-02	22.30	3.66	0.11	20.00	49.00
BPG-09	Feb-03	1.00	5.22	0.53	0.15	42.00
BPK-07	Jan-01	4.07	6.58	0.04	-2.45	9.80
BPK-07	Mar-01	1.70	11.25	0.02	6.31	3.80
BPK-07	Jul-01	2.11	8.37	0.06	26.82	12.80
BPK-07	Oct-01	1.94	8.46	0.23	15.40	100.00
BPK-07	Jan-02	2.26	7.45	0.03	0.28	4.60
BPK-07	Apr-02	4.12	11.37	0.05	14.05	15.70
BPK-07	Jun-02	6.81	14.51	0.24	20.50	203.00
BPK-07	Jun-03	2.54	13.57	0.19	20.35	129.00
BPK-07	Sep-03	2.34	4.53	0.20	19.50	95.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-1. continued

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (℃)*	*Turb (NTU)*
C-21	Jul-02	16.20	1.10	0.13	26.80	13.00
C-23	Oct-00	29.60	1.43	0.14	16.80	27.00
C-23	Mar-01	12.50	2.63	0.42	5.20	180.00
C-23	Oct-01	4.65	2.80	0.67	15.00	100.00
C-23	Mar-02	12.30	2.48	0.31	2.80	150.00
C-23	May-02	5.69	1.00	0.28	16.00	68.00
C-23	Aug-03	30.80	1.36	0.10	27.00	28.00
C-23	Nov-03	17.80	1.26	0.10	14.00	25.00
CA-05	Aug-00	18.00	1.75	0.26	23.20	100.00
CA-05	Dec-00	3.54	2.10	0.18	3.30	22.40
CA-05	Feb-01	11.20	2.28	0.55	9.00	310.00
CA-05	Oct-01	5.03	1.65	0.28	17.30	31.00
CA-05	Jan-02	4.36	2.04	0.28	8.60	76.00
CA-05	Apr-02	53.70	0.87	0.11	12.90	36.00
CA-05	Jun-02	16.60	2.06	0.11	26.50	25.00
CA-05	Aug-03	35.20	0.99	0.10	26.80	20.00
CA-05	Oct-03	10.10	0.61	0.05	16.00	9.00
D-05	Oct-00	67.30	2.91	0.42	19.95	51.20
D-05	Jan-01	6.63	5.83	0.52	0.94	19.10
D-05	Jun-01	32.70	10.30	0.42	22.24	109.00
D-05	Aug-01	33.00	2.81	0.60	24.50	71.00
D-05	Nov-01	21.90	5.29	0.43	9.56	56.00
D-05	Feb-02	28.10	8.80	0.37	4.33	64.00
D-05	Apr-02	47.40	8.31	0.25	12.10	58.00
D-05	Jul-02	106.00	4.63	0.69	31.10	101.00
D-05	Sep-03	54.00	2.88	0.49	23.50	64.00
D-09	Oct-03	72.50	5.65	0.69	12.39	66.00
D-23	Aug-00	44.80	4.74	0.72	29.29	47.00
D-23	May-01	32.40	4.38	0.53	20.59	16.00
D-23	Jul-01	22.50	5.27	0.95	30.37	20.10
D-23	Nov-01	5.80	6.00	0.65	10.61	13.80
D-23	Apr-02	15.50	6.57	0.24	19.35	24.00
D-23	Jun-02	21.00	6.62	0.51	29.22	15.00
D-23	Jul-03	12.10	7.24	0.35	23.80	56.00
D-30	Oct-00	29.00	3.72	0.49	14.32	58.20
D-30	Jan-01	3.37	5.60	0.50	0.04	15.20
D-30	Jun-01	81.60	10.85	0.29	22.14	55.00
D-30	Dec-01	29.50	5.50	0.47	9.34	53.00
D-30	Feb-02	10.60	8.28	0.32	2.53	42.00
D-30	May-02	99.40	8.84	0.23	17.20	33.00
D-30	Jun-03	83.50	4.55	0.45	24.90	91.00
D-30	Sep-03	51.90	3.05	0.58	25.00	74.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus,
Temp = temperature, Turb = turbidity

