Feasibility of Estimating Constituent Concentrations and Loads Based on Data Recorded by Acoustic Instrumentation

U.S. GEOLOGICAL SURVEY
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Prepared in cooperation with the
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

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By A.C. Lietz

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Conversion Factors, Acronyms, and Datum

Multiply	By	To obtain
foot	0.3048	meter
foot per second	0.3048	meter per second
cubic foot per second	0.02832	cubic meter per second
mile	1.609	kilometer
ton (short) per day	907.2	kilogram per day

Acronyms	
ADCP	acoustic Doppler current profiler
ADVM	acoustic Doppler velocity meter
CERP	Comprehensive Everglades Restoration Plan
MSE	Mean square error

***Sea level*:** In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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Abstract

The acoustic Doppler current profiler (ADCP) and acoustic Doppler velocity meter (ADVM) were used to estimate constituent concentrations and loads at a sampling site along the Hendry-Collier County boundary in southwestern Florida. The sampling site is strategically placed within a highly managed canal system that exhibits low and rapidly changing water conditions. With the ADCP and ADVM, flow can be gaged more accurately rather than by conventional field-data collection methods.

An ADVM velocity rating relates measured velocity determined by the ADCP (dependent variable) with the ADVM velocity (independent variable) by means of regression analysis techniques. The coefficient of determination (R^2) for this rating is 0.99 at the sampling site. Concentrations and loads of total phosphorus, total Kjeldahl nitrogen, and total nitrogen (dependent variables) were related to instantaneous discharge, acoustic backscatter, stage, or water temperature (independent variables) recorded at the time of sampling. Only positive discharges were used for this analysis. Discharges less than 100 cubic feet per second generally are considered inaccurate (probably as a result of acoustic ray bending and vertical temperature gradients in the water column.)

Of the concentration models, only total phosphorus was statistically significant at the 95-percent confidence level (p-value less than 0.05). Total phosphorus had an adjusted R^2 of 0.93, indicating most of the variation in the concentration can be explained by the discharge. All of the load models for total phosphorus, total Kjeldahl nitrogen, and total nitrogen were statistically significant. Most of the variation in load can be explained by the discharge as reflected in the adjusted R^2 for total phosphorus (0.98), total Kjeldahl nitrogen (0.99), and total nitrogen (0.99).

INTRODUCTION

Water-management practices have evolved over the last century to accommodate rapid urbanization and intensive agricultural uses along coastal southern Florida. A highly regulated system of canals, levees, surface-water impoundments, and pumping stations was designed to provide for drainage, flood control, saltwater intrusion control, agricultural requirements, and various environmental needs. Development of this system has altered Everglades hydropatterns and caused water-quality degradation in both coastal and interior regions of southern Florida.

Monitoring canal and river discharge has historically emphasized the coastal regions of southern Florida. Increased emphasis has been placed on providing a more accurate accounting of canal flows in interior regions of southern Florida (Murray, 1996). Recent efforts have been directed toward establishing water-budget and constituent load estimates in the interior regions. As part of the Comprehensive Everglades Restoration Plan (CERP), a consortium of Federal and State agencies have recommended increased water deliveries to Native American Lands, Big Cypress

National Preserve, and Water Conservation Area 3A in southern Florida. These recommendations are designed to partially restore the remaining Everglades to its predevelopment state, provide adequate flood protection and water supply for urban and agricultural purposes, and restore historical hydropatterns to Native American Lands.

This report, prepared by the U.S. Geological Survey in cooperation with the South Florida Water Management District, describes a methodology for estimating constituent concentrations and loads based upon data supplied by acoustic instrumentation. The methodology is applied to a site on L-28 Interceptor Canal in Hendry County, southern Florida. Estimation of constituent transport using innovative approaches will aid water managers in decision making and also substantially contribute to restoration efforts.

Description of Sampling Site

A strategically placed water-level, discharge, and water-quality gaging site was established in October 1996 along the east bank of the L-28 Interceptor Canal (station 261533080571600) in Hendry County. The sampling site is about 500 feet north of the northern boundary of the Big Cypress National Preserve and inside the southern boundary of the Seminole Indian Reservation (fig. 1). Upstream is structure S-190 located 0.5 mile downstream of the confluence of the L28IN and West Feeder Canals.

