ANALYSIS OF TRENDS IN WATER-QUALITY DATA FOR WATER CONSERVATION AREA 3A, THE EVERGLADES, FLORIDA

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ANALYSIS OF TRENDS IN WATER-QUALITY DATA FOR WATER CONSERVATION AREA 3A, THE EVERGLADES, FLORIDA

By Harold C. Mattraw, Jr.[1], Daniel J. Scheidt[2], and Anthony C. Federico[3]

ABSTRACT

Rainfall and water-quality data bases from the South Florida Water Management District were used to evaluate water-quality trends at 10 locations near or in Water Conservation Area 3A in The Everglades. The Seasonal Kendall test was applied to specific conductance, orthophosphate-phosphorus, nitrate-nitrogen, total Kjeldahl nitrogen, and total nitrogen regression residuals for the period 1978–82. Residuals of orthophosphate and nitrate quadratic models, based on antecedent 7-day rainfall at inflow gate S–11B, were the only two constituent-structure pairs that showed apparent significant (p less than 0.05) increases in constituent concentrations. Elimination of regression models with distinct residual patterns and data outliers resulted in 17 statistically significant station-water quality combinations for trend analysis. No water-quality trends were observed.

The 1979 Memorandum of Agreement outlining the water-quality monitoring program between the Everglades National Park and the U.S. Army Corps of Engineers stressed collection four times a year at three stations and extensive coverage of water-quality properties. Trend analysis and other rigorous statistical evaluation programs are better suited to data monitoring programs that include more frequent sampling and that are organized in a water-quality data-management system. Pronounced areal differences in water quality suggest that a water-quality monitoring system for Shark River Slough in Everglades National Park include collection locations near the source of inflow to Water Conservation Area 3A.

INTRODUCTION

The historical Everglades extended from Lake Okeechobee south to the Gulf of Mexico prior to drainage methods introduced by man in the 20th century. During the wet season, from May through October, water flowed in a large sheet through this predominantly sawgrass marsh to the Gulf of Mexico. A major part of this historical marsh is currently (1987) delineated by five Water Conservation Areas, which are shallow wetlands enclosed by levees during the 1950's and 1960's for water-management purposes. The largest, Water Conservation Area 3A (WCA–3A), releases water into the major undisturbed part of The Everglades, the Shark River Slough, within Everglades National Park (fig. 1).

The schedule for releasing water and the quantity of water released to the park have undergone several changes. From 1970 to 1983, deliveries to Shark River Slough were managed by the South Florida Water Management District according to water-level regulation schedules set by the U.S. Army Corps of

[1]U.S. Geological Survey.

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[3]South Florida Water Management District.

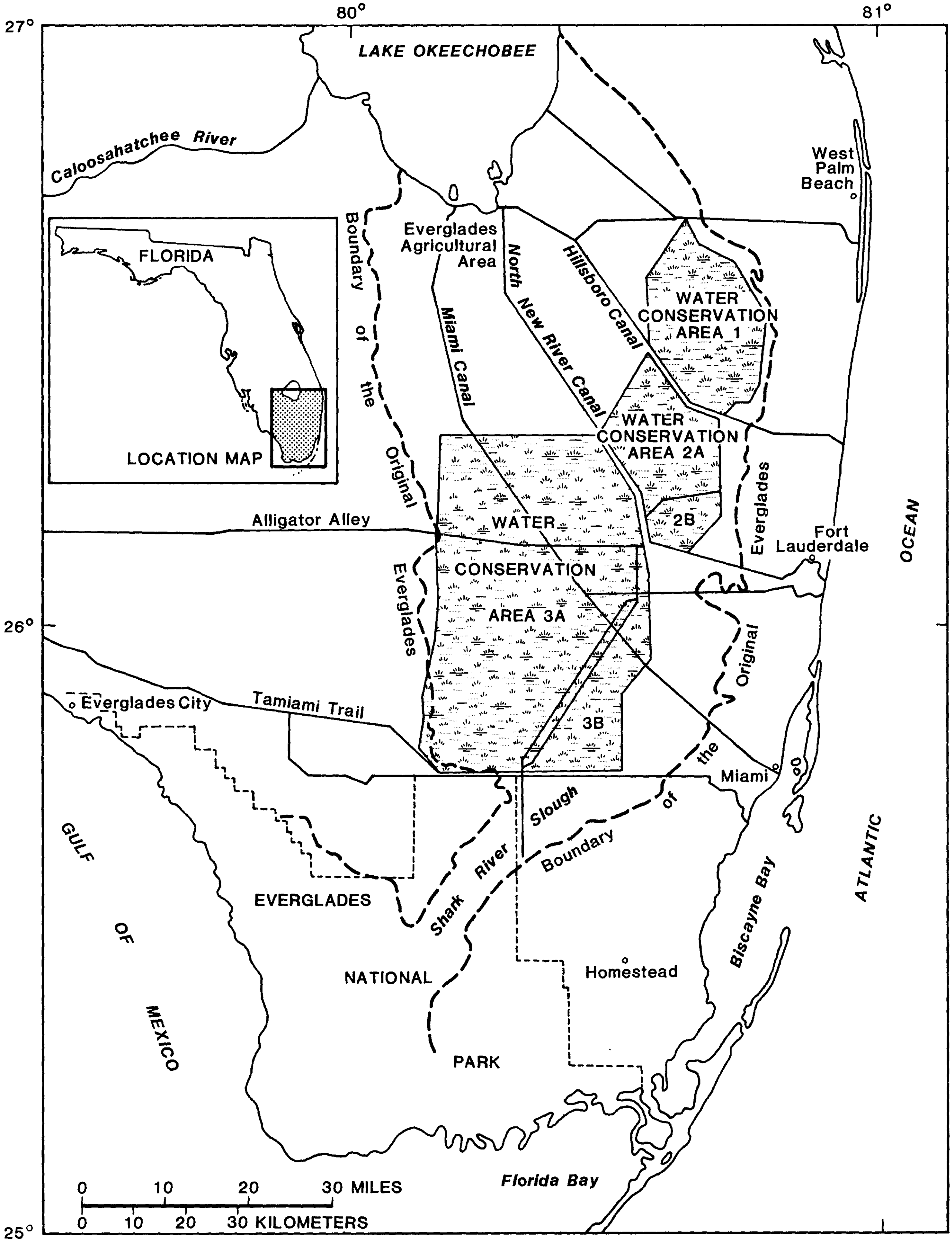

Figure 1.—The locations of the five Water Conservation Areas and Shark River Slough.

Engineers and a minimum monthly surface-water delivery schedule mandated by the U.S. Congress in 1970 (Public Law 91–282). Concurrently, Senate Report No. 91–895 charged the U.S. Army Corps of Engineers and the National Park Service with establishing water-quality requirements for maintaining the environment of the Everglades National Park. The water-quality standards for the released water were based on an upper control chart limit that reflected the true mean concentration, standard deviation, and sampling frequency (Rosendahl and Rose, 1979) for samples collected between 1970 and 1978 at S–12C and L–67A. The true mean is calculated from the arithmetic mean with an assumption of a normal concentration distribution (Bowker and Liberman, 1972). In 1979, the U.S. Army Corps of Engineers began water-quality monitoring near three inflow structures to the Everglades National Park to assure that water of acceptable quality was being delivered to the park. Water-quality information at five inflow structures that supply WCA–3A were not part of the formal agreement but were included in the U.S. Army Corps of Engineers' monitoring program.

Concentrations of water-quality constituents could be below the standards established in 1979 but show an upward concentration trend that would indicate a probable future exceedance. Recognition of constituent trend increases would be useful in identifying sources and proposing mitigation solutions prior to significant ecological damage. In an attempt to evaluate any statistically significant time trends in water quality, the National Park Service and the U.S. Geological Survey evaluated the water-quality data base used by the U.S. Army Corps of Engineers. Because of the data-collection frequency of four times per year, the U.S. Army Corps of Engineers and Everglades National Park agreed that evaluation of a semimonthly data set used by the South Florida Water Management District would be more appropriate for testing the application of trend analysis to water quality. Equally important to the trend evaluation were the existence of discharge and rainfall data bases stored in the computer by South Florida Water Management District.

Purpose and Scope

The purpose of this report is to present a description of the methods and results of a time-trend analysis of water-quality data from 10 water flow structures around WCA–3A (fig. 2). Another purpose is to consider the applicability of this type of trend analysis to the current monitoring program as defined by the 1979 Memorandum of Agreement between the National Park Service, South Florida Water Management District, and the U.S. Army Corps of Engineers (Supplementary Data I). The test for trend used in this analysis is the Seasonal Kendall test (Hirsch and others, 1982). Specific conductance (COND) and concentrations of orthophosphate (PO_4), nitrate-nitrogen (NO_3), total Kjeldahl nitrogen (TKN), and total nitrogen (TN) were tested for trends over the 5-year period 1978 through 1982. Many of the 10 flow structures tested had 24 samples per year.

The time-trend analysis included regression models that relate water-quality constituents and antecedent rainfall history for the 10 flow structures. Where the r-squared value indicated a regression relation representing greater than 5 percent of the concentration variation, the model residuals were tested for trend. Relations between antecedent discharge history and water-quality constituents also were defined by multiple regression models. Residuals from discharge-based regression models were not evaluated for trend because of flow control changes within the 5-year period.

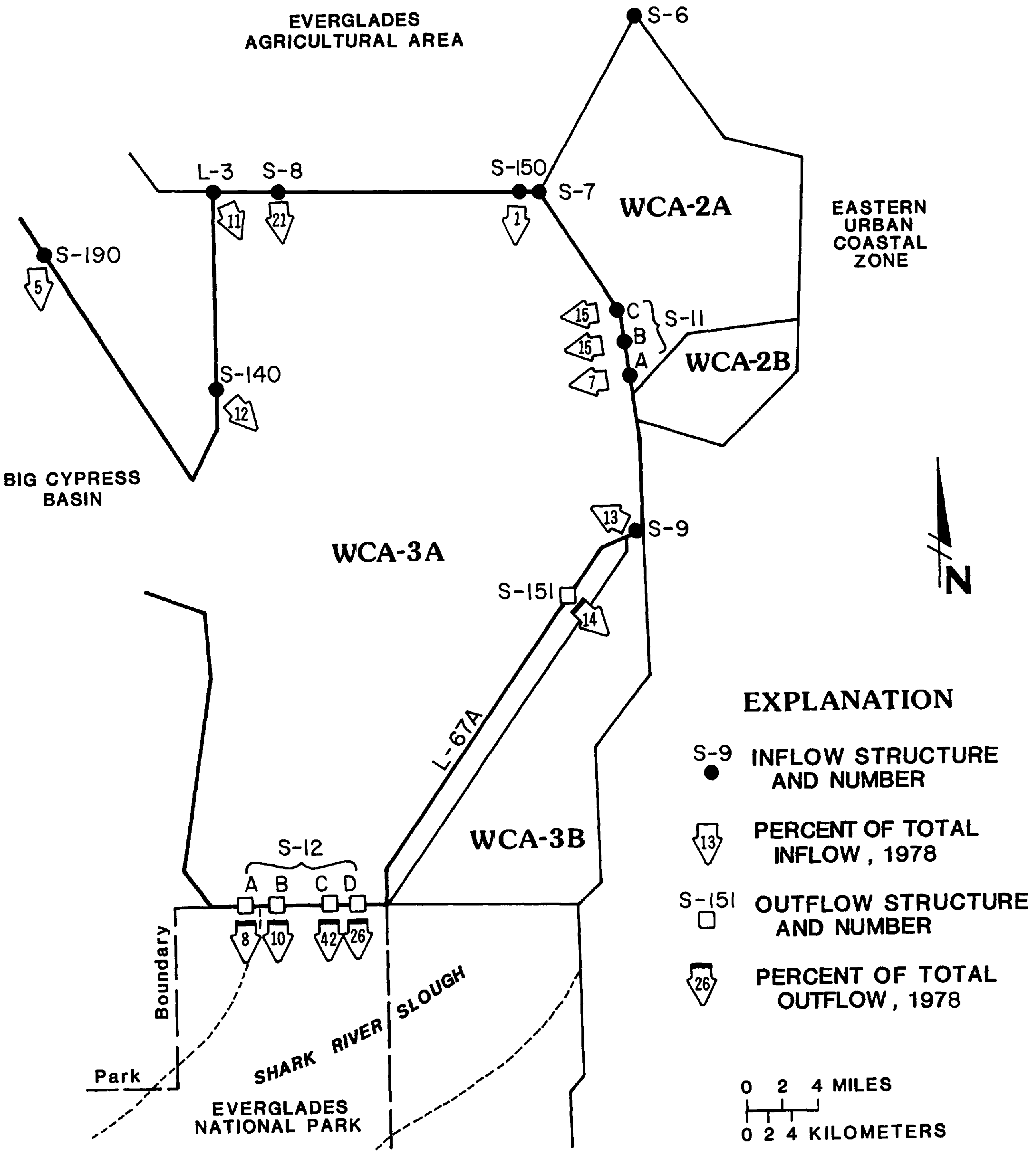

Figure 2.—The locations of the major inflow and outflow structures of Water Conservation Area 3A, and percentage of total flow for 1978.