Appendix C-1. continued

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (℃)*	*Turb (NTU)*
D-32	Aug-00	43.40	2.84	0.34	27.38	14.60
D-32	Dec-00	30.90	6.19	0.38	-0.14	55.10
D-32	Feb-01	9.33	7.03	0.24	2.30	39.80
D-32	Jun-01	34.60	6.27	0.46	24.53	102.00
D-32	Oct-01	10.20	5.10	0.42	13.60	120.00
D-32	Jan-02	28.60	7.64	0.38	1.49	52.00
D-32	Apr-02	47.70	7.54	0.29	10.69	88.50
D-32	Jun-02	18.20	7.24	0.50	28.00	651.50
D-32	Feb-03	3.08	5.57	0.59	1.24	77.80
D-32	May-03	34.34	7.05	0.61	18.51	285.20
D-32	Aug-03	80.90	2.89	0.51	27.60	109.00
DG-01	Jun-02	3.57	3.80	0.37	21.70	200.00
DT-01	Feb-01	4.27	5.43	0.26	1.01	25.00
DT-01	Jul-01	166.00	3.65	0.33	26.60	123.00
DT-01	Nov-01	48.70	3.82	0.19	7.09	11.00
DT-01	Apr-02	102.00	5.52	0.30	19.43	39.00
DT-01	Jun-02	151.00	7.17	0.29	20.93	52.00
DT-01	Sep-03	155.00	2.77	0.42	22.68	77.50
DT-35	Aug-00	160.00	2.49	0.06	22.71	11.40
DT-35	Apr-01	47.80	2.94	0.12	11.80	65.00
DT-35	Jun-01	15.00	5.39	0.15	13.76	51.00
DT-35	Sep-01	13.30	3.41	0.12	13.48	33.00
DT-35	Nov-01	19.80	3.29	0.07	10.68	22.00
DT-35	Feb-02	5.78	4.76	0.04	0.67	7.00
DT-35	May-02	37.30	2.86	0.11	10.76	32.00
DT-35	Jul-02	155.00	2.39	0.14	28.11	41.00
DT-35	Jun-03	130.00	2.66	0.14	26.10	30.90
DT-35	Sep-03	127.00	3.02	0.19	20.03	31.90
DV-04	Jan-02	1.06	10.51	0.04	0.62	3.00
DV-04	Apr-02	15.35	13.89	0.09	7.89	12.30
DV-04	Jun-02	14.55	12.35	0.06	23.48	11.40
DV-04	Mar-03	1.26	1.79	0.16	13.50	7.80
DV-04	Jul-03	14.50	9.60	0.25	21.26	313.00
DV-04	Sep-03	4.08	0.55	0.04	19.33	5.88
E-06	Jun-03	35.90	7.36	0.17	23.60	34.00
E-25	Oct-00	19.10	4.17	0.51	15.83	22.80
E-25	Jan-01	15.00	5.83	0.61	0.21	4.50
E-25	Mar-01	10.50	9.26	0.18	7.81	38.00
E-25	Jun-01	22.18	7.71	0.35	23.51	42.00
E-25	Oct-01	15.50	7.09	0.57	10.00	84.00
E-25	Jan-02	2.89	7.67	0.19	0.67	13.00
E-25	Apr-02	10.95	10.21	0.37	10.08	140.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-1. continued

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*
E-26	Sep-00	36.90	2.42	2.80	24.30	28.00
E-26	Dec-00	15.00	8.46	0.49	2.51	7.80
E-26	Feb-01	372.00	8.42	0.68	4.89	290.00
E-26	May-01	7.19	10.09	0.67	17.81	55.00
E-26	Nov-01	32.20	5.60	0.68	9.99	33.00
E-26	Feb-02	10.50	9.61	0.21	4.37	27.00
E-28	Dec-01	3.74	7.97	0.07	5.12	4.00
F-01	Feb-01	40.10	6.93	0.18	-0.06	64.00
F-01	Jun-01	13.80	7.90	0.12	24.66	36.00
F-01	Jan-02	3.13	3.68	0.07	2.02	7.00
F-01	Jun-02	19.40	4.84	0.09	27.86	21.60
F-04	Oct-00	10.70	0.61	0.06	15.09	5.30
F-12	Oct-00	20.40	0.61	0.04	12.73	17.00
F-16	Aug-03	14.60	3.59	0.14	23.58	24.40
FA-01	Sep-00	0.88	0.29	0.03	24.25	9.00
FC-01	Sep-00	0.59	0.86	0.01	21.96	1.20
FCC-01	Sep-00	2.94	0.94	0.03	19.67	17.30
FFB-01	Sep-00	4.01	3.57	0.58	19.26	1.20
FK-01	Oct-00	0.78	0.11	0.02	11.89	2.10
FL-05	Nov-00	22.60	0.68	0.10	14.26	20.00
FLD-03	Nov-00	4.97	0.95	0.04	13.60	17.00
FLF-01	Nov-00	1.96	0.88	0.07	13.87	56.00
FLH-01	Nov-00	7.34	0.72	0.08	12.10	21.00
FLH-03	Nov-00	54.20	1.15	0.12	11.98	70.00
FLI-06	Oct-01	3.00	0.86	0.02	16.20	4.40
FLIC-04	Nov-00	0.88	4.20	0.01	14.18	7.60
FQ-01	Sep-00	0.36	1.48	0.04	17.59	2.90
G-08	Jan-02	4.78	5.48	0.05	14.63	9.00
G-08	Apr-02	5.19	3.43	0.03	3.42	7.00
G-08	Jul-02	72.50	2.14	0.44	28.69	91.00
G-08	Nov-03	53.80	4.43	0.12	8.14	31.90
G-11	Feb-02	28.50	4.64	0.63	5.08	22.00
G-11	Jun-02	166.00	7.93	0.85	27.73	63.00
G-11	Jul-03	104.20	4.67	0.94	27.54	50.80
G-18	Jun-03	26.70	5.18	0.73	19.82	32.00
G-25	Jun-03	21.60	4.94	0.14	18.86	65.00
G-33	Jun-03	24.80	5.15	0.56	19.75	30.00
G-35	Jun-03	27.00	6.86	0.73	19.71	34.00
GB-11	Jul-03	5.35	5.99	0.67	22.61	30.00
GBK-07	Jun-03	8.55	5.30	1.00	16.87	33.00
GBL-07	Jun-03	34.10	9.33	1.35	17.23	23.00
GCA-01	Jun-03	9.38	16.42	0.30	16.90	10.30