Daily stage and discharge data at the L-28 Interceptor Canal below S-190 (the sampling site) have been recorded since 1998. From water years 1997 to 2000, maximum and minimum water levels were 13.80 and 9.77 feet above sea level, respectively (Price

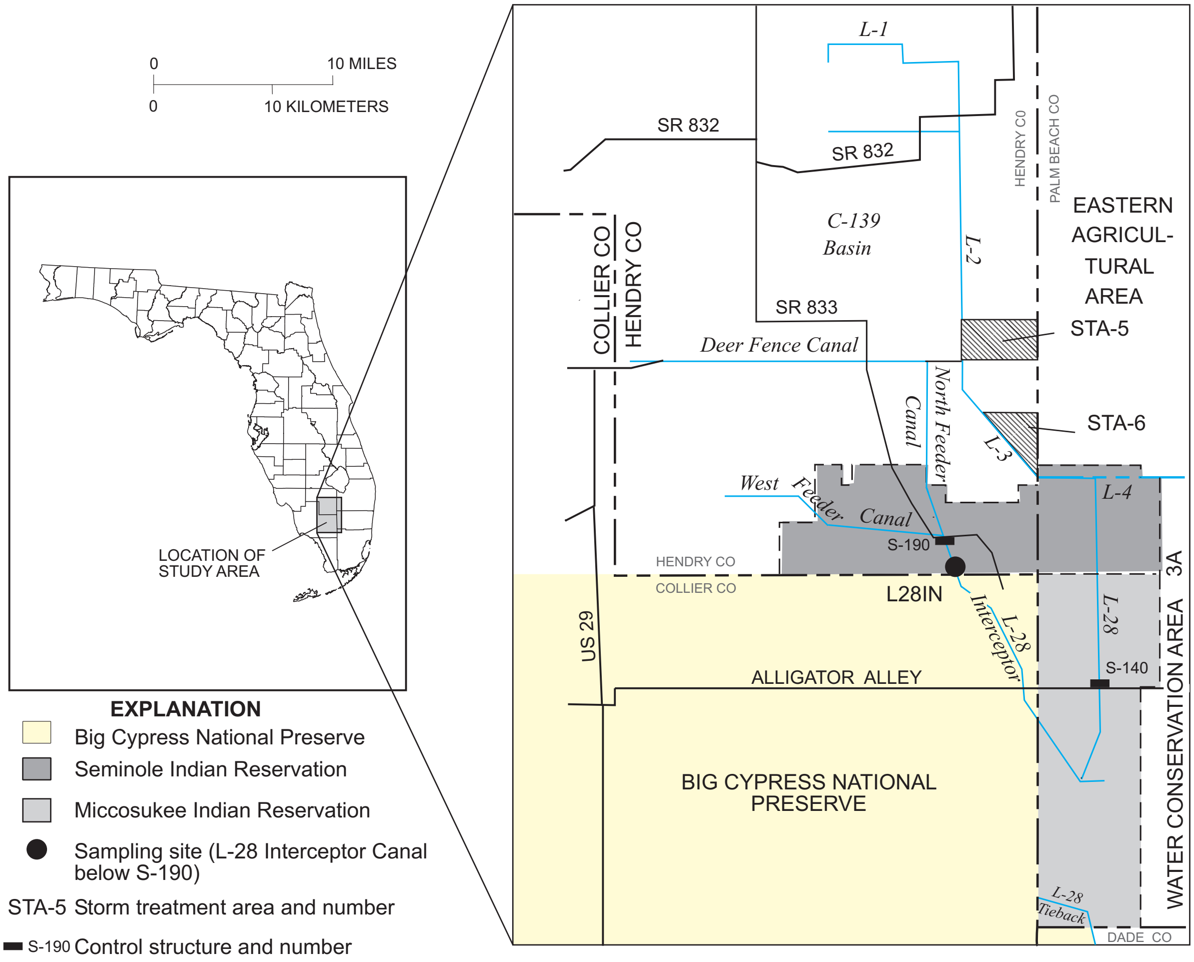

Figure 1. Location of study area and physical and hydrologic features in southwestern Florida.

and others, 2001); a water year is defined as the period from October 1 to September 30. For the same period of record, the highest daily mean discharge was 1,200 cubic feet per second; the lowest daily mean discharge was -135 cubic feet per second.

Flow is regulated upstream by S-190, which is a dual vertical-lift gate weir structure. The L-28 Interceptor Canal ends in marsh about 15 miles downstream of S-190. During low-flow periods, ground- and surface-water flows are affected by pumping at structure S-140 along the L-28 Canal. A flow duration curve for positive discharge at the sampling site is shown in figure 2.