Background

The watershed of WCA-3A includes a variety of land-use types. From west to east there is a general progression from relatively undisturbed land near inflow structure S-190 (fig. 2), to extensive agricultural usage near inflow structure S-8, to more urban areas near inflow structure S-9. The proportion of total surface inflow or outflow at each structure for 1978 is depicted in figure 2, but the actual discharge is seasonal and varies annually on the basis of management decisions and rainfall. Total minimum discharge (260,000 acre-feet per year) through the four S-12 outflow gates on the south end of WCA-3A was guaranteed by congressional mandate (Public Law 91-282) until 1983, but could vary considerably among the four S-12 gates. South Florida Water Management District records for 1978 indicate the following inflow and outflow from WCA-3A, in acre-feet.

Inflow (in acre-feet)		Outflow (in acre-feet)	
S-8	260,163	S-151	90,543
S-9	157,719	S-12A	54,590
S-140	147,381	S-12B	64,714
S-150	14,281	S-12C	271,878
S-190	66,451	S-12D	168,807
L-3	140,677	Outflow	650,532
S-11A	86,364	Evapotranspiration	2,169,360
S-11B	188,766		
S-11C	180,322	Total out	2,819,892
Inflow	1,242,124		
Rainfall	1,629,749		
Total in	2,871,873		

The largest source of inflow to WCA-3A is rainfall (approximately 50 to 80 percent), and the largest source of outflow for the 786-square-mile marsh is evapotranspiration (approximately 70 percent, or 2 million acre-feet). The mean residence time of water is 0.81 year for the shallow (ranging from dry to 2 feet, 6 inches) marsh. Because of the physical characteristics of WCA-3A, nitrogen and phosphorus are readily incorporated into marsh vegetation and are largely retained in the conservation area (74 and 96 percent, respectively) (Federico and others, in press).

The rainfall pattern over Water Conservation Area 3A varies seasonally with a 44.27-inch per year, 30-year moving average for the period 1952 through 1981 (Lin and others, 1984). The rainfall for the years 1978 through 1982 was 88, 83, 95, 106, and 121 percent of normal, respectively. This generally increasing rainfall component of the total inflow may affect water-quality concentration by dilution or by acting as a source for specific constituents.

The general annual rainfall pattern is highly seasonal with numerous examples of seasonal effects on concentration (Waller and Earle, 1975). Water-quality concentrations are serially dependent and the Seasonal Kendall test for trend was chosen in an attempt to employ a statistical technique that eliminates the effects of serial correlation.

An implicit assumption in the overall analysis is that the probability distribution of rainfall or discharge is unchanged through the 5-year evaluation period. A conscious change in flow causes predicted values early or late in an evaluation period to be consistently higher or lower than observed values. Any water-quality model constructed as a function of discharge may inadvertently produce an apparent trend that is a result of flow control. The regression model produces a set of concentration residuals generally higher or lower than warranted; this causes an apparent trend because of the change in water management. In 1983, the National Park Service, the U.S. Army Corps of Engineers, and the South Florida Water Management District agreed to a continuous flow policy for water entering Shark River Slough. This anticipated policy change is reflected in figure 3, which is a plot of the 30-day cumulative rainfall and discharge at outflow structure S-12A for the 1978-82 evaluation period. The last 6 months of 1982 show a definite increase of discharge over rainfall compared to previous years. Other examples of discharge pattern shifts appear throughout the period of record at all 10 flow structures. Therefore, regression models based on discharge, although constructed, were not considered in determining trends in model residuals.

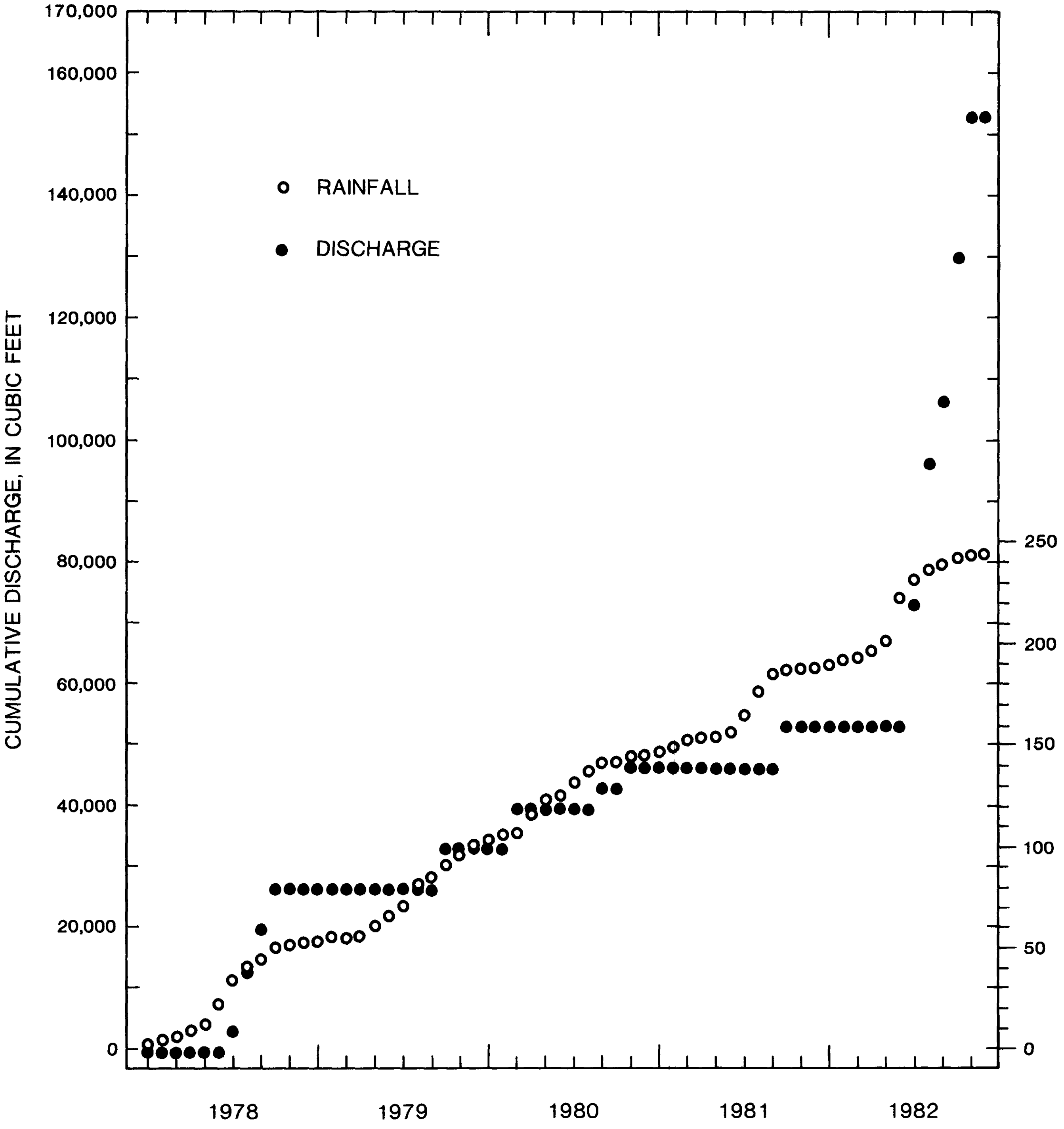

Figure 3.—Thirty-day cumulative discharge and rainfall at structure S-12A.

DATA PROCESSING AND ANALYSIS

Parts of three data sets (water quality, discharge, and rainfall) were retrieved from the South Florida Water Management District computer onto a magnetic tape and loaded onto a U.S. Geological Survey PR1ME[1] computer located in Tampa, Fla. These data sets were edited and transferred to the Amdahl computer in Reston, Va., which had a Statistical Analysis System (SAS) library. Additional editing, merging, model construction, and trend analyses were performed with SAS format routines run in batch mode from the Tampa PR1ME. Figure 4 summarizes the major steps in reformatting the South Florida Water Management District data sets and for performing the statistical analyses.

Water-Quality Data

The water-quality data set (WCAQW) contained 22,242 card images representing 3,707 water-quality analyses, from the 10 flow structures, for the period 1978 through 1982. Each analysis was represented by the six-card format listed in Supplementary Data II. A sample code type was included on card six and provided the main mechanism for deleting samples that were related to quality assurance (replicates) and special collection techniques (flow-weighted sampling, bottom samples, and others). The number of samples retained for analysis at the 10 flow structures from the WCAQW water-quality set are listed in table 1. Inflow structures S–150, S–11A and C, and outflow structures S–12B and C were excluded from the analyses. Entries into the computer for samples that were collected twice monthly by standard grab-sample methods were retained for transfer to the Amdahl computer in Reston, Va. The program transferring the edited data files is termed IEBGENER (fig. 4).

Discharge Data Base

Daily discharge, in cubic feet per second, for the 10 flow structures was represented by 1,810 card images that had three cards per month. The day of the month was implicit in the column of the card. An example of the format is shown in Supplementary Data II. The 5-year period at a structure would be represented by 180 card images. Each file was reviewed for missing and duplicate records, corrected, and then transferred to an Amdahl computer in Reston, Va. A program was used to reassemble a discharge data file (for example, QS7 in fig. 4) that contained an explicit date. A listing of this program (TRANSPOSE) is given in Supplementary Data III.

Rainfall Data Base

The South Florida Water Management District rainfall data files employed the same format of three cards per month, implicit day, format used for the discharge data files. The 33 rainfall collection stations in the proximity of the 10 flow structures are shown in figure 5. All records had some missing data for the 5-year period. Table 2 lists the 10 flow structures and identifies the rainfall stations that are most representative of each structure. Parts of adjacent rainfall records were spliced into the primary rainfall station records to complete a continuous record at each rainfall station near the 10 flow structures. Imbedded in the rainfall records were seven alpha remark codes that indicated missing or accumulated rainfall data. After editing, the remark codes were deleted, and the file transferred to the Amdahl and TRANSPOSED (fig. 4).

[1]Use of brand, firm, or trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

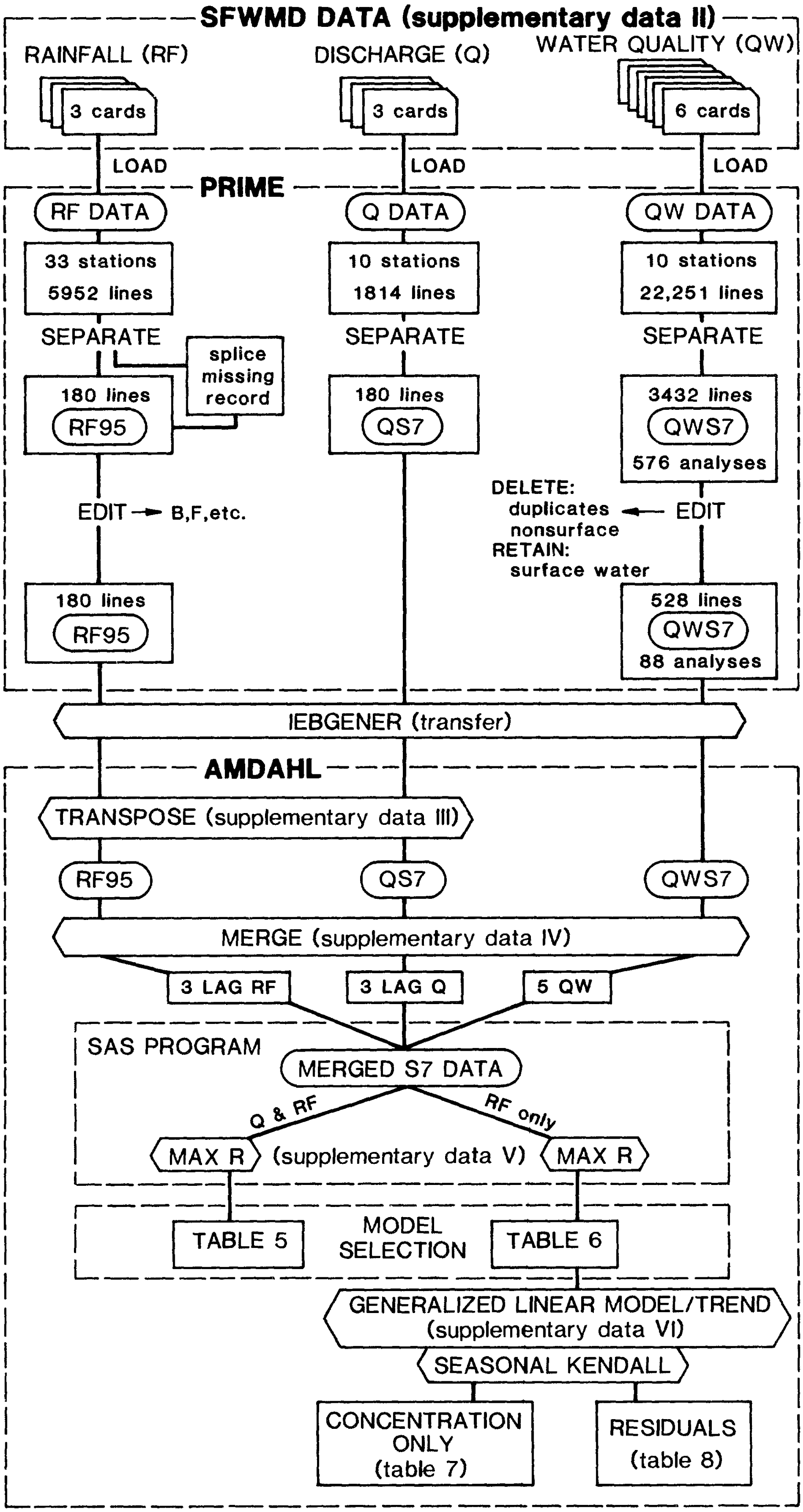

Figure 4.—Schematic diagram of major data-processing steps in the time-trend analysis.