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-1. continued

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*
GG-06	Jun-03	3.35	4.36	0.66	19.33	7.70
GGC-FN-A	Aug-03	6.19	1.13	0.11	24.96	43.00
GGC-FN-C	Jul-03	8.19	1.67	0.55	20.01	60.00
GGC-FN-C	Sep-03	3.00	7.90	0.93	20.63	14.00
GGC-FN-C	Aug-03	3.77	4.85	1.89	22.32	23.00
GGC-FN-E	Jul-03	2.31	2.35	2.08	20.00	13.00
GGC-FN-E	Sep-03	1.47	9.05	1.10	21.04	4.30
GI-02	Dec-00	0.92	9.06	1.30	11.31	14.00
GI-02	Mar-01	5.99	6.69	0.74	11.83	17.00
GI-02	Jun-01	3.47	6.77	1.40	29.98	16.00
GI-02	Sep-01	5.14	5.79	1.10	27.49	17.00
GI-02	Dec-01	1.00	7.42	1.30	17.95	21.00
GI-02	Feb-02	3.12	9.42	1.80	11.19	18.00
GI-02	May-02	3.78	5.95	0.64	17.18	19.00
GI-02	May-03	17.10	7.36	0.57	21.73	8.90
GI-02	Aug-03	8.84	5.63	0.98	29.98	23.80
GL-09	Oct-01	2.12	5.45	1.12	15.74	15.90
GL-09	Jan-02	33.20	11.92	2.18	6.25	23.00
GL-09	May-02	3.51	5.94	1.10	19.89	21.20
GL-09	Jul-02	72.14	9.72	2.00	25.56	22.20
GL-09	Mar-03	6.86	8.86	1.28	9.20	13.70
GL-09	Jun-03	1.60	12.10	2.11	22.09	15.50
GU-06	Jun-03	7.61	1.56	0.15	17.80	21.00
HA-04	Aug-01	9.16	4.71	0.98	24.15	15.00
HB-01	Aug-01	15.70	3.08	0.91	22.84	57.00
HBD-05	Aug-01	11.60	1.68	0.11	20.65	30.00
HBDA-01	Aug-01	1.26	1.49	0.22	19.20	27.00
HBDC-02	Jun-01	9.37	3.66	0.68	21.57	50.00
HCC-07	Nov-01	5.37	4.41	0.74	11.63	20.00
HCC-07	Jan-02	13.80	8.47	1.35	4.00	17.00
HCC-07	May-02	22.10	3.23	0.32	12.04	29.00
HCC-07	Jun-03	9.81	4.95	0.69	14.75	14.70
HCC-07	Aug-03	4.54	8.84	1.76	24.75	33.40
HCCA-02	Jul-01	3.90	1.43	0.11	22.04	52.00
HCCA-04	Jul-01	2.64	10.05	1.40	24.51	27.00
HCCB-05	Sep-01	10.80	11.22	1.80	19.93	55.00
HCCC-02	Jan-02	11.30	1.16	0.11	0.94	52.00
HCCC-02	May-02	3.33	2.07	0.07	10.91	27.00
HCCC-02	Jun-03	7.31	1.36	0.09	14.02	20.40
HCCC-04	Jul-01	4.33	7.43	1.60	18.92	21.00
HCCC-04	Sep-01	9.51	3.16	0.74	15.08	30.00
HCCD-09	Aug-01	5.02	11.45	2.70	22.79	23.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-1. continued

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*
HF-01	Jun-01	0.00	1.10	0.07	21.24	16.00
I-05	Sep-01	84.40	1.67	0.24	23.40	32.00
I-05	Mar-02	35.70	5.57	0.30	7.30	46.00
I-05	Oct-03	22.20	1.30	0.18	17.70	37.00
J-98	Dec-01	27.40	3.14	0.18	10.50	17.00
J-98	Jun-02	19.70	6.18	0.32	27.70	69.00
K-04	Sep-00	14.40	2.08	0.17	16.70	14.90
K-21	Jul-01	19.20	5.64	0.22	27.30	50.00
K-21	Mar-02	75.00	3.88	0.21	5.13	96.00
K-21	Aug-03	68.50	1.87	0.13	27.30	22.00
K-22	Nov-01	13.90	3.82	0.16	10.90	22.00
K-22	Aug-03	32.10	1.80	0.15	27.40	19.00
M-02	Nov-01	29.50	2.24	0.11	9.75	18.00
M-02	Jun-03	68.30	3.55	0.17	18.40	45.00
M-12	Jul-01	4.09	2.35	0.10	26.74	2.60
M-12	May-02	67.30	3.75	0.23	16.03	75.00
M-12	Jul-03	19.50	2.03	0.14	25.13	20.00
M-13	Jul-01	17.50	2.19	0.13	27.26	8.30
M-13	May-02	49.80	1.98	0.16	14.78	30.00
M-13	Jul-03	23.40	2.08	0.14	24.37	21.00
MJ-02	Oct-00	7.62	5.77	0.02	13.79	2.30
MN-04	Oct-00	12.00	4.89	0.09	14.33	4.20
MN-17	Oct-00	7.08	3.33	0.06	13.90	11.00
MND-01	Oct-00	5.15	2.69	0.04	13.77	14.00
MNIA-11	Oct-00	3.22	5.34	0.06	15.03	2.60
MQB-01	Oct-00	3.43	2.97	0.06	14.03	4.40
N-08	Sep-03	98.60	1.62	0.30	16.90	24.00
N-12	Nov-00	83.60	2.41	0.49	6.50	95.00
N-12	Feb-01	15.00	2.04	0.20	7.90	41.30
N-12	May-01	20.40	1.11	0.10	23.60	11.00
N-12	Oct-01	31.70	2.73	0.48	14.70	53.00
N-12	Jan-02	6.55	2.09	0.12	3.90	11.00
N-12	Apr-02	22.60	2.34	0.23	15.70	64.00
N-12	Jun-02	22.40	1.02	0.22	26.40	43.00
N-12	May-03	5.67	2.56	0.24	18.40	83.00
NJ-07	Sep-03	1.59	6.43	0.08	17.80	14.00
NK-01	Aug-01	2.37	0.86	0.12	22.40	11.50
NK-01	Jan-02	1.00	1.92	0.08	0.90	12.00
NK-01	May-02	1.94	1.32	0.13	16.20	35.75
NK-01	Jul-02	9.46	3.17	0.07	27.10	14.60
NK-01	Sep-03	25.40	1.14	0.17	17.90	23.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-1. concluded