Acoustic Instrumentation, Data Collection, and Sampling

Since implementation of the sampling site, stage data have been collected by means of shaft encoders, and velocity data have been recorded using acoustic instruments. The acoustic Doppler current profiler (ADCP) and acoustic Doppler velocity meter (ADVM) can quickly measure low and rapidly changing water conditions. With these instruments, flow can be gaged more accurately rather than by conventional field data-collection methods.

Discharge is measured periodically at the sampling site by means of the ADCP. The highly managed canal system has low and rapidly changing water velocities, flow reversals, and substantial aquatic vegetation; the ADCP is capable of measuring discharge under these conditions. Because of flow reversals caused by backwater, there is no relation between stage and discharge at this site. Discharge is computed using stage/area ratings to relate water level to cross-sectional area, and velocity ratings are used to relate acoustic line velocity to mean measured velocity. Thus, discharge was computed for the sampling site using stage and acoustic line velocity ratings.

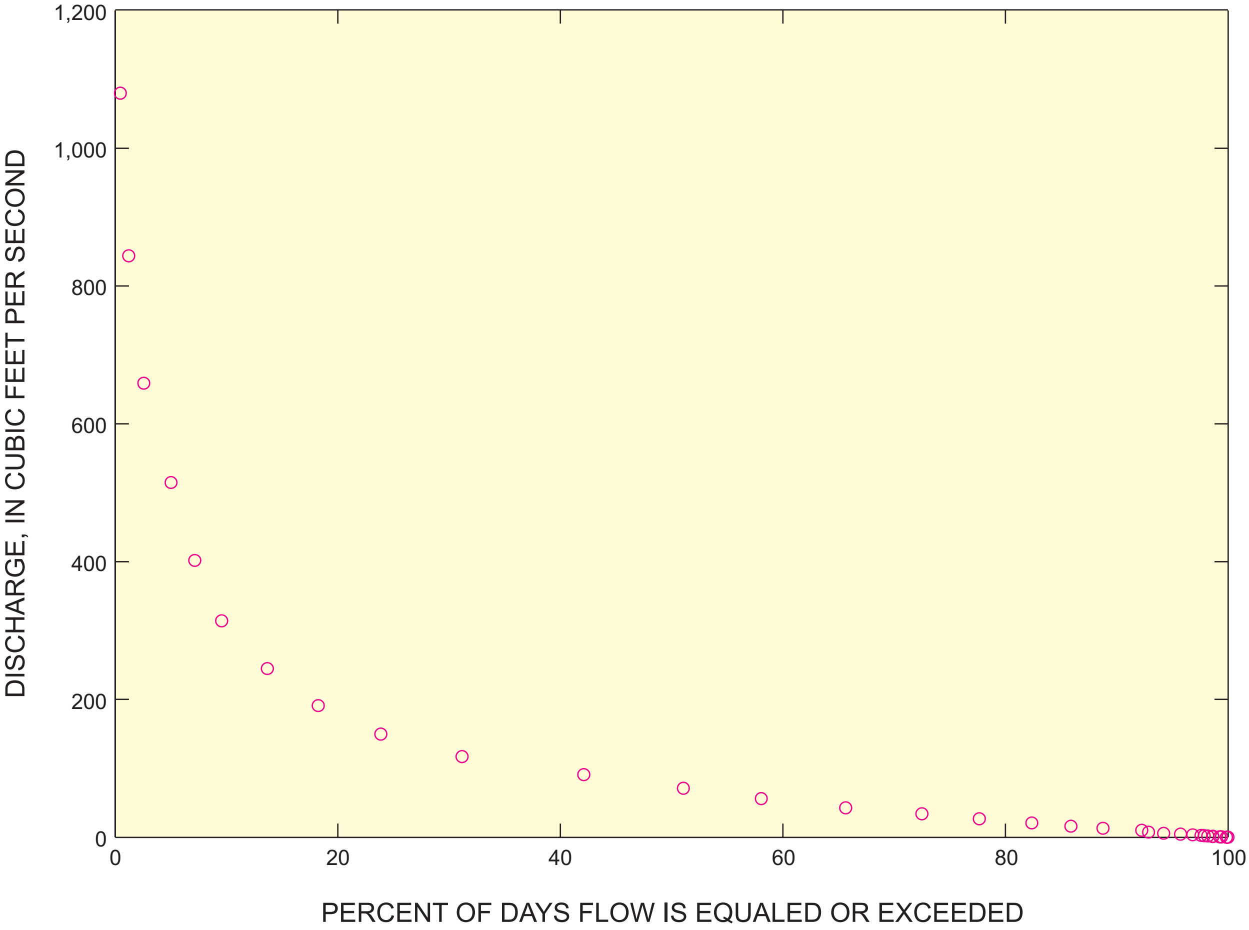

Figure 2. Flow-duration curve for L-28 Interceptor Canal below S-190.