Table 1.—Sample collection location descriptions, total number of water-quality samples, and number suitable for trend analysis

[SFWMD = South Florida Water Management District]

Sample collection location (flow structure)	Total number of samples in SFWMD data base	Number of samples suitable for trend analysis	Sample collection location description
S-190	375	89	Discharge from S-190 in C-28 canal under State Road 84 bridge.
L-3	97	85	L-3 canal near the Deer Fence Canal bridge.
S-8	124	62	S-8 structure pumps water from the Everglades agricultural area into the Miami Canal. Upstream sample site.
S-140	418	101	S-140 pumping station near State Road 84. Upstream sample site.
S-7	571	88	S-7 pump station along State Road 27 that discharges to WCA-2A. Upstream sample site.
S-11B	124	62	Gate structure on U.S. Highway 27 that releases water from WCA-2A to WCA-3A. Upstream sample site.
S-9	502	108	S-9 pumps water into WCA-3A near U.S. Highway 27. Upstream sample site.
S-151	326	96	Gate structure on the Miami Canal that releases water from WCA-3A to WCA-3B. Upstream sample site.
S-12D	376	116	Easternmost S-12 gate structure at U.S. Highway 41 that releases water from WCA-3A into the Shark River Slough. Upstream sample site.
S-12A	309	90	Westernmost S-12 gate at U.S. Highway 41 structure that releases water from WCA-3A into marshes and prairies of Everglades National Park. Upstream sample site.

Constituent Selection and Merging of Data Files

The water-quality, discharge, and rainfall data files were stored on the Amdahl. The water-quality file contained 37 constituents in the format shown in Supplementary Data II. The five constituents (COND, PO_4, NO_3, TKN, and TN) were selected from statistical summaries of 37 constituents at the 10 flow structures. The South Florida Water Management District and Everglades National Park selected these five as being representative of many other constituents or having particular ecological significance. Specific conductance was selected because it integrates all the dissolved charged chemical constituents. Previous work (Flora and Rosendahl, 1981) has shown significant relations between specific conductance and most of the major cations and anions in water in The Everglades. Specific conductance also may be used as an indicator of the origin of water (that is, canal, marsh, or precipitation). Nitrogen and phosphorus are important to the types of plant growth in the marsh ecosystem (Swift, 1981). The general pattern of specific conductance, orthophosphate, and nitrate can be seen in figures 6 through 8, which show the 5-year mean concentrations at the 10 flow structures. Elevated concentrations of nitrogen and phosphorus and elevated specific conductance are related to agricultural activities in the Everglades Agricultural Area (fig. 2).

Table 2.—Ten flow structures and most representative rainfall-collection stations

Flow structure	Rainfall-collection station
S-190	RF145
L-3	RF182
S-8	RF98
S-140	RF145
S-7	RF99
S-11B	RF106
S-9	RF115
S-151	RF115
S-12D	RF6054
S-12A	RF6054

Water quality, discharge, and rainfall were merged into a single SAS data set (for example, MS7 in fig. 4) on the basis of water-quality sample date. An important feature of the MERGE program is the creation of three antecedent conditions for discharge and rainfall. The MERGE program is listed in Supplementary Data IV. The three cumulative antecedent periods chosen were for 7, 14, and 30 days prior to the sample date.

Model Selection with Stepwise Regression

The cumulative antecedent discharge or rainfall are the independent variables used to construct regression models for the water-quality dependent variables. Both the independent and the dependent variables can be transformed into a variety of complex functions. The simplest relation is linear concentration versus linear independent variable. Table 3 shows the matrix of simple relations tested.

Table 3.—Combinations of mathematical transformations used in model construction

Water-quality constituent form	Independent variables (rainfall and discharge)			
	Linear	Inverse	Log	Quadratic
Linear	X	X	X	X
Log	X	X	X	

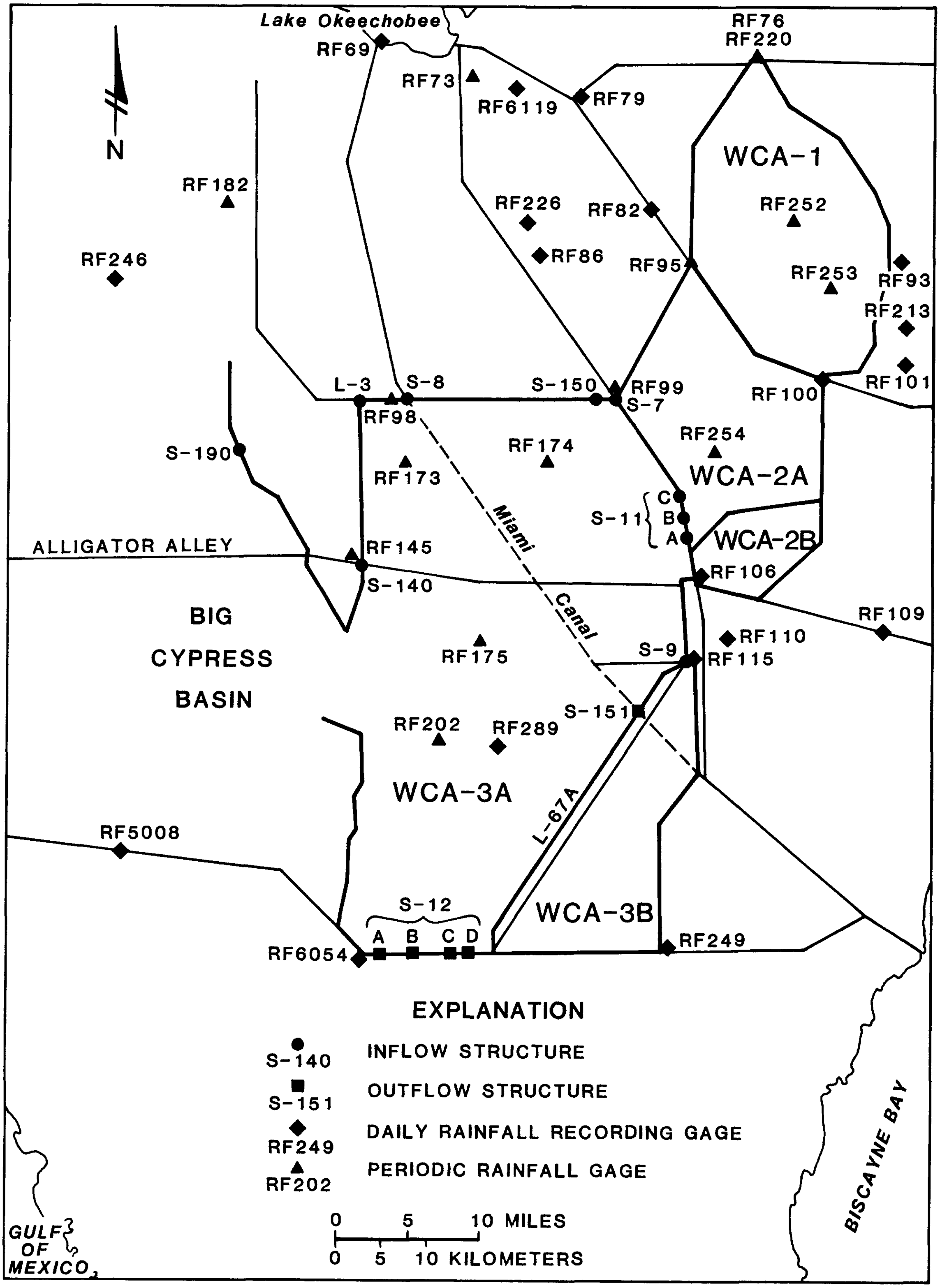

Figure 5.—The locations of the 33 rainfall collection stations near Water Conservation Area 3A.

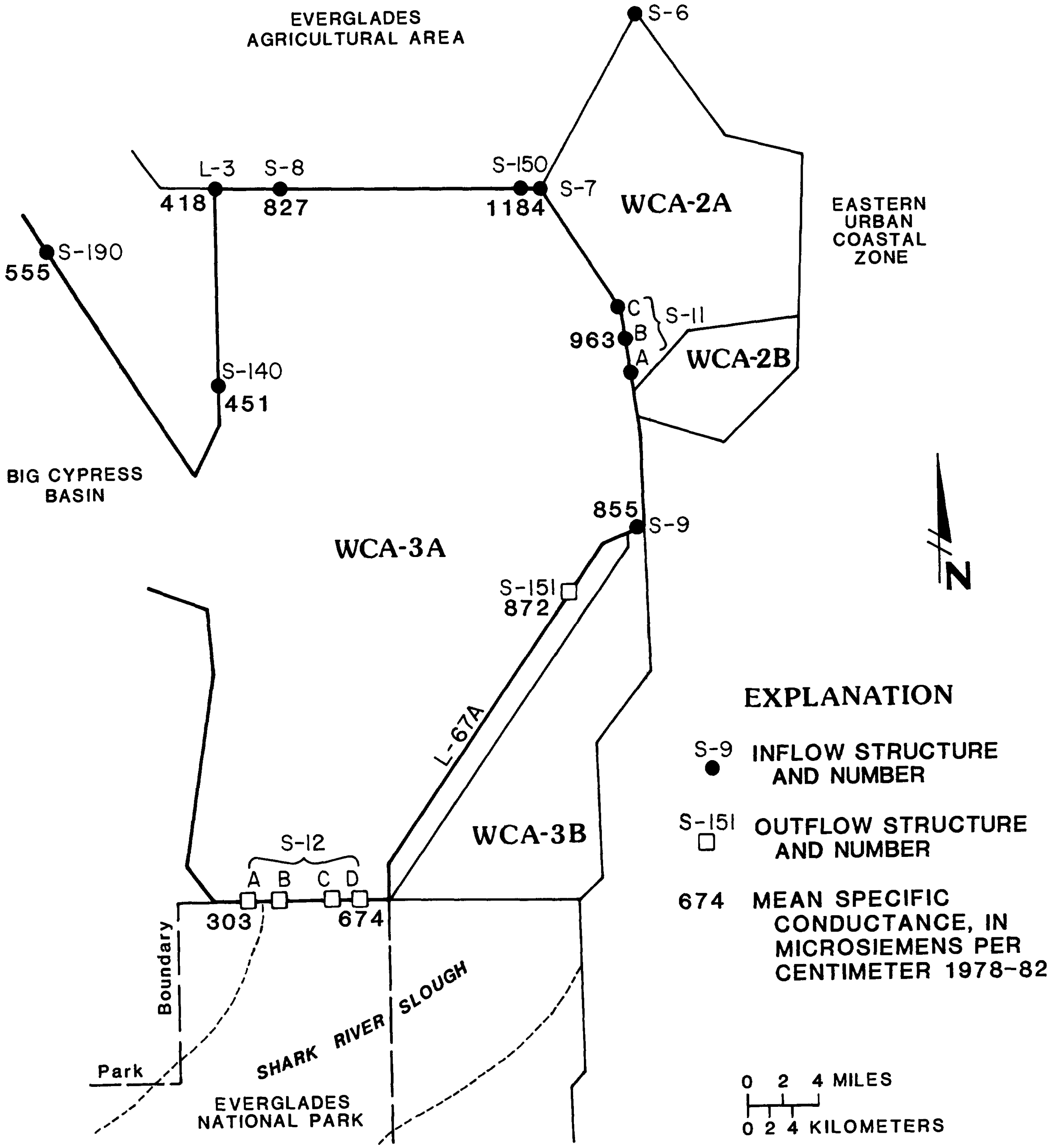

Figure 6.—Mean specific conductance at the 10 flow structures.