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*
O-02	Sep-00	9.33	5.70	0.28	21.19	22.00
O-02	Nov-00	0.00	10.45	0.11	6.46	6.30
O-02	Feb-01	0.89	9.54	0.22	0.91	11.60
O-02	Jun-01	17.00	8.36	0.22	15.37	55.00
O-02	Aug-01	20.20	3.47	0.42	22.60	62.00
O-02	Nov-01	5.57	6.75	0.10	8.24	18.00
O-02	Jan-02	15.30	8.48	0.07	5.81	14.00
O-02	Apr-02	10.50	13.58	0.10	20.50	36.00
O-02	Jun-02	6.10	13.93	0.14	25.70	63.00
O-02	Jun-03	35.30	8.05	0.13	20.90	62.00
O-02	Nov-03	33.50	3.12	0.11	11.86	6.00
O-08	Jul-02	3.53	5.64	0.22	21.30	86.00
O-20	Sep-00	58.50	1.13	0.20	18.20	42.00
O-20	Jan-01	0.38	3.71	0.13	3.50	15.50
O-20	Mar-01	16.40	4.10	0.18	10.20	37.00
O-20	Jun-01	19.80	5.39	0.47	18.10	72.00
O-20	Oct-01	30.40	1.28	0.33	16.00	27.00
O-20	Jan-02	8.81	3.24	0.23	3.00	34.00
O-20	Mar-02	69.50	4.82	0.48	10.10	210.00
O-20	Jul-02	18.80	2.42	0.02	27.20	39.00
O-20	Aug-03	53.00	1.23	0.36	25.50	50.00
OT-02	Jun-02	2.70	13.22	0.06	21.40	29.00
P-20	Apr-01	96.60	5.99	0.16	12.27	38.00
P-20	Jan-02	30.50	6.65	0.14	2.29	7.40
P-20	Apr-02	86.20	6.65	0.17	6.36	21.00
P-20	Jun-02	26.20	7.81	0.13	20.54	29.20
P-20	Aug-03	457.00	3.41	0.30	24.27	34.30
P-20	Oct-03	46.80	4.30	0.22	10.77	22.10
PQ-07	Aug-01	9.12	3.20	0.12	16.61	11.00
PQ-13	Aug-01	11.00	4.10	0.30	17.65	28.00
PQB-03	Jun-01	2.97	11.55	0.03	21.98	24.00
PQC-11	Jun-01	6.07	11.74	0.21	23.02	37.00
PQC-13	Aug-01	69.70	2.11	0.34	18.75	53.00
PQCL-02	Aug-01	15.50	4.98	1.10	23.91	34.00
PQD-05	Aug-01	16.80	3.85	0.37	21.90	19.00
PQD-07	Aug-01	8.27	2.60	0.24	18.49	15.00
PQE-06	Aug-01	3.56	7.39	0.12	17.51	9.00
PQI-10	Aug-01	103.00	4.41	0.90	19.91	16.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-2. IEPA Monthly Data, Testing Dataset B