In July 2000, a side looking ADVM was installed at the sampling site to record water velocity, acoustic backscatter, water temperature, and time. The ADVM records water velocity by: (1) emitting an acoustic signal pulse of known frequency and wavelength, (2) pausing for a predetermined period of time; and (3) measuring the phase shift (Doppler shift) of the return signal (acoustic backscatter). This shift is proportional to the water velocity. The ADVM measures temperature to accurately compute the speed of sound in water, which is necessary for velocity calculations.

American Sigma portable autosamplers were used at the site to collect phosphorus data by means of flow-proportional sampling. The sampler collects a 100-milliliter volume of water when the flow volume recorded by the data logger reaches a predetermined sampling level. The weekly cumulative flow volume is expressed as a function of the number of samples (aliquots) and the sampling flow volume. The weekly samples are composited to obtain one flow-weighted representative sample. The weekly constituent load is then computed from the cumulative weekly flow volume and the weekly flow-weighted mean constituent concentration.

Grab samples from the intake were collected less frequently using a fixed interval sampling schedule; grab samples were analyzed for nitrogen and phosphorus species. Quality assurance samples include field blanks, equipment blanks, replicate and duplicate samples.

REGRESSION TECHNIQUES

An ADVM velocity rating relates measured velocity determined by the ADCP (dependent variable) with the ADVM velocity (independent variable) by means of regression analysis techniques. The coefficient of determination (R^2) for this rating is 0.99 at the sampling site (fig. 3). Concentrations and loads of nitrogen and phosphorus species found in grab samples were related to properties recorded by the ADVM using the Campbell Scientific CR10 data logger and the radio frequency telemetry operated by the South Florida Water Management District. The multiple linear regression analysis can be illustrated by the following equation:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_k x_k + \varepsilon, \qquad (1)$$

where:

y is the dependent variable,
b_0 is the intercept,
$b_{1,2..k}$ are slope coefficients for the independent variables,
$x_{1,2...k}$ are independent variables, and
ε represents random errors or residuals.

Concentrations and loads of total phosphorus, total Kjeldahl nitrogen, and total nitrogen (dependent variables) were related to instantaneous discharge, acoustic backscatter, stage, or water temperature (independent variables) recorded at the time of