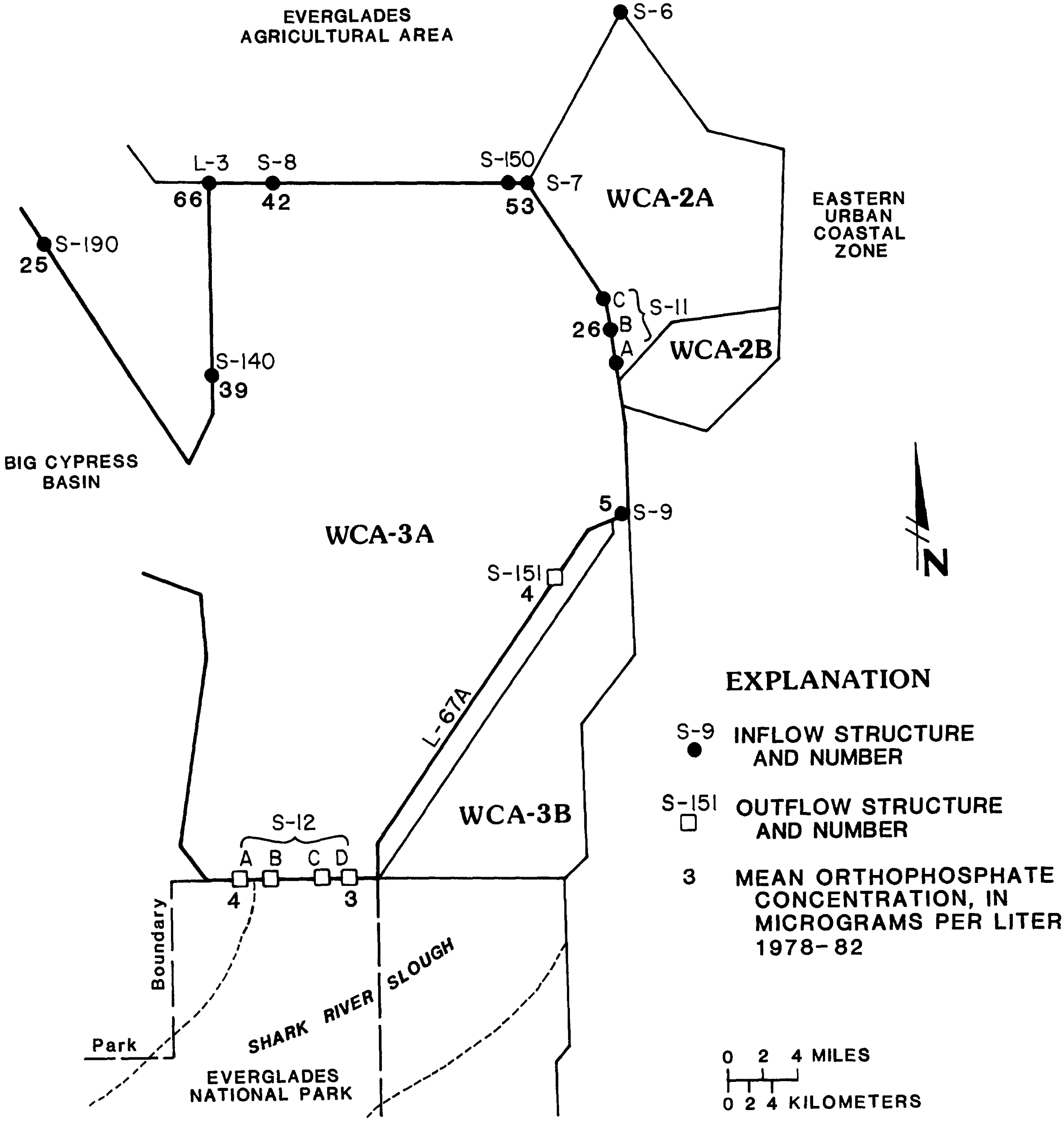

Figure 7.—Mean orthophosphate concentration at the 10 flow structures.

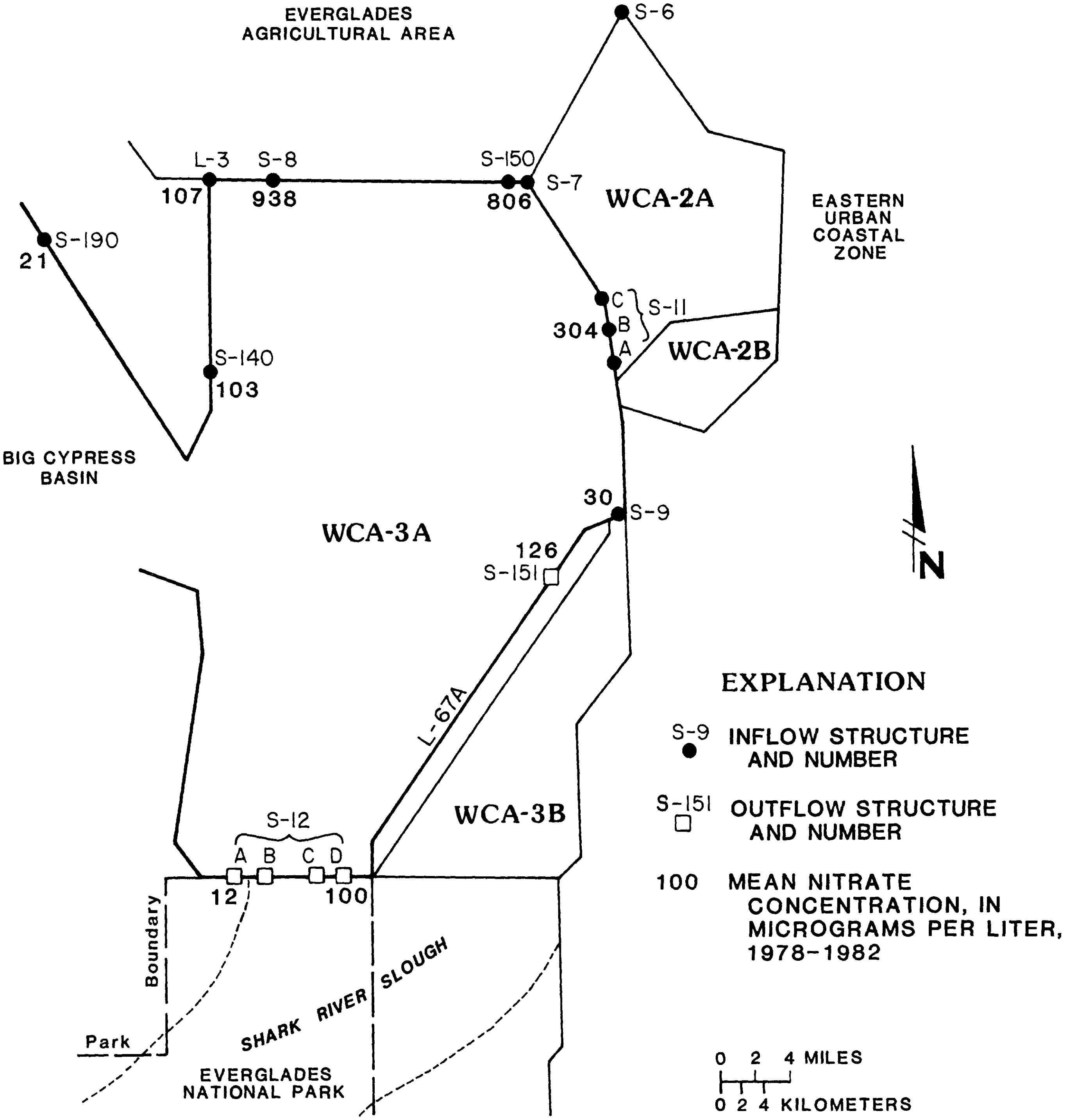

Figure 8.—Mean nitrate concentration at the 10 flow structures.

The linear equation for orthophosphate-phosphorus (PO_4) at inflow structure L-3 would have the form:

$$(PO_4) = 0.0222(RF30T) - 0.034 \quad (1)$$

where:

(PO_4) is orthophosphate-phosphorus concentration, in milligrams per liter,

(PO_4) $\geq$ 0.004 (the detection limit), and

RF30T is antecedent 30-day cumulative rainfall, in inches.

The equation, for example, would predict a concentration of 0.188 mg/L (milligrams per liter) for 10 inches of rainfall in the previous 30 days (RF30T = 10). The relation had an r-squared value of 0.63, which means that 63 percent of the observed PO_4 concentration variation is explained by this simple relation between 30-day antecedent rainfall and orthophosphate concentration. Each water-quality constituent at each structure had both a linear and log-transformed concentration regression model that had three or more forms of the independent rainfall and discharge variables (table 3). The water-quality constituent model for a particular site was the best single relation from 42 variations of concentration, rainfall, or discharge transformations. There are 50 final models representing the best stepwise regression model selected for each of the five water-quality constituents at each of the 10 flow structures.

An example of the type of stepwise regression program that was used to select the best independent variable (MAXR) is listed in Supplementary Data V. The approach is to allow the best single variable with the maximum r-squared value to be selected from the available independent variables.

Model Output with General Linear Models

The SAS stepwise model construction (MAXR) was used to find the single best independent variable. When this variable is defined, model construction is repeated with GLM (GLM is the SAS acronym for General Linear Models (Helwig and Council, 1979)) using only the best independent variable. The GLM program contains provisions for retaining predicted and residual values as output (Supplementary Data VI). A residual is the difference between the observed concentration and the concentration predicted by the model. In each case, a graph of residuals versus predicted concentrations was plotted to eliminate model output that had obvious patterns. Three major patterns in the residuals plot may occur (Daniel and Wood, 1971):

1. Pronounced departure of the residuals related to the size of the predicted value; this is usually wedge shaped.
2. A U-shaped pattern that indicates a curvilinear model relation would produce a better representation of the data.
3. A plot that indicates clustering of predicted values; high or low values (outliers) offset from the cluster may have an unwarranted effect on the slope of predictive equation.

Figure 9 is a plot of PO_4 residuals from the model based on RF30T versus predicted concentrations for structure L-3, whereas figure 10 is a plot of PO_4 residuals from the Log (PO_4) = 0.001 (RSQ30) + 0.016 regression model.

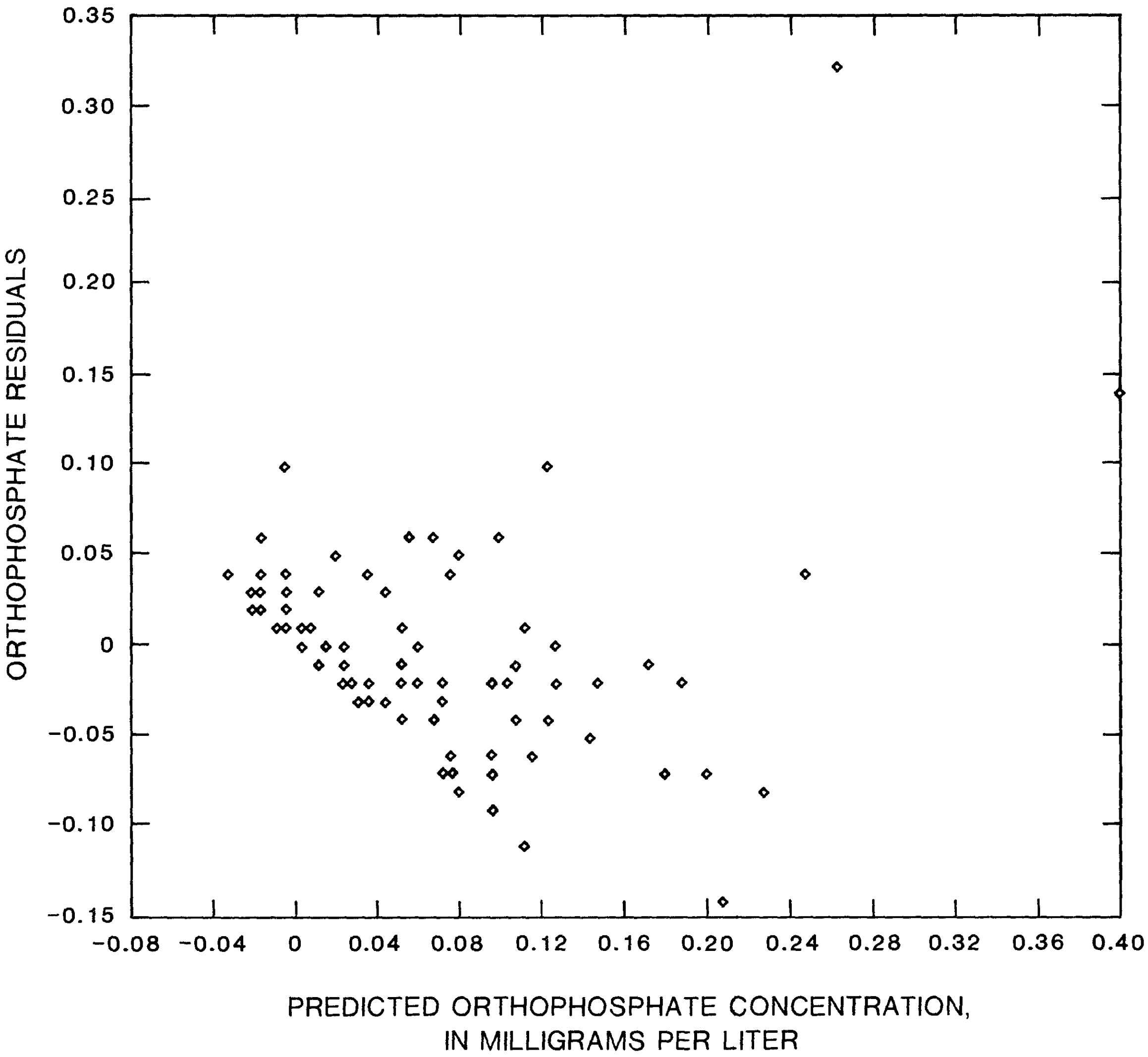

Figure 9.—Orthophosphate residuals from the model based on 30-day antecedent precipitation (RF30T) at site RF182 versus predicted concentrations for inflow structure L-3.