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*
AK-02	Jan-01	0.39	0.20	0.01	1.20	2.60
AK-02	Apr-01	7.35	0.46	0.13	12.00	64.00
AK-02	Jun-01	0.63	0.36	0.01	28.20	2.20
AK-02	Nov-01	2.05	0.65	0.02	12.80	3.00
AK-02	Feb-02	1.00	0.39	0.01	7.20	4.50
AK-02	May-02	1.00	0.22	0.02	15.35	7.60
AK-02	Jul-02	3.18	0.90	0.01	28.50	3.10
AK-02	Jun-03	2.30	0.23	0.01	23.45	18.55
AK-02	Sep-03	5.13	0.47	0.06	23.50	38.80
AT-06	Feb-01	4.34	2.95	0.32	8.80	190.00
ATG-03	Jan-01	5.38	3.44	0.26	2.60	7.30
ATG-03	Aug-01	1.83	2.61	0.32	26.50	9.00
ATG-03	Nov-01	2.85	1.80	0.13	10.90	3.50
ATG-03	Feb-02	2.62	1.94	0.09	8.00	13.00
ATG-03	May-02	3.69	1.93	0.12	18.00	31.00
ATG-03	Jul-02	49.50	2.87	0.27	26.40	25.00
ATG-03	Aug-03	3.84	2.57	0.21	27.20	18.00
B-06	Nov-00	1.93	5.05	0.18	5.70	22.00
B-06	Apr-01	164.00	8.67	0.33	11.80	130.00
B-06	Nov-01	9.33	4.20	0.19	10.80	45.00
B-06	Mar-02	13.20	9.09	0.28	5.50	170.00
B-06	May-02	12.50	4.16	0.32	14.90	220.00
B-06	May-03	16.00	6.81	0.24	19.50	80.00
B-06	Aug-03	55.20	3.21	0.23	25.90	50.00
BM-02	Oct-01	5.52	9.41	0.24	11.80	133.00
BM-02	Jan-02	2.36	5.93	0.20	0.34	5.00
BP-08	Jul-01	49.20	6.23	0.21	27.40	7.00
BP-08	Nov-01	13.40	6.97	0.15	9.66	5.00
BP-08	Feb-02	4.74	10.82	0.19	6.02	57.00
BP-08	Apr-02	6.21	12.39	0.08	12.97	15.85
BP-08	Jun-02	9.67	12.57	0.15	21.45	50.35
BP-08	Feb-03	19.60	4.86	0.42	0.85	11.70
BP-08	Sep-03	7.40	4.84	0.20	19.90	39.00
BPG-09	Jun-03	3.04	12.78	0.22	18.78	121.00
BPG-09	May-02	3.75	13.48	0.26	12.50	91.00
BPG-09	Jul-02	4.17	8.44	0.14	25.85	39.50
BPK-07	Dec-00	5.33	6.10	0.01	-0.29	3.90
BPK-07	Feb-01	62.60	10.34	0.97	3.94	450.00
BPK-07	May-01	6.43	15.76	0.08	18.08	28.40
BPK-07	Aug-01	14.70	0.81	0.06	21.80	40.00
BPK-07	Nov-01	10.60	5.07	0.02	7.50	5.90
BPK-07	Mar-02	1.21	8.75	0.03	3.36	6.68
BPK-07	May-02	5.37	12.09	0.34	14.95	257.00
BPK-07	Jul-02	8.95	6.16	0.07	28.70	34.70
BPK-07	Jul-03	4.18	5.44	0.04	22.70	10.20
BPK-07	Oct-03	22.40	3.72	0.02	12.40	2.50

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-2. continued

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (℃)*	*Turb (NTU)*
C-23	Aug-00	0.00	1.94	0.26	23.90	70.00
C-23	Nov-00	20.70	2.54	0.39	5.70	27.00
C-23	Jul-01	70.50	1.85	0.25	27.40	75.00
C-23	Jan-02	10.00	3.54	0.20	7.10	70.00
C-23	Apr-02	8.83	2.91	0.48	17.50	35.00
C-23	Jul-03	41.60	2.59	0.17	29.80	41.80
C-23	Sep-03	23.90	2.43	0.15	25.00	48.00
CA-03	Jul-01	86.10	2.79	0.37	27.50	182.00
CA-05	Oct-00	19.60	1.63	0.27	15.10	27.00
CA-05	Jan-01	2.52	2.69	0.17	2.00	22.50
CA-05	Apr-01	38.90	1.20	0.12	23.00	31.70
CA-05	Nov-01	16.90	1.36	0.12	12.40	24.00
CA-05	Feb-02	20.70	1.25	0.05	7.70	10.50
CA-05	May-02	4.75	1.42	0.38	16.40	157.00
CA-05	Jun-03	14.40	2.07	0.19	22.60	40.00
CA-05	Sep-03	19.10	0.69	0.07	25.50	20.00
CA-05	Nov-03	8.89	0.64	0.05	12.50	7.50
D-05	Nov-00	30.70	7.36	0.40	4.39	55.20
D-05	Apr-01	108.00	9.82	0.30	11.19	64.80
D-05	Jul-01	75.30	4.17	0.68	28.50	130.00
D-05	Oct-01	26.30	8.63	0.68	13.30	217.00
D-05	Jan-02	16.70	8.70	0.45	1.49	63.00
D-05	Mar-02	36.70	7.53	0.28	6.80	67.00
D-05	Jun-02	33.70	7.69	0.19	23.10	30.00
D-05	Jun-03	92.70	4.44	0.42	27.20	71.00
D-09	Mar-02	10.80	9.14	0.35	5.34	70.00
D-23	Apr-01	43.20	6.05	0.33	18.33	15.90
D-23	Mar-01	8.42	7.17	0.31	5.54	14.00
D-23	Jun-01	60.70	5.62	0.54	29.47	9.60
D-23	Sep-01	48.40	3.48	0.53	26.82	14.00
D-23	Mar-02	7.38	8.79	0.30	6.93	85.00
D-23	May-02	6.87	7.49	0.24	13.68	37.00
D-23	Jun-03	43.00	9.06	0.43	25.56	40.00
D-23	Oct-03	9.79	6.06	0.89	13.72	78.00
D-30	Dec-00	38.60	6.74	0.47	0.73	73.70
D-30	Feb-01	0.00	6.86	0.38	0.64	99.60
D-30	Aug-01	41.70	3.09	0.58	24.20	76.00
D-30	Jan-02	14.10	8.31	0.37	0.36	31.00
D-30	Mar-02	20.90	7.69	0.32	5.59	78.00
D-30	Jun-02	14.30	5.76	0.25	23.10	41.00
D-30	Jul-03	183.00	4.27	0.41	26.00	79.00
D-30	Oct-03	45.00	3.98	0.57	15.00	64.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-2. continued