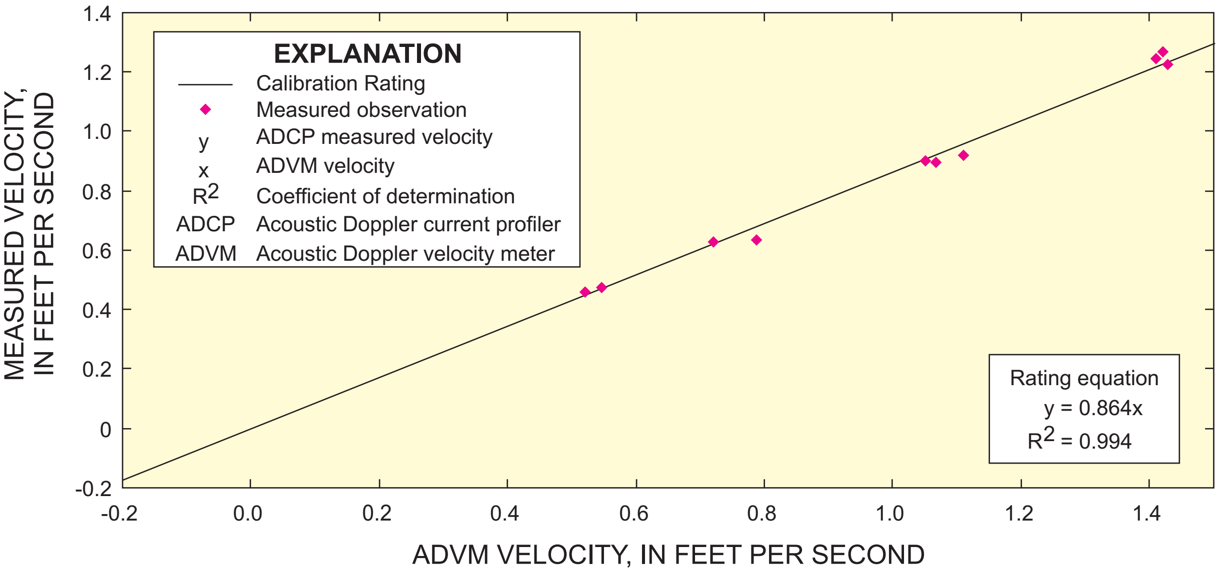

Figure 3. Velocity index rating for L-28 Interceptor Canal below S-190.

sampling. Only positive discharges were used for this analysis. Discharges less than 100 cubic feet per second generally are considered inaccurate (probably as a result of acoustic ray bending and vertical temperature gradients in the water column).

The criterion used for model selection was Mallow's *Cp*. This statistic explains as much variation in the response variable as possible by including all relevant variables, and minimizes the variance in the resulting estimates by minimizing the number of coefficients (Helsel and Hirsch, 1992). The *Cp* statistic can be expressed as:

$$Cp = p + (n - p) \cdot \frac{(s_p^2 - \hat{\delta}^2)}{\hat{\delta}^2}, \qquad (2)$$

where:

n is number of observations,

p is the number of coefficients or explanatory variables plus 1,

s_p^2 is the mean square error (MSE) of the model, and

$\hat{\delta}^2$ is the best estimate of the true error, which usually is the minimum MSE for the possible models.

The best model is the one with the lowest *Cp* statistic.

ANALYSIS OF CONSTITUENT CONCENTRATIONS AND LOADS

Results of concentration and load models for total phosphorus, total Kjeldahl nitrogen, and total nitrogen are summarized in table 1. The only concentration model statistically significant at the 95-percent confidence level (*p*-value less than 0.05) was that for total phosphorus, which had an adjusted coefficient of determination (R^2) of 0.93, indicating most of the variation in the concentration can be explained by the discharge. However, only one concentration value was available to define the upper end of this concentration/discharge relation. A weak linear relation exists between $\log_{10}$ total nitrogen and acoustic backscatter, which resulted in an adjusted R^2 of 0.69 for the concentration model that was not statistically significant (*p*-value = 0.08). The concentration model for total Kjeldahl nitrogen had discharge and stage as explanatory variables, but was not statistically significant (*p*-value = 0.17) and had a low adjusted R^2 of 0.32. Relations between the measured and fitted values for the total phosphorus, total Kjeldahl nitrogen, and $\log_{10}$ total nitrogen concentration models and predictive equations are shown in figures 4A, 5A, and 6A, respectively.

Table 1. Summary of concentration and load models for phosphorus and nitrogen species

[Statistically significant at 95-percent confidence level if *p*-value is less than 0.05. Load = concentration x discharge x 0.0027. Abbreviations: Q, discharge; S, stage; ABS, acoustic backscatter]

Constituent	Best equation	Number of values	Adjusted coefficient of determination (R^2)	*p*-value	Range of discharge (cubic feet per second)
Concentration Model					
Total phosphorus	$2.02 \times 10^{-2} + 2.0 \times 10^{-4}$ Q	12	0.93	0.00	17 - 1,290
Total Kjeldahl nitrogen	$7.22 + 7.0 \times 10^{-4}$ Q $- 5.53 \times 10^{-1}$ S	12	.32	.17	20 - 1,290
$\log_{10}$ total nitrogen	$-0.41 + 9.5 \times 10^{-2}$ ABS	5	.69	.08	17 - 1,290
Load Model					
Total phosphorus	$-6.4 \times 10^{-2} + 1.0 \times 10^{-3}$ Q	12	.98	.00	17 - 1,290
Total Kjeldahl nitrogen	$-5.3 \times 10^{-3} + 3.0 \times 10^{-3}$ Q	12	.99	.00	20 - 1,290
Total nitrogen	$-5.0 \times 10^{-3} + 3.0 \times 10^{-3}$ Q	5	.99	.00	17 - 1,290