Deletion of an observed value from a data set based on residual patterns can improve a model relation. Unfortunately, removal of an observed value may also remove the most important observation in terms of recognizing cause and effect relations (for example, fig. 10). Five models were adjusted by observation deletion in order to permit expansion of the residual cluster and avoid an unwarranted effect on the prediction equation. The 30 residual plots for the highest r-squared regression models greater than r-squared = 0.05 are shown in Supplementary Data VII. Indicated on table 4 are the 5 models that had subsequent observation deletion and the 13 regression models that were rejected because of a residual pattern. A regression model with another form was substituted for a rejected model if it met the r-squared criteria of greater than 0.05.

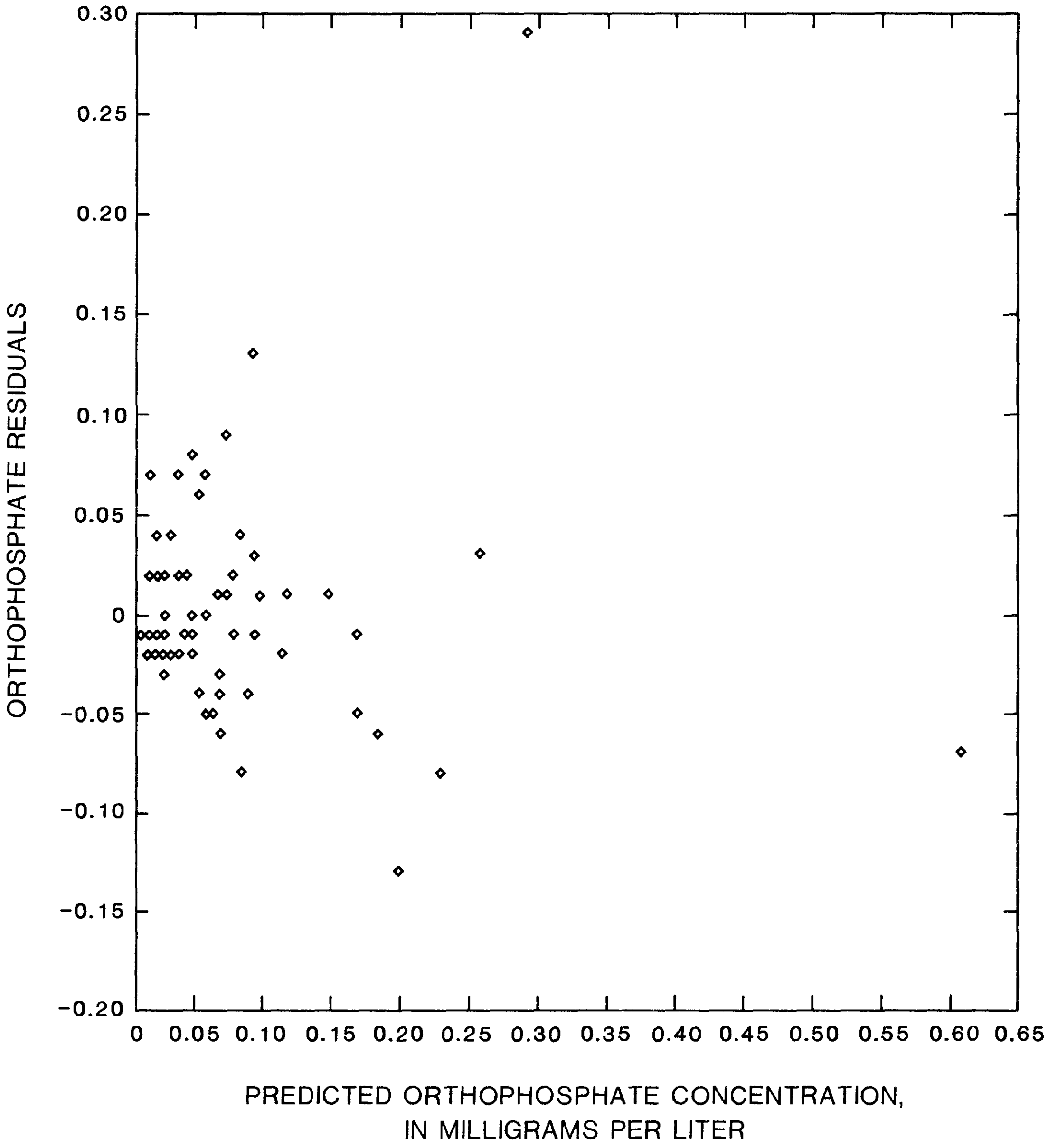

Figure 10.—Orthophosphate residuals from the quadratic model based on the square of 30-day antecedent precipitation (RSQ30) at site RF 182 versus predicted concentrations for inflow structure L-3.

Seasonal Kendall Test

The second major feature of GLM residuals is to permit output directly into the Seasonal Kendall test (Hirsch and others, 1982). Observed concentrations for 50 structure-constituent combinations and 29 model residuals were tested for time trend.

Table 4.—Water quality-rainfall regression model equations for Water Conservation Area 3A

Structure	Quality variable (y)	Model coefficient (m)	Rainfall variable (x)	Y-axis intercept (b)	r^2	Acceptance problem	Substitute
S-190	LNCOND	-0.034	RF30	6.446	0.3904		
S-190	PO4	.002	RSQ14	.004	.4836	Residuals	No
S-190	TKN	.035	INVRF30	1.438	.0534		
S-190	TN	.036	INVRF30	1.461	.0536		
L-3	LNCOND	-.058	RF30	6.263	.5690		
L-3	PO4	.001	RSQ30	.016	.7216	Residuals	Yes
L-3-Rerun	LNPO4	.028	RF30	-4.815	.4758		
L-3	LNTN	-.052	INVRF30	.711	.0525	Outliers	No
S-8	COND	-.826	RSQ30	869.003	.0648	Residuals	Yes
S-8-Rerun	COND	-21.94	RF14	886.519	.0588		
S-8	LNPO4	.198	RF30	-5.418	.3593	Residuals	No
S-8	NO3	.065	RSQ7	.565	.4563	Residuals	No
S-8	LNTKN	.061	LNRF14	.888	.0894		
S-8	TN	.530	RF7	2.803	.3545		
S-140	LNCOND	-.032	RF30	6.232	.3794		
S-140	PO4	.002	RSQ14	.020	.3815	Residuals	No
S-7	COND	-3.139	RSQ7	1,198.537	.1332	Outliers	No
S-7	PO4	.002	RSQ7	.034	.6230	Residuals	No
S-7	NO3	.361	RF7	.327	.5361	Residuals	Yes
S-7-Rerun	LNNO3	-.034	RF7	7.093	.2476		
S-7	TKN	.092	RF7	2.635	.0593	Residuals	No
S-7	TN	.462	RF7	3.011	.3703		
S-11B	LNCOND	-.068	RF7	6.950	.456	Outliers	Yes
S-11B-Rerun	LNCOND	-.056	RF7	6.939	.1157		
S-11B	PO4	.002	RSQ7	.001	.9570	Residuals	No
S-11B	NO3	.021	RSQ7	.102	.7403	Residuals	No
S-11B	TN	.021	RSQ7	2.627	.3698		
S-9	LNCOND	-.034	RF7	6.776	.3600	Outlier	Yes
S-9-Rerun	LNCOND	-.027	RF7	6.771	.1010		
S-9	PO4	.000	RSQ7	.004	.8801		
S-9	NO3	.025	RF7	.007	.5407	Residuals	No
S-151	PO4	9.275	RSQ14	.005	.0573		
S-12D	COND	-2.260	RSQ14	691.819	.0887	Outliers	No
S-12D	PO4	.000	RF14	.003	.0543	Residual	No
S-12A	COND	-23.318	LNRF30	326.734	.1121		

The Seasonal Kendall test is a nonparametric trend test based on Kendall's Tau test (Kendall, 1975). The seasonal provision permits comparison of data pairs from the same season (Supplementary Data VI). Season = 6 causes the median concentration from January and February 1978 to be compared (higher or lower) with January and February 1979. Other season = 6 time periods are March–April, May–June, July–August, September–October, and November–December. Adjacent time periods (pairs, for example, 1978–79, 1979–80, and so forth) are compared, and the number of intervals (nvals) would be 24 for a 5-year time span with 1 or more concentrations recorded for each 2-month segment. An increase between a pair is recorded as a plus (concordant) and a decrease as a minus (discordant). The differences between the plus and minus pairs are tested for significance (p-level). The Seasonal Kendall test has an additional provision to calculate a slope based on the statistical distribution of the concordant pairs (Hirsh and others, 1982).

RESULTS

Evaluation with Rainfall and Discharge Stepwise Models

The initial model construction phase permitted a choice of three rainfall and three discharge independent variables. The linear, log, and inverse functions listed in table 3 were evaluated. The initial stepwise analysis of water quality included discharge as an independent variable, and the results are presented in table 5. Discharge entered the stepwise regression in 13 cases of 50 possible constituent-structure cases. Rainfall had the highest r-squared for 24 cases. The remaining 13 cases lacked significance; they had an r-squared less than 0.05.

Evaluation with Rainfall Stepwise Model

With the elimination of discharge as a possible independent variable, MAXR was revised to simultaneously evaluate linear, log, and inverse forms of rainfall history. An additional modification was the program statement setting all PO_4 concentrations less than 0.004 to 0.004 mg/L. The reported detection limit for PO_4 was raised from 0.002 to 0.004 during the study period. This reporting change of the higher detection limit resulted in apparent significant PO_4-trend increases at several structures. Supplementary Data V lists the SAS program used for evaluating the linear and log concentration versus the three transformations of antecedent cumulative rainfall (linear, log, and inverse).

An additional set of rainfall transformations was entertained with a simple quadratic model: RSQ30 = RF30T x RF30T. The r-squared comparison of the three evaluations is listed in table 6. The addition of the quadratic rainfall, independent variable, resulted in 14 models with a greater r-squared value than the other 6 independent rainfall variable forms evaluated by linear and log concentrations. An arbitrary level of 0.05 for r-squared was used as the lower limit for an acceptable concentration-rainfall model. Using this criteria, 20 of 50 water-quality-structure combinations had r-squared values less 0.05. This means that 20 water-quality-structure combinations failed to show a relation with 21 possible antecedent rainfall model choices (table 3).