Station ID	*Date*	*Chl a, Corrected (μg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (℃)*	*Turb (NTU)*
D-32	Sep-00	35.60	3.98	0.56	21.49	53.00
D-32	Jan-01	5.98	5.78	0.55	0.16	55.40
D-32	Apr-01	16.10	8.10	0.35	14.04	81.70
D-32	Jul-01	23.00	2.94	0.42	29.80	47.00
D-32	Dec-01	26.60	5.12	0.33	6.89	35.00
D-32	Mar-02	13.58	9.32	0.30	1.05	63.00
D-32	May-02	13.49	6.94	0.25	17.05	87.90
D-32	Jul-02	40.55	5.00	0.39	30.05	62.20
D-32	Mar-03	10.66	5.20	0.56	5.43	54.45
D-32	Jul-03	69.60	4.60	0.38	27.30	64.00
D-32	Nov-03	18.90	2.59	0.46	14.60	70.00
DG-04	Jun-02	8.55	8.17	0.71	19.20	425.00
DT-01	Apr-01	112.00	3.98	0.17	14.88	13.00
DT-01	Oct-01	26.40	5.83	0.22	10.97	48.00
DT-01	Mar-02	19.30	6.91	0.11	4.36	15.00
DT-01	May-02	66.70	7.22	0.22	12.65	32.00
DT-01	Jun-03	192.00	2.88	0.32	24.75	40.00
DT-06	Jul-02	192.00	2.09	0.24	24.00	45.00
DT-35	Mar-01	8.96	3.66	0.08	4.36	14.00
DT-35	May-01	83.40	2.95	0.17	15.88	63.00
DT-35	Jul-01	115.00	2.64	0.22	27.65	52.00
DT-35	Oct-01	6.30	4.52	0.10	8.82	27.00
DT-35	Jan-02	3.72	4.33	0.04	-0.11	4.00
DT-35	Apr-02	18.90	3.74	0.04	4.23	12.00
DT-35	Jun-02	4.40	4.56	0.21	24.81	71.00
DT-35	May-03	15.90	3.16	0.09	17.92	32.70
DT-35	Aug-03	116.00	2.99	0.18	22.85	31.90
DV-04	Dec-01	2.54	9.79	0.03	11.17	7.00
DV-04	Feb-02	5.43	13.92	0.16	4.59	80.00
DV-04	May-02	5.07	13.32	0.26	12.78	117.00
DV-04	Jul-02	17.50	3.93	0.15	27.21	11.20
DV-04	Jun-03	5.88	14.79	0.08	17.79	21.80
DV-04	Aug-03	7.42	7.55	0.05	26.21	36.80
DV-04	Oct-03	17.80	1.00	0.07	10.42	9.23
E-18	Apr-02	3.08	13.96	0.07	6.58	23.00
E-25	Nov-00	12.20	6.04	0.29	4.14	8.90
E-25	Feb-01	9.53	7.81	0.47	3.75	100.00
E-25	Apr-01	19.60	7.25	0.26	18.08	40.00
E-25	Aug-01	191.00	3.24	0.70	26.90	44.00
E-25	Nov-01	13.70	4.27	0.52	10.60	25.00
E-25	Feb-02	13.40	8.51	0.29	2.81	65.00
E-25	Jul-02	28.90	9.09	0.30	26.30	88.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-2. continued

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*
E-26	Oct-00	9.71	3.85	0.50	10.73	62.60
E-26	Jan-01	17.00	8.00	0.66	-0.24	7.40
E-26	Mar-01	6.45	10.74	0.20	5.34	24.00
E-26	Jul-01	73.00	4.01	1.90	25.07	60.00
E-26	Jan-02	24.70	10.00	0.38	3.05	7.20
E-26	Jul-02	31.40	9.94	0.39	26.80	74.00
E-28	Mar-02	1.59	13.55	0.08	5.48	17.00
F-01	Mar-01	0.00	0.11	0.10	3.40	23.00
F-01	Dec-01	5.29	7.09	0.15	8.51	42.00
F-01	Mar-02	4.33	4.36	0.05	3.82	7.00
F-03	Oct-00	3.90	0.77	0.05	11.52	9.80
F-11	Nov-00	5.31	0.53	0.02	13.54	9.40
F-16	Jun-03	23.40	6.15	0.10	26.66	25.60
F-16	Sep-03	5.19	2.45	0.15	21.86	20.40
FB-01	Oct-00	0.19	2.87	0.01	15.01	3.70
FC-01	Nov-00	1.87	1.95	0.01	12.87	1.90
FF-01	Sep-00	0.96	2.05	0.17	22.66	1.10
FFB-01	Oct-00	2.90	3.38	0.63	15.47	1.90
FKA-01	Sep-00	1.50	0.24	0.02	18.81	0.80
FLD-01	Nov-00	4.72	1.00	0.02	14.44	3.20
FLDA-01	Nov-00	6.54	1.17	0.03	15.67	18.00
FLF-01	Oct-01	10.30	1.40	0.11	18.57	120.00
FLH-02	Nov-00	18.50	0.70	0.30	12.52	21.00
FLI-06	Nov-00	3.17	0.56	0.01	15.87	26.00
FLIA-01	Nov-00	2.16	0.77	0.56	14.46	9.70
FLIC-04	Oct-01	1.30	1.96	0.03	15.70	5.50
G-07	Jun-03	25.20	6.31	0.59	18.77	38.00
G-08	Feb-02	3.60	6.68	0.09	0.62	12.00
G-08	Jun-02	60.60	8.00	0.11	23.61	6.00
G-08	Jun-03	16.80	5.16	0.14	19.90	40.00
G-11	Jan-02	7.17	9.77	1.44	1.10	11.00
G-11	May-02	19.80	3.91	0.43	13.76	41.00
G-11	May-03	113.00	5.52	0.61	21.03	29.40
G-11	Sep-03	16.70	6.11	1.03	19.83	37.90
G-18	Jul-03	57.70	6.01	0.73	23.67	40.00
G-26	Jun-03	22.20	5.30	0.45	18.78	38.00
G-33	Jul-03	54.10	5.27	0.71	24.57	32.00
GB-01	Jun-03	21.10	5.82	0.95	20.81	19.00
GBK-02	Jun-03	25.40	4.22	0.75	19.91	18.00
GBL-02	Jun-03	6.47	9.79	1.45	16.92	36.00
GC-03	Jun-03	4.98	7.81	0.33	18.59	20.00
GG-04	Jun-03	3.49	4.46	0.89	19.34	6.30