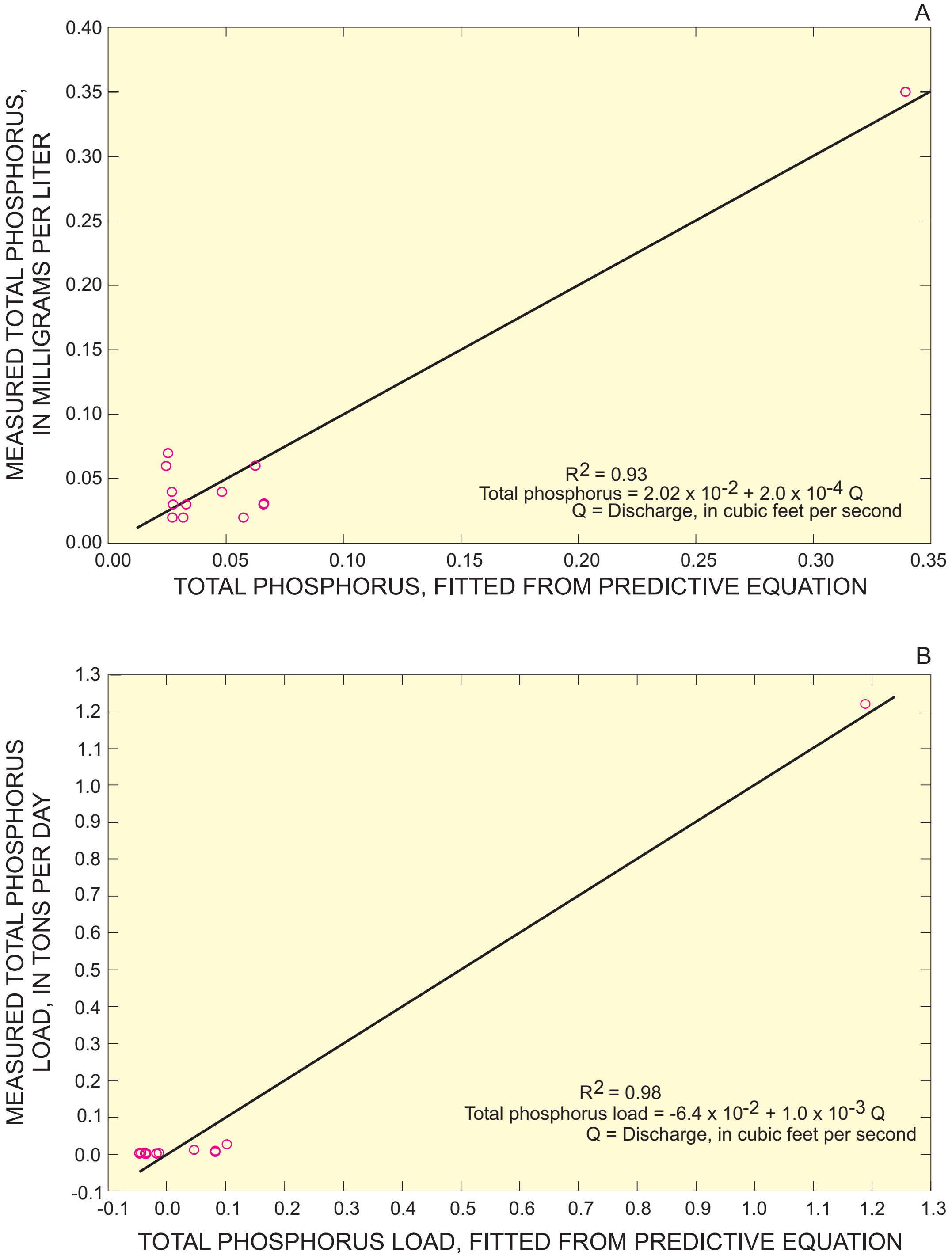

Figure 4. Relation between measured and fitted values for the total phosphorus (A) concentration and (B) load models.