Table 5.—Correlation coefficients for discharge and rainfall water-quality models for Water Conservation Area 3A

[Best model r-squared is underlined if greater than 0.05; (N) = not significant]

Station name	Dependent variable (y)	Linear-Linear (y = mx + b) Independent variable (x)	r-square	Linear-Inverse (y = m/x + b) Independent variable (1/x)	r-square	Linear-Log (y = m(lnx) + b) Independent variable (lnx)	r-square	Log-Linear (Lny = mx + b) Independent variable (x)	r-square
S-190	COND	RF30T	0.3642	INVQ30	0.1174	LNRF30	0.1848	RF30T	0.3904
S-190	PO4	RF14T	.2721	INVQ7	.0440	LNQ7	.1123	Q7T	.3577
S-190	NO3	Q30T	.0716	INVRF30	.0334	LNQ30	.1026	Q30T	.1005
S-190	TKN	Q30T	.0314	INVRF30	.1225	LNRF30	.0294	Q7T	.0412
S-190	TN	Q30T	.0372	INVRF30	.1267	LNRF30	.0292	Q7T	.0406
L-3	COND	RF30T	.4878	INVRF30	.2541	LNRF30	.4406	RF30T	.5690
L-3	PO4	RF30T	.6341	INVRF30	.1430	LNRF30	.3641	RF30T	.4378
L-3	NO3 (N)	Q30T	.0289	INVQ7	.0229	LNQ14	.0337	Q30T	.0150
L-3	TKN	Q30T	.0224	INVQ14	.0699	LNQ30	.0581	Q30T	.0353
L-3	TN	Q30T	.0477	INVQ14	.0801	LNQ30	.0877	Q30T	.0542
S-8	COND	Q14T	.1200	INVRF14	.0649	LNRF14	.1130	Q14T	.1420
S-8	PO4	RF30T	.2990	INVRF7	.0410	LNRF30	.1720	Q7T	.3528
S-8	NO3	RF7T	.3989	INVQ7	.0516	LNRF7	.1887	Q7T	.1348
S-8	TKN	RF7T	.0572	INVQ7	.0723	LNQ7	.1138	RF7T	.0876
S-8	TN	RF7T	.3123	INVQ7	.0874	LNRF7	.2020	RF7T	.2485
S-140	COND	Q7T	.3802	INVQ7	.0135	LNQ14	.2788	Q7T	.4312
S-140	PO4	Q7T	.4984	INVQ7	.0336	LNQ7	.2333	Q7T	.4492
S-140	NO3 (N)	RF30T	.0062	INVQ7	.0030	LNQ7	.0092	RF30T	.0309
S-140	TKN (N)	RF30T	.0063	INVQ30	.0359	LNQ30	.0192	RF30T	.0289
S-140	TN (N)	Q7T	.0032	INVQ30	.0309	LNQ30	.0218	Q7T	.0176
S-7	COND	RF7T	.0771	INVQ14	.0289	LNQ14	.0265	RF7T	.1169
S-7	PO4	RF7T	.5522	INVRF7	.0318	LNRF14	.2120	RF14T	.2705
S-7	NO3	RF7T	.5346	INVRF7	.0382	LNRF7	.2379	Q7T	.3036
S-7	TKN	Q7T	.0861	INVQ30	.0388	LNRF7	.0538	Q7T	.0938
S-7	TN	RF7T	.3682	INVRF7	.0436	LNRF7	.2001	Q7T	.2573
S-11B	COND	RF7T	.4043	INVRF14	.0771	LNRF14	.2484	RF7T	.4570
S-11B	PO4	RF7T	.7756	INVQ30	.1580	LNRF7	.1929	RF7T	.4311
S-11B	NO3	RF7T	.6061	INVQ30	.2291	LNQ30	.2054	RF7T	.2154
S-11B	TKN	RF30T	.0383	INVRF30	.0513	LNRF30	.0662	RF30T	.0398
S-11B	TN	RF7T	.2436	INVQ30	.2015	LNQ30	.1952	RF7T	.1382
S-9	COND	RF7T	.2902	INVQ14	.0958	LNQ7	.1735	RF7T	.3609
S-9	PO4	RF7T	.5438	INVQ7	.0024	LNRF7	.0521	RF7T	.0969
S-9	NO3	RF7T	.5445	INVQ7	.0513	LNRF7	.2308	RF7T	.2724
S-9	TKN	Q30T	.0481	INVQ30	.0019	LNRF30	.0712	Q30T	.0448
S-9	TN	Q30T	.0397	INVQ7	.0036	LNRF30	.0544	Q30T	.0348
S-151	COND	Q30T	.0502	INVRF14	.0261	LNQ30	.0262	Q30T	.0475
S-151	PO4 (N)	RF14T	.0391	INVQ30	.0451	LNQ30	.0198	RF14T	.0256
S-151	NO3 (N)	Q30T	.0117	INVQ7	.0083	LNRF7	.0036	Q30T	.0387
S-151	TKN (N)	RF7T	.0206	INVRF14	.0299	LNRF7	.0030	RF7T	.0131
S-151	TN (N)	RF7T	.0105	INVRF14	.0256	LNQ7	.0014	RF7T	.0061
S-12D	COND	RF7T	.0584	INVRF14	.0232	LNRF30	.0225	RF7T	.0682
S-12D	PO4	RF14T	.0653	INVQ14	.0162	LNRF14	.0271	RF14T	.0728
S-12D	NO3	Q30T	.0229	INVQ7	.0548	LNQ30	.0542	RF7T	.0061
S-12D	TKN (N)	RF7T	.0178	INVRF14	.0199	LNRF7	.0169	RF14T	.0168
S-12D	TN (N)	RF7T	.0155	INVRF14	.0233	LNRF7	.0154	RF7T	.0123
S-12A	COND	RF14T	.0568	INVRF30	.0184	LNRF30	.0351	RF14T	.0700
S-12A	PO4 (N)	RF14T	.0075	INVRF7	.0167	LNRF7	.0244	Q7T	.0481
S-12A	NO3	Q30T	.0153	INVQ14	.0443	LNQ14	.0507	Q7T	.0535
S-12A	TKN (N)	Q14T	.0366	INVQ14	.0309	LNQ14	.0291	Q14T	.0355
S-12A	TN (N)	Q14T	.0407	INVQ14	.0326	LNQ14	.0310	Q14T	.0422

Table 6.—Correlation coefficients for rainfall water-quality regression models for Water Conservation Area 3A

[Best model r-squared is underlined if greater than 0.05; (N) = not significant]

Structure	Variable (y)	Linear (y = m(x) + b)	r^2	Log (lny = m(x) + b)	r^2	Quadratic (y = m(x^2) + b)	r^2
S-190	COND	RF30T	0.3642	RF30T	0.3904	RSQ30	0.3144
S-190	PO4	RF14T	.2722	RF30T	.2513	RSQ14	.4828
S-190	NO3 (N)	RF7T	.0073	LNRF7	.0126	RSQ30	.0056
S-190	TKN	INVRF30	.0534	INVRF7	.0303	RSQ30	.0031
S-190	TN	INVRF30	.0536	INVRF14	.0293	RSQ30	.0038
L-3	COND	RF30T	.4878	RF30T	.5690	RSQ30	.3803
L-3	PO4	RF30T	.6335	RF30T	.4758	RSQ30	.7216
L-3	NO3 (N)	RF7T	.0148	INVRF30	.0157	RSQ7	.0064
L-3	TKN (N)	INVRF30	.0242	INVRF30	.0471	RSQ30	.0077
L-3	TN	INVRF30	.0252	INVRF30	.0525	RSQ30	.0023
S-8	COND	RF14T	.0588	RF14T	.0560	RSQ30	.0648
S-8	PO4	RF30T	.2972	RF30T	.3593	RSQ30	.3279
S-8	NO3	RF7T	.3990	RF14T	.1228	RSQ7	.4554
S-8	TKN	RF7T	.0573	LNRF14	.0893	RSQ7	.0651
S-8	TN	RF7T	.3124	RF7T	.2484	RSQ7	.3545
S-140	COND	RF30T	.3341	RF30T	.3794	RSQ30	.2683
S-140	PO4	RF30T	.3103	RF30T	.2698	RSQ14	.3803
S-140	NO3 (N)	RF30T	.0062	LNRF30	.0335	RSQ30	.0029
S-140	TKN (N)	RF30T	.0063	RF30T	.0289	RSQ30	.0121
S-140	TN (N)	INVRF7	.0014	RF30T	.0131	RSQ30	.0035
S-7	COND	RF7T	.0773	RF7T	.1172	RSQ7	.1342
S-7	PO4	RF7T	.5536	RF14T	.3106	RSQ7	.6230
S-7	NO3	RF7T	.5346	RF14T	.2445	RSQ7	.5174
S-7	TKN	RF7T	.0569	RF7T	.0493	RSQ7	.0487
S-7	TN	RF7T	.3681	RF7T	.2340	RSQ7	.3436
S-11B	COND	RF7T	.4042	RF7T	.4569	RSQ14	.3734
S-11B	PO4	RF7T	.7773	RF7T	.5214	RSQ7	.9570
S-11B	NO3	RF7T	.6063	RF7T	.2155	RSQ7	.7403
S-11B	TKN (N)	RF30T	.0384	RF30T	.0398	RSQ30	.0410
S-11B	TN	RF7T	.2436	RF7T	.1382	RSQ7	.3698
S-9	COND	RF7T	.2901	RF7T	.3609	RSQ14	.2991
S-9	PO4	RF7T	.5779	RF7T	.2135	RSQ7	.8801
S-9	NO3	RF7T	.5446	RF7T	.2722	RSQ7	.4330
S-9	TKN (N)	RF30T	.0270	RF30T	.0248	RSQ30	.0140
S-9	TN (N)	RF30T	.0145	LNRF30	.0115	RSQ30	.0051
S-151	COND (N)	INVRF30	.0191	INVRF30	.0188	RSQ14	.0048
S-151	PO4	RF14T	.0402	RF14T	.0335	RSQ14	.0569
S-151	NO3 (N)	LNRF7	.0177	INVRF7	.0394	RSQ30	.0012
S-151	TKN (N)	RF7T	.0206	INVRF30	.0415	RSQ7	.0122
S-151	TN (N)	INVRF30	.0205	INVRF30	.0401	RSQ14	.0086
S-12D	COND	RF7T	.0585	RF7T	.0682	RSQ14	.0887
S-12D	PO4	RF14T	.0543	RF14T	.0501	RSQ14	.0384
S-12D	NO3 (N)	LNRF14	.0191	LNRF7	.0112	RSQ7	.0025
S-12D	TKN (N)	INVRF14	.0202	INVRF14	.0202	RSQ14	.0224
S-12D	TN (N)	INVRF14	.0269	INVRF14	.0276	RSQ14	.0162
S-12A	COND	LNRF30	.1121	LNRF30	.0967	RSQ30	.0439
S-12A	PO4 (N)	RF14T	.0101	RF14T	.0183	RSQ7	.0050
S-12A	NO3 (N)	LNRF14	.0328	LNRF14	.0368	RSQ30	.0054
S-12A	TKN (N)	RF30T	.0289	RF30T	.0302	RSQ30	.0283
S-12A	TN (N)	RF30T	.0319	RF30T	.0355	RSQ30	.0300

The highest acceptable water-quality concentration-rainfall regression model was entered into the GLM procedure (Supplementary Data VI). The 30 regression models each produced a residuals versus predicted values plot (Supplementary Data VII) that was reviewed for patterns and outliers which might unnecessarily influence the model equation. Table 4 lists the 30 initial regression relations selected for WCA-3A. Thirteen models were rejected for patterns similar to that depicted in figure 10. Substitute model candidates were selected from table 6. If the resulting residuals plot was free of patterns, it was used for further analysis. The five successful substitutes are indicated on table 4 as "rerun." An additional five models had serious outlier problems. Figure 10 depicts this basis for rejection also. After deleting the few data points that were isolated (outlier), the model was rerun (table 4). In most cases the new model relation was no longer significant at the 0.05 r-squared level. This left 17 models available for residual trend analysis.

Trend Results

Uncorrected Concentrations

The observed concentrations uncorrected for the influence of rainfall history were evaluated for time trends with Seasonal Kendall tests (Crawford and others, 1983). Season was set at six (Supplementary Data VI). Table 7 lists the results of the 50 tests with a significance level (p). None of the observed concentrations showed a statistically significant, p less than 0.05, time trend for the period 1978 through 1982.

The initial test for trend with observed concentration data yielded a significant increase in orthophosphate-phosphorus between 1978 and 1982 at 4 of the 10 sample locations. Review of concentration versus time plots indicated that the generally low concentrations of 0.002 mg/L or greater abruptly increased to values equal to or greater than 0.004 in 1980. Discussion with the Water Quality Laboratory Section supervisor for the South Florida Water Management District confirmed a reporting change in orthophosphate phosphorus concentrations, with a revised detection limit from 0.002 mg/L to 0.004 mg/L beginning in 1980. Any analysis of water-quality trends must evaluate potential impacts of analytical procedure or reporting changes in the test period.

Model Residuals

The GLM regression models (table 4) are used to calculate a predicted concentration for each water-quality constituent. The residual is the observed concentration minus the model predicted concentration. Figures 9 and 10 illustrate "residuals" plots for two models. The Seasonal Kendall procedure tests the number of discordant and concordant residuals pairs to evaluate increasing or decreasing trends in time. Table 8 lists the trend results for the 17 statistically significant ($r^2 > 0.05$) concentration model residuals. Initially, orthophosphate and nitrate residuals from station S-11B (table 4) showed the only statistically significant increase for the 5-year time period ($p < 0.05$). However, both had pronounced outliers and a distinctly linear shape to the model residuals, so substitute regression models were selected and analyzed for trend. The new regression model residuals based on log concentration and linear RF7 did not show evidence of trend (table 8).