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-2. continued

Station ID	*Date*	*Chl a, Corrected (μg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (℃)*	*Turb (NTU)*
GGC-FN-A	Jul-03	11.20	1.51	0.15	21.19	75.00
GGC-FN-A	Sep-03	9.53	1.41	0.11	17.50	80.00
GGC-FN-C	Aug-03	2.09	5.11	2.69	21.92	10.40
GGC-FN-C	Jul-03	8.12	1.57	0.36	19.55	70.00
GGC-FN-C	Sep-03	6.74	3.84	0.48	17.67	45.00
GGC-FN-E	Aug-03	1.24	5.76	2.83	21.94	10.90
GI-02	Aug-00	4.50	5.20	1.10	29.76	11.20
GI-02	Jan-01	2.46	8.66	1.10	12.41	6.00
GI-02	Apr-01	5.57	9.12	0.92	15.21	12.00
GI-02	Aug-01	7.93	5.61	0.70	27.41	18.00
GI-02	Oct-01	2.06	6.12	0.63	16.60	30.00
GI-02	Jan-02	1.00	13.33	1.95	11.01	13.00
GI-02	Apr-02	3.86	9.02	0.82	12.93	24.00
GI-02	Jun-02	11.50	7.12	0.85	30.48	15.00
GI-02	Jul-03	12.50	6.41	0.76	28.97	13.80
GI-02	Sep-03	6.69	6.15	0.94	25.70	25.40
GL-09	Dec-01	8.47	6.54	1.05	9.08	21.00
GL-09	Apr-02	16.96	5.03	0.66	10.94	17.25
GL-09	Jun-02	5.73	6.99	1.22	21.36	64.03
GL-09	Feb-03	3.28	13.44	2.91	0.02	27.10
GL-09	May-03	120.65	7.83	1.31	21.90	11.20
GL-09	Jul-03	20.19	3.23	0.73	24.88	22.70
GV-01	Jun-03	5.93	1.93	0.07	18.16	36.00
HB-01	Jun-01	14.30	5.55	2.30	23.64	26.00
HBD-05	Jun-01	0.19	0.97	0.15	21.17	14.00
HBD-06	Aug-01	4.82	12.11	5.90	23.45	10.00
HBDB-03	Jun-01	2.30	1.88	0.37	21.09	34.00
HCC-02	Jul-01	1.50	9.85	2.30	22.05	15.00
HCC-07	Dec-01	7.55	4.27	0.58	6.94	41.00
HCC-07	Apr-02	12.60	5.36	0.73	6.68	11.00
HCC-07	Jul-02	23.35	7.62	1.42	24.54	25.50
HCC-07	Jul-03	14.30	3.39	0.72	22.60	51.30
HCC-07	Nov-03	13.20	2.06	0.19	10.45	37.40
HCCA-02	Sep-01	2.11	2.43	0.46	15.27	16.00
HCCB-05	Jul-01	4.68	16.79	3.80	18.14	36.00
HCCC-02	Dec-01	7.89	1.03	0.07	4.70	27.00
HCCC-02	Mar-02	5.12	0.63	0.04	1.49	17.00
HCCC-02	Jul-02	1.87	2.36	0.26	23.49	13.50
HCCC-02	Jul-03	36.50	1.56	0.15	22.63	24.80
HCCC-04	Aug-01	7.58	8.69	1.80	25.82	14.00
HCCD-09	Jul-01	7.61	8.58	2.00	18.25	29.00
HCCD-09	Sep-01	7.42	2.80	0.44	16.10	21.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-2. continued