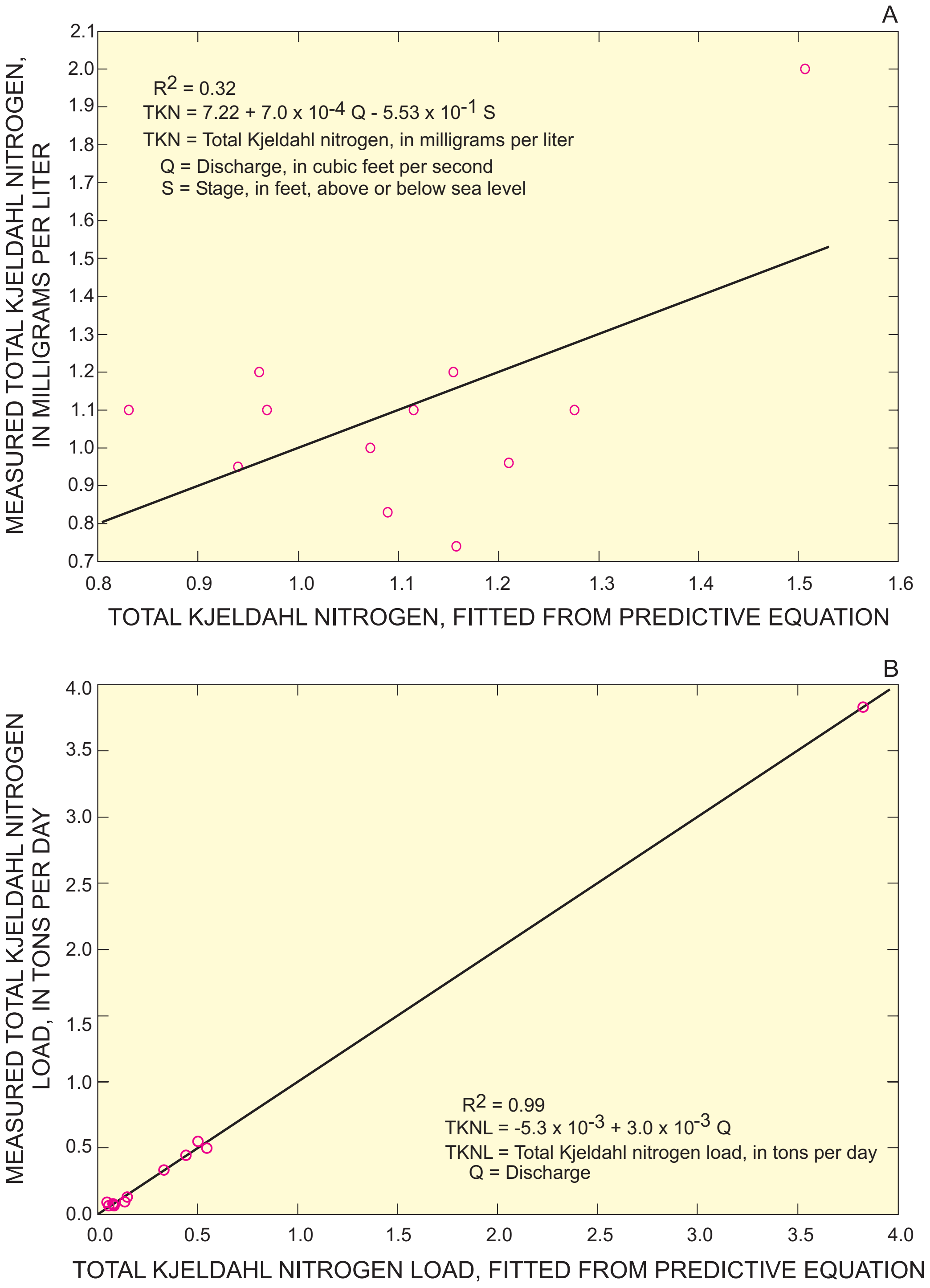

Figure 5. Relation between measured and fitted values for the total Kjeldahl nitrogen (A) concentration and (B) load models.