Table 7.—Significance level of Seasonal Kendall Trend test for water-quality concentrations for Water Conservation Area 3A

[Season equals six. NOBS is the number of non-missing observations in the original data. NVALS is the number of non-missing seasonal values constructed]

Structure	Variable	NOBS	NVALS	Tau	p-level	Slope (m)
S-190	COND	84	28	-0.200	0.342	-17.50
S-190	PO4	89	26	.133	.507	.0
S-190	NO3	89	26	.244	.203	.1667E-03
S-190	TKN	89	26	-.289	.154	-.5000E-01
S-190	TN	89	26	-.244	.235	-.4750E-01
L-3	COND	83	24	-.027	1.000	-1.625E-01
L-3	PO4	85	24	.0	1.000	.0625E-01
L-3	NO3	82	24	.0	1.000	.0625E-01
L-3	TKN	85	24	.189	.419	.4167E-01
L-3	TN	85	24	.189	.419	.9667E-01
S-8	COND	94	29	-.214	.251	-26.42E-01
S-8	PO4	144	29	.321	.066	.3125E-02
S-8	NO3	143	29	-.179	.348	-.5029E-01
S-8	TKN	143	29	.107	.602	.3500E-01
S-8	TN	143	29	.018	1.000	.2000E-01
S-140	COND	99	29	.140	.472	3.750E-01
S-140	PO4	100	29	.088	.679	.7000E-03
S-140	NO3	100	29	.018	1.000	.0
S-140	TKN	100	29	.088	.683	.5750E-01
S-140	TN	100	29	.053	.838	.4000E-01
S-7	COND	79	30	-.180	.326	-16.25E-01
S-7	PO4	88	30	.279	.113	.2500E-02
S-7	NO3	88	30	.049	.844	.2000E-02
S-7	TKN	86	30	.148	.432	.9000E-01
S-7	TN	86	30	.115	.556	.1050E-01
S-11B	COND	61	24	-.263	.237	-33.71E-01
S-11B	PO4	62	24	.105	.635	.0
S-11B	NO3	60	24	.263	.229	.1767E-01
S-11B	TKN	61	24	.105	.694	.4875E-01
S-11B	TN	60	24	.053	.896	.4500E-01
S-9	COND	104	30	.164	.374	4.600E-01
S-9	PO4	108	30	.197	.169	.0
S-9	NO3	108	30	-.033	.917	.0
S-9	TKN	108	30	-.049	.844	-.8750E-02
S-9	TN	108	30	.016	1.000	.1500E-01
S-151	COND	92	26	.200	.342	7.000E-01
S-151	PO4	96	26	.0	1.000	.0000E-01
S-151	NO3	96	26	.200	.342	.5750E-02
S-151	TKN	96	26	.333	.097	.1133E-02
S-151	TN	96	26	.289	.154	.1075E-02
S-12D	COND	112	31	-.215	.217	-17.33E-02
S-12D	PO4	115	31	-.031	.724	.0
S-12D	NO3	116	31	-.185	.296	-.6500E-02
S-12D	TKN	115	31	.046	.849	.1000E-01
S-12D	TN	115	31	-.031	.924	-.1125E-01
S-12A	COND	88	26	.348	.083	19.58E-01
S-12A	PO4	90	26	.0	1.000	.0058E-01
S-12A	NO3	90	26	.022	1.000	.0
S-12A	TKN	89	26	.130	.563	.2979E-01
S-12A	TN	89	26	.152	.485	.2062E-01

Table 8.—Significance level of Seasonal Kendall Trend tests on water-quality regression model residuals for Water Conservation Area 3A

[Season equals six. NOBS is the number of non-missing observations in the original data. NVALS is the number of non-missing seasonal values constructed]

Structure	Variable	NOBS	NVALS	Tau	p-level	Slope (m)
S-190	CONDRES	82	25	-0.366	0.078	-0.3895E-01
S-190	TKNRES	87	25	- .268	.208	-.5242E-01
S-190	TNRES	87	25	- .220	.314	-.4853E-01
L-3	CONDRES	81	23	- .091	.771	-.1195E-01
L-3	PO4RES	83	23	.030	1.000	.3586E-03
S-8	CONDRES	94	29	- .214	.215	-26.42E-01
S-8	TKNRES	142	29	.143	.466	.1023E-01
S-8	TNRES	142	29	- .071	.754	-.2940E-01
S-140	CONDRES	97	28	.038	.913	.4422E-02
S-7	NO3RES	87	30	.049	.844	.3485E-01
S-7	TNRES	85	30	.148	.432	.9526E-01
S-11B	CONDRES	58	24	- .211	.358	-.3378E-01
S-11B	TNRES	60	24	.053	.896	.3437E-01
S-9	CONDRES	103	30	.148	.432	.1208E-01
S-9	PO4RES	107	30	.311	.077	.1348E-03
S-151	PO4RES	95	26	.022	1.000	.8349E-06
S-12A	CONDRES	86	25	.366	.078	19.55E-04

Apparent Trends

Water-quality trend analysis in WCA-3A was evaluated for two major purposes. The first purpose was to detect any significant increases in constituent concentrations for water flowing into WCA-3A or flowing south into the Shark River Slough. The second purpose was to evaluate the 1978-82 U.S. Army Corps of Engineers monitoring program (Supplementary Data I) from the standpoint of discriminating water-quality trends.

The South Florida Water Management District water-quality data base was used to evaluate trend at 10 selected locations. The choice of the South Florida Water Management District data set was based on coverage of water-quality properties, uniform collection procedures, frequency of collection, location of sampling, and, in part, on the availability of a compatible electronic file for the 5-year period 1978-82. Twenty-eight water-quality constituents were screened with SAS statistical summaries for frequency of sample collection. Data on major cations, anions, and nutrients were generally available on a frequency of twice per month. Five representative constituents were selected to reduce the amount of data processing and resulting information. Models based on 7-, 14-, and 30-day cumulative antecedent rainfall were constructed and the statistically significant models based on r-squared and residual patterns were tested for trend. Orthophosphate and nitrate residuals for 7-day antecedent rainfall at station S–11B were the only two apparent constituent structure pairs that had statistically significant increases.

Plots of the observed concentrations of nitrate and orthophosphate for the 1978–82 collection period at S–6, S–7, and S–11B are shown in figure 11. Unusually high nitrate concentrations were plotted in August 1981. The extremely high rainfalls that occurred prior to these sample dates reflect Tropical Storm Dennis. The rises in nitrate and orthophosphate concentration during July 1981 shown in figure 11 resulted from the conscious management decision to dewater WCA–2A in 1980 and the controlled burning of much of the area in 1980–81 by the Florida Game and Fresh Water Fish Commission (Worth, 1983). A dry, recently burned area was inundated as a result of more than 11 inches of rainfall on August 16–18, 1981. In addition, the Eastern Everglades Agricultural Area was drained to provide flood relief by pumping water through S–6 and S–7 into WCA–1 and WCA–2A. The high nutrient concentrations of these source waters for S–11B are shown in figure 11. The effects on concentrations were greatly diminished by the next sampling, September 15, 1981. The combination of a fresh source (the burned marsh area), an extraordinary rainfall (Tropical Storm Dennis), and enriched agricultural inflow produced highly significant ($r^2 = 0.957$ for orthophosphate and $r^2 = 0.740$ for nitrate) quadratic regression models (RSQ7) whose residuals had a significant ($p < 0.05$) upward trend for the 5-year period 1978–82. The Seasonal Kendall test had been set to season = 6, which means that equivalent 2-month period, median concentration residuals were tested for trend.

The U.S. Army Corps of Engineers sampled for water quality at three locations four times annually (Memorandum of Agreement, Supplementary Data I). The U.S. Army Corps of Engineers, South Florida Water Management District, and National Park Service agreement specified that samples be collected in October, January, April, and July during the period 1978–82. The three locations were all adjacent to Everglades National Park boundaries. The South Florida Water Management District S–11B data were edited to determine whether less frequent sampling would also detect an apparent trend. Samples collected at times approximating the months agreed upon were retained and trend analysis for concentrations and model residuals performed. The trend test was repeated at both season = 6 and season = 4. The results presented in table 9 show no detection of trend with quarterly samples. Changing season from 6 to 4 did not change the lack of significance of either concentration or model residual trends at S–11B.

MONITORING CONSIDERATIONS

The trend analysis approach is almost ideally suited to the South Florida Water Management District computer-based water-quality data management system. The frequency of collection used by South Florida Water Management District is often twice monthly for many important water-quality constituents. This frequent data collection facilitates testing relations with other variables, such as the antecedent rainfall used in this analysis. The South Florida Water Management District water-quality file contains chemical analyses from many locations throughout the district. This widely distributed areal coverage provides a distinct advantage in any attempt to analyze water quality superimposed on a complex, highly managed flow system.

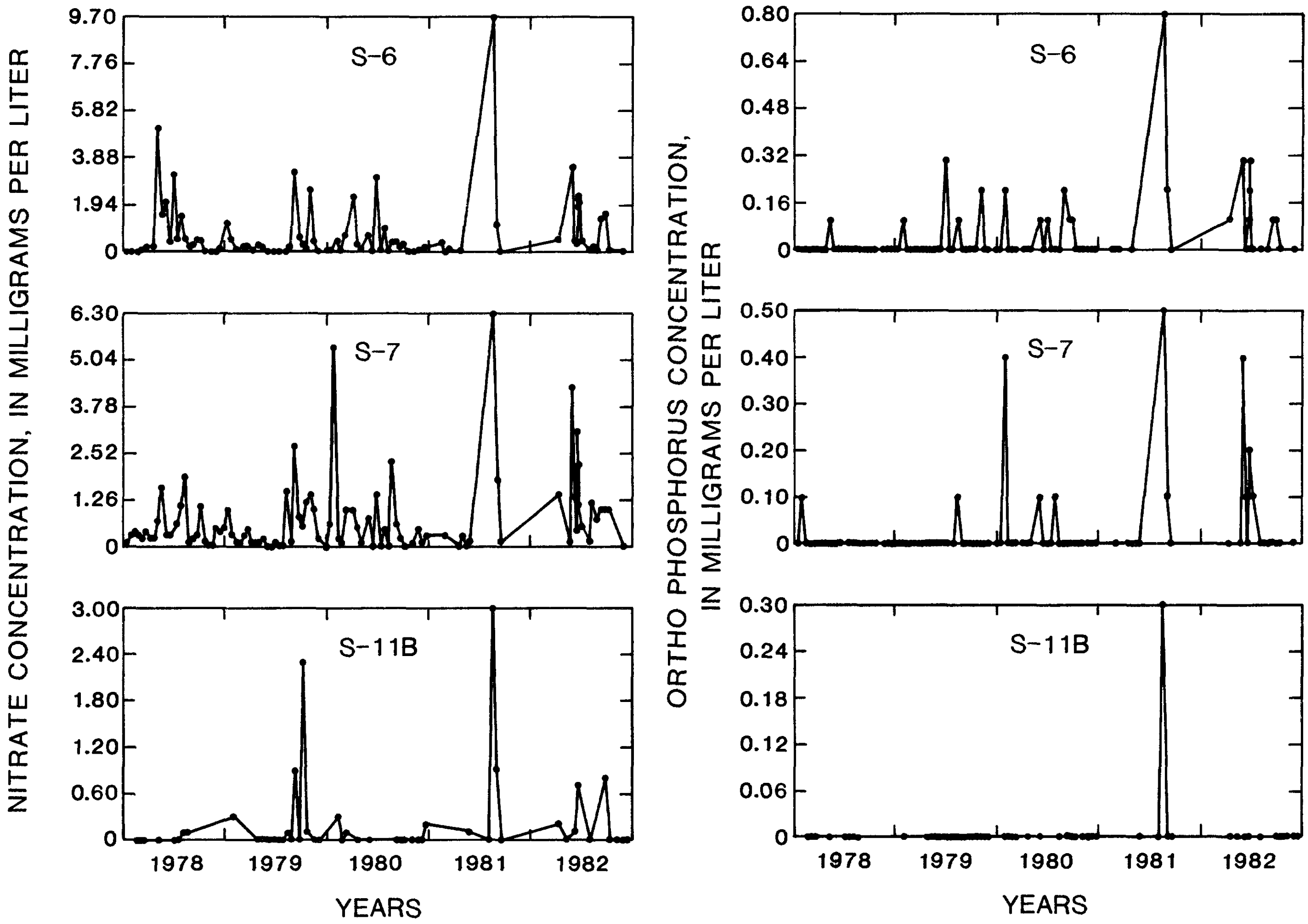

Figure 11.—Comparison of nitrate and orthophosphate at inflow structure S-11B with two major upstream inflow structures, S6 and S7.

Table 9.—Seasonal Kendall test and slope estimator for trend magnitude at structure S-11B from 1978 through 1982

[NOBS is the number of non-missing observations in the original data. NVALS is the number of non-missing seasonal values constructed]

Variable	Season	NOBS	NVALS	Tau	p-Level	Slope
PO4	4	21	16	0.080	0.854	0.1000E-29
PO4RES	4	21	16	.080	.869	.1593E-05
NO3	4	19	14	.111	.840	.5271E-02
NO3RES	4	19	14	.222	.546	.1301E-01
PO4	6	21	19	.091	.834	.1000E-29
PO4RES	6	21	19	.0	1.000	-.2587E-04
NO3	6	19	17	.294	.390	.5000E-02
NO3RES	6	19	17	.059	1.000	.6459E-02

Several aspects of the South Florida Water Management District water-quality monitoring network correspond to components of an idealized network similar to that shown in figure 12. Wide geographic distribution enhances identification of a chemical constituent close to the source of the constituent. The combination of extensive coverage of water-quality constituents, frequent sample collection, and rapid chemical analyses increases the lead time for affecting contaminant containment or dispersal. A frequent sample collection program also permits a water-quality data base that provides a more robust statistical analysis of changes (trend analysis) and the factors such as antecedent rainfall or discharge that might influence change.