Station ID	Date	Chl a, Corrected (µg/L)	TN (mg/L)	TP (mg/L)	Temp (℃)	Turb (NTU)
HF-01	Aug-01	5.47	1.25	0.07	20.62	13.00
I-05	Dec-01	20.30	2.96	0.18	8.70	21.50
I-05	Aug-03	69.20	2.96	0.23	27.80	39.00
J-98	Feb-01	0.00	5.67	0.46	2.30	95.00
J-98	Mar-02	8.29	8.42	0.27	11.30	54.00
J-98	Aug-03	76.90	2.89	0.21	28.10	21.00
K-17	Jun-02	8.32	5.86	0.27	23.10	113.00
K-21	Nov-01	8.81	3.57	0.16	11.10	23.00
K-21	Jun-02	8.46	5.61	0.26	22.80	111.00
K-21	Nov-03	5.60	1.36	0.16	8.76	27.00
K-22	Jun-02	5.09	6.05	0.18	23.60	44.00
K-22	Nov-03	50.50	2.05	0.14	7.58	25.00
M-02	May-02	42.20	1.97	0.15	15.45	41.00
M-02	Nov-03	4.26	2.32	0.16	7.09	27.00
M-12	Feb-02	65.30	3.08	0.12	4.55	32.00
M-12	Jun-03	72.10	3.23	0.15	18.45	38.00
M-12	Nov-03	34.90	2.40	0.22	6.56	73.00
M-13	Nov-01	68.00	2.24	0.11	9.87	17.00
M-13	Jun-03	62.20	3.51	0.14	18.29	23.00
M-13	Nov-03	12.90	3.53	0.14	3.89	36.00
MJB-03	Oct-00	5.96	17.32	0.04	13.14	12.00
MN-07	Oct-00	4.78	3.08	0.07	14.71	1.60
MN-19	Oct-00	18.90	3.77	0.06	14.26	9.10
MNI-12	Oct-00	5.06	8.85	0.22	15.28	2.30
MQ-02	Oct-00	4.99	5.44	0.02	14.25	11.00
MS-01	Oct-00	6.71	4.83	0.05	13.69	16.00
N-12	Oct-00	71.60	1.16	0.10	18.80	35.00
N-12	Jan-01	4.79	2.96	0.38	1.50	105.00
N-12	Mar-01	25.30	1.65	0.13	9.50	32.50
N-12	Aug-01	45.20	1.21	0.30	27.90	53.00
N-12	Nov-01	81.00	1.78	0.24	12.70	37.00
N-12	Feb-02	20.40	1.17	0.16	7.20	27.00
N-12	May-02	10.10	0.79	0.16	16.90	17.00
N-12	Jul-02	44.30	0.79	0.06	28.50	56.00
N-12	Jun-03	9.22	1.88	0.25	22.70	55.00
NK-01	Jun-01	15.60	5.53	0.90	21.10	384.00
NK-01	Nov-01	4.86	1.04	0.23	13.00	5.00
NK-01	Apr-02	3.76	1.34	0.12	12.73	52.20
NK-01	Jun-02	11.32	1.95	0.12	24.13	15.73
NK-01	Jun-03	5.26	1.49	0.14	23.65	17.65
NK-01	Oct-03	17.40	0.50	0.37	10.60	7.60

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

Appendix C-2. concluded

Station ID	*Date*	*Chl a, Corrected (µg/L)*	*TN (mg/L)*	*TP (mg/L)*	*Temp (°C)*	*Turb (NTU)*
O-02	Oct-00	2.93	9.59	0.12	11.63	14.90
O-02	Jan-01	2.46	9.99	0.04	-0.16	2.30
O-02	May-01	9.39	9.65	0.15	18.99	84.00
O-02	Jul-01	59.10	4.53	0.23	26.42	55.00
O-02	Oct-01	12.50	2.22	0.24	16.80	38.00
O-02	Dec-01	1.00	11.62	0.06	0.90	4.00
O-02	Mar-02	4.92	11.62	0.04	6.63	9.00
O-02	May-02	3.63	12.01	0.20	11.90	67.00
O-02	Jul-02	23.90	10.80	0.17	28.80	48.40
O-02	Jul-03	40.70	6.69	0.19	24.20	46.00
O-07	Jul-02	29.00	2.44	0.19	27.00	22.00
O-11	Oct-01	8.13	2.52	0.03	15.50	15.00
O-20	Nov-00	35.60	0.86	0.11	18.30	32.00
O-20	Feb-01	10.60	3.88	0.38	5.10	131.00
O-20	May-01	27.80	3.07	0.19	22.00	32.00
O-20	Aug-01	16.00	0.89	0.28	26.50	25.50
O-20	Nov-01	44.70	1.39	0.21	13.30	14.00
O-20	Feb-02	52.00	2.54	0.20	6.30	32.00
O-20	May-02	24.20	3.76	0.29	17.30	82.00
O-20	Jun-03	15.30	7.03	1.09	20.50	539.00
O-20	Oct-03	1.75	1.11	0.20	12.50	24.00
P-20	Mar-01	32.30	6.82	0.23	1.94	20.00
P-20	Aug-01	86.10	5.55	0.33	28.15	40.00
P-20	Feb-02	74.60	6.90	0.16	3.47	17.00
P-20	May-02	53.90	9.00	0.26	15.01	29.90
P-20	Jun-03	162.00	4.97	0.25	25.27	56.60
P-20	Sep-03	15.20	3.99	0.28	18.95	33.90
PQ-07	Jun-01	6.11	4.50	0.20	9.66	32.00
PQ-13	Jun-01	3.04	3.19	0.20	20.76	22.00
PQ-14	Aug-01	9.03	4.68	0.13	21.36	19.00
PQC-02	Jun-01	15.30	13.07	0.47	19.80	30.00
PQC-11	Aug-01	155.00	3.70	0.44	21.87	24.00
PQCL-02	Jun-01	3.16	8.45	0.25	18.49	34.00
PQD-05	Jun-01	8.35	6.15	0.22	19.23	54.00
PQD-07	Jun-01	9.04	4.66	0.20	21.64	31.00
PQE-06	Jun-01	4.06	7.33	0.12	16.55	20.00
PQF-06	Jun-01	6.01	8.88	0.16	21.64	49.00
PQJ-01	Jun-01	15.80	7.81	0.06	20.22	14.00

Notes: Chl *a* = Chlorophyll *a*, TN = total nitrogen, TP = total phosphorus, Temp = temperature, Turb = turbidity

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