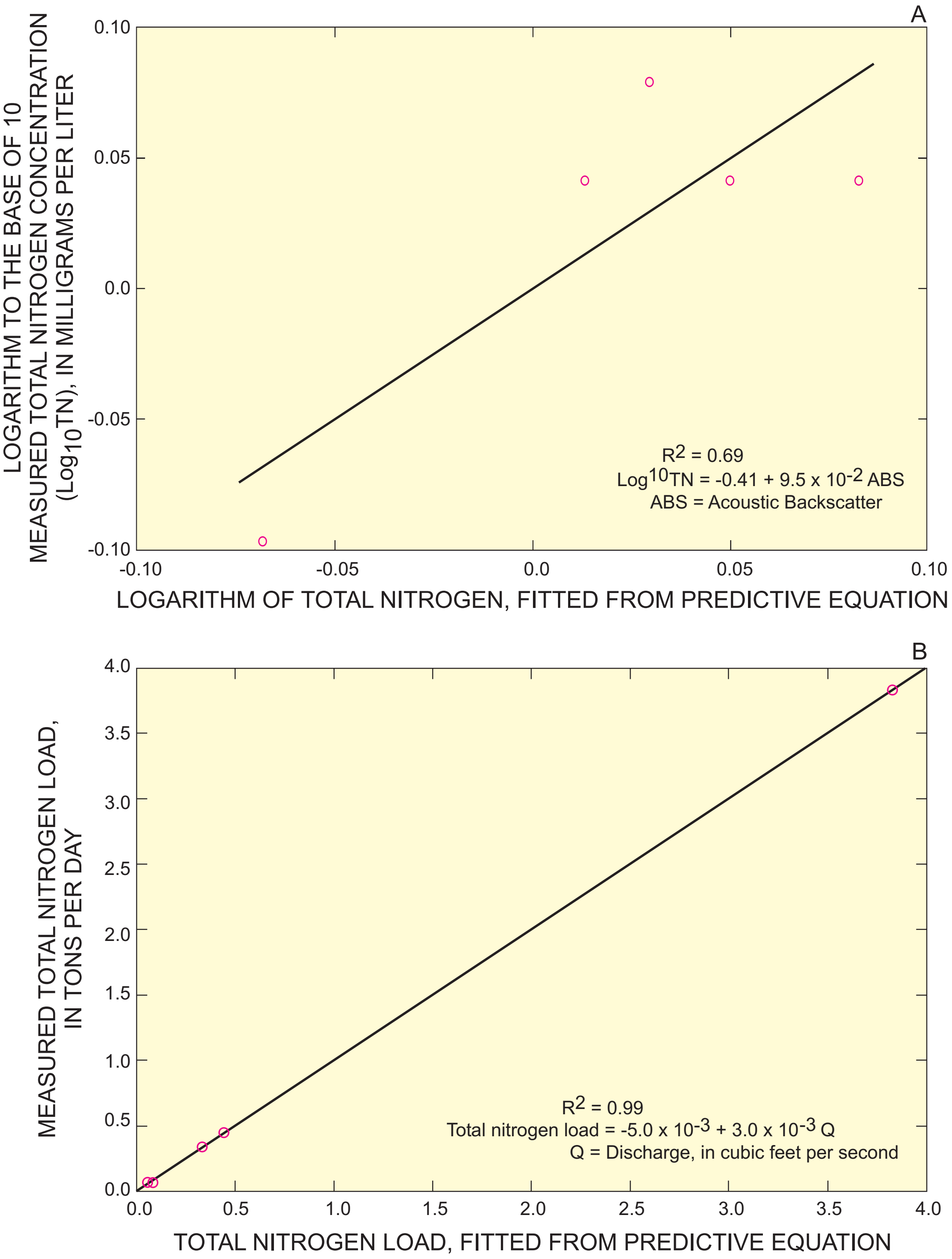

Figure 6. Relation between measured and fitted values for the total nitrogen (A) concentration and (B) load models.

All of the load models for total phosphorus, total Kjeldahl nitrogen, and total nitrogen were statistically significant (table 1). Most of the variation in load can be explained by the discharge as reflected in the adjusted R^2 for total phosphorus (0.98), total Kjeldahl nitrogen (0.99), and total nitrogen (0.99). Relations between the measured and fitted values and the predictive equations for the constituent load models are shown in figures 4B, 5B, and 6B.

CONCLUSIONS

Monitoring approaches based on relations with surrogate variables by use of multiple linear regression analysis are commonly used in hydrology, and are economically feasible as they reduce the need for intensive manual or automatic sampling. Several factors should be emphasized with regard to the sampling process performed for the study. Sampling sizes in the analyses were small and did not represent a wide range of flow conditions. Samples were not collected by means of depth integration, leading to the possibility that grab samples *may* not represent cross-sectional stream water quality. Additionally, sampling was not done on an event-driven basis. Consequently, further investigation into the relation between acoustic variables and stream water quality is needed, including larger sample sizes as well as samples collected on a rainfall event-driven basis. However, the high adjusted R^2 for the constituent load models based on the ADVM-computed discharge suggests the method may be feasible for determining real-time load estimates for selected discharge points throughout southern Florida.

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