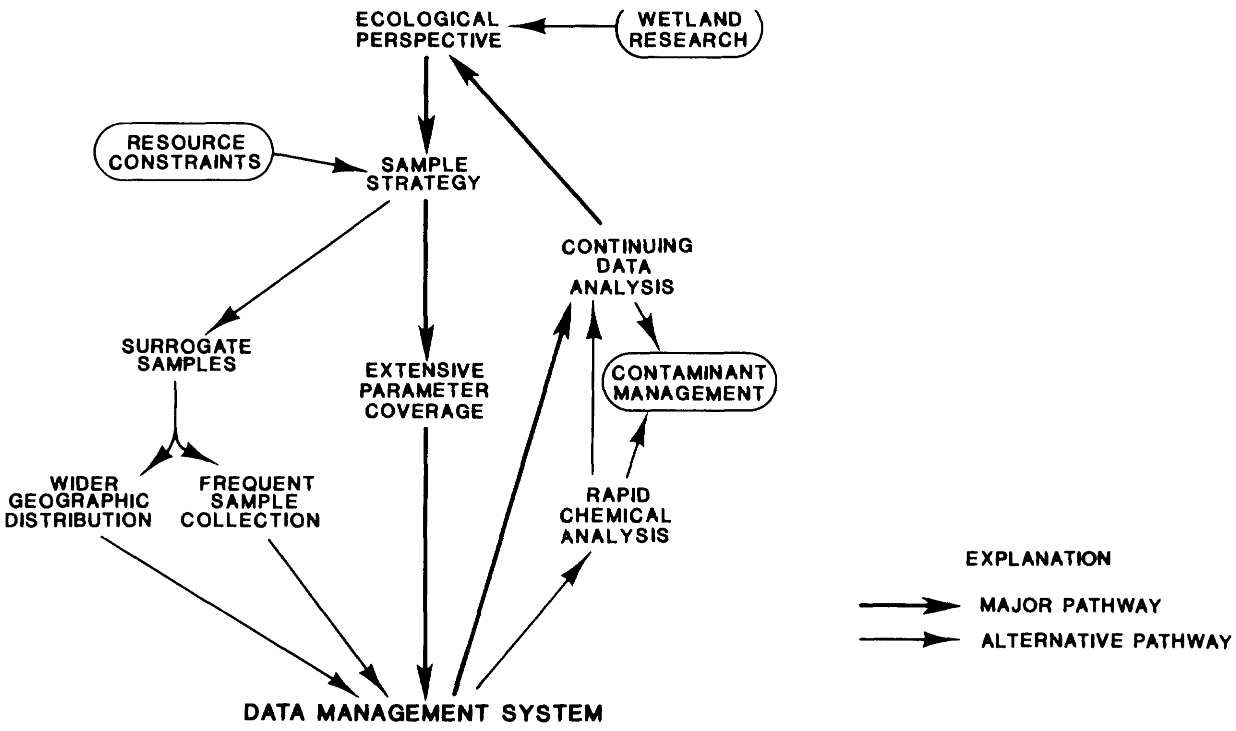

Figure 12.—Schematic representation of the components of an idealized water-quality monitoring network.

The U.S. Army Corps of Engineers data-collection effort included analyses for 36 water-quality constituents and 21 individual pesticides. Extensive coverage on a watershed like the Shark River Slough provides resource managers with information on changes from a wide variety of sources in the basin. The cost of extensive coverage on a frequent sample-collection interval is excessive and diverts laboratory facilities and personnel resources from other responsibilities. The idealized water-quality monitoring network would use water-quality surrogates for extensive coverage. This approach was agreed to in the 1979 Memorandum of Agreement by specifying daily samplings for dissolved oxygen, specific conductance, and pH. The twice monthly collection of nutrients and other constituents by South Florida Water Management District accomplishes a similar goal. The revised Memorandum of Agreement of 1984 incorporated the concepts of more frequent sample collection, more sample collection locations, and fewer types of chemical analyses.

Many of the objectives of an idealized water-quality monitoring network depend on two attributes that are facilitated by current laboratory technology; rapid chemical analyses and storage of the results in an accessible computerized data-management system. The U.S. Army Corps of Engineers results could not be readily analyzed because four different types of data storage and retrieval were used in the 5-year period covered by the 1979 Memorandum of Agreement. Rapid access to the analytical results of any monitoring system facilitates recall of previous results and testing for change. Continuing data analysis not only recognizes change but permits revisions to the judicious use of surrogates and allows sample collection adjustments to more clearly characterize water-quality changes.

Ecological perspective is a component of the idealized water-quality monitoring network to the extent that the network sampling strategy may be revised. Judgments of sampling location, frequency, parameter coverage, type of data analysis, and use of surrogates, all depend on understanding how the entire ecological system functions. This understanding needs to be revised by a continuing data analysis of the network. A series of research programs, external to the monitoring network, designed to determine the biogeochemical processes that operate in southern Florida would enhance a reevaluation of sampling strategy.

CONCLUSIONS

The specific approach of model construction and Seasonal Kendall trend analysis is but one type of continuing data analysis. The trend analysis approach is applied to a single constituent and station versus time and cannot address the marked concentration gradient that exists across the water conservation flow system. The trend analysis of samples from 10 flow structure locations around WCA–3A leads to a number of conclusions:

- It is possible to amend the Seasonal Kendall trend procedure used by the U.S. Geological Survey to a more generalized approach for data sets with other data formats.
- The application of model construction and Seasonal Kendall test for trend to the South Florida Water Management District data bases was successful.
- Antecedent rainfall and water-quality constituent regression models were constructed for 10 flow stations. Only 17 statistically significant regression models from 350 possible combinations were available for trend analysis.
- No trends for specific conductance, orthophosphate-phosphorus, nitrate-nitrogen, total Kjeldahl nitrogen, or total nitrogen were detected by the Seasonal Kendall test for the 1978–82 time period at the 10 flow structures.
- An apparent trend for orthophosphate-phosphorus and nitrate-nitrogen initially seen at S–11B was not accepted because of the influence of outliers. Elimination of outliers eliminated the statistical significance of the apparent trend.
- Monthly or more frequent sample collection is highly desirable for trend analysis.

- Although pronounced areal differences in water quality exist around Water Conservation Area 3A, no water-quality trends were detected adjacent to the agricultural areas for the 1978–82 time period.

- Discharge was excluded from the evaluation of models because specific changes were made in the release strategy during the evaluation period. If water release followed a consistent set of rules during an evaluation period, then discharge could be a basis for trend evaluation.

- The S–12 outflow structures yielded the fewest statistically significant regression models, possibly because the flow regulation was independent of rainfall and the Conservation Area which contributes flow is a large flood pool that is independent of short term (30 days or less) rainfall.

On the basis of this analysis, certain aspects of an ideal water-quality monitoring network for the Shark River Slough can be defined. These include:

- A computerized data-management system is needed for this and many other rigorous evaluation programs.

- Each station has distinguishable water-quality characteristics that suggest that the number of sample locations is important and that lumping of inflow data needs to be done cautiously in any evaluation effort.

- Location of sampling sites away from Shark River Slough and closer to source areas of nutrients and other chemical constituents affords early identification of problems and possible ameliorative response.

- Coordination between the Everglades National Park, South Florida Water Management District, and U.S. Army Corps of Engineers is highly desirable for any water-quality monitoring network for Shark River Slough.

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SUPPLEMENTARY DATA I

Copy Of

MEMORANDUM OF AGREEMENT BETWEEN THE U.S. ARMY CORPS OF ENGINEERS, THE SOUTH FLORIDA WATER MANAGEMENT DISTRICT, AND THE NATIONAL PARK SERVICE FOR THE PURPOSE OF PROTECTING THE QUALITY OF WATER ENTERING EVERGLADES NATIONAL PARK

WHEREAS the Congress, in connection with the Everglades National Park, has directed the Corps and the National Park Service "to reach an early agreement on measures to assure that the water delivered to the park is of sufficient purity to prevent ecological damage or deterioration of the park's environment." (River Basin Monetary Authorizations and Miscellaneous Civil Works Amendments, Senate Report No. 91—895, p. 24); and

WHEREAS the quality of existing water deliveries to the park does not depart significantly from that of waters which have not been altered by the works of man; and

WHEREAS the Corps, the National Park Service (NPS), and the Water Management District (WMD) are concerned that waters delivered to the park are not degraded;

NOW, THEREFORE, the Corps, NPS, and WMD do hereby mutually agree to the following:

1. Water quality criteria for 36 parameters as enumerated in Appendix A attached hereto and made a part of hereof shall apply to waters delivered to the park. Federal, State, and local water quality criteria which are more stringent than those appended criteria shall continue to apply.
2. The concentrations of pesticides in park delivery waters is to be 0.0. Actual concentrations are to be below the limits of detection. A listing of pesticides is shown in Appendix B attached hereto and made a part hereof.
3. The Corps shall collect and analyze for the specified 36 parameters and 21 pesticide residues samples from delivery waters at the following locations: L—67A Canal, L—31—W Canal, and C—111 Canal. (See map in Appendix C attached hereto and made a part hereof).
4. The Corps shall make available to the NPS and WMD all sample collection data and analysis of that collection within 60 days of the collection date.
5. That the Corps, NPS, and WMD shall meet at such times as may be necessary at the request of any party, but not less frequently than once a year to review the monitoring station locations and the collected data to determine whether or not water quality criteria are being met.
6. Should water quality criteria not be met, the Corps, NPS, and WMD shall take appropriate and legal action to restore or protect the quality of water entering the Park.
7. In the event that a clear and present danger to water quality has been determined to exist by the National Park Service, appropriate actions or such legal process as may be necessary to restore or protect the quality of water entering the Park shall be taken by the Corps, NPS, and WMD.
8. The Corps, NPS, and WMD recognize that the data base for the appended standards needs periodic review. Therefore, the standards will be reviewed for adequacy and necessary revisions made before January 1, 1984.

IN WITNESS WHEREOF, THE PARTIES HERETO HAVE SIGNED THIS AGREEMENT ON THE DATES INDICATED.

(CORPORATE SEAL)

ATTEST

(original signed)

SECRETARY

EXECUTED IN THE PRESENCE OF:

(original signed)

AS TO WMD

SOUTH FLORIDA WATER MANAGEMENT DISTRICT,
BY ITS GOVERNING BOARD

(original signed)

BY CHAIRMAN

DATE

EXECUTED IN THE PRESENCE OF:

(original signed)

AS TO CORPS OF ENGINEERS

THE UNITED STATES ARMY CORPS OF ENGINEERS

(original signed)

BY COLONEL, CORPS OF ENGINEERS

DISTRICT ENGINEER, JACKSONVILLE DISTRICT

DATE

EXECUTED IN THE PRESENCE OF:

(original signed)

AS TO NATIONAL PARK SERVICE

THE NATIONAL PARK SERVICE

(original signed)

BY SUPERINTENDENT, EVERGLADES NATIONAL PARK

DATE

SUPPLEMENTARY DATA I.—Copy Of: MEMORANDUM OF AGREEMENT BETWEEN THE U.S. ARMY CORPS OF ENGINEERS, THE SOUTH FLORIDA WATER MANAGEMENT DISTRICT, AND THE NATIONAL PARK SERVICE FOR THE PURPOSE OF PROTECTING THE QUALITY OF WATER ENTERING EVERGLADES NATIONAL PARK--Continued

APPENDIX A

Parameter	Mean concentration 1970-1978 $\overline{X}$	Upper limit[1] L
Turbidity, JTU	4.44	11
Color, PCU	65.56	124
Spec. Conductance (umho)	573.6	647
DO, mg/L	5.18	4.5
BOD, mg/L	1.42	3
NH4, mg/L, as N	.089	0.24
NO2, mg/L, as N	.0128	0.04
NO3, mg/L, as N	.16	0.7
OrgN, mg/L, as N	1.52	2.1
Total N, mg/L, as N	1.8	2.9
PO4, mg/L, as P	.008	0.02
Total P, mg/L, as P	.033	0.24
TOC, mg/L	32.7	51
TIC, mg/L	40.4	60
pH, Units	7.8	7.6-8.0
Alkalinity, mg/L, as CaCO3	176.9	269
TDS, mg/L	344.8	566
Hardness, mg/L, as CaCO3	174	330
Non carb Hard, mg/L	19	54
Calcium, mg/L	58.3	86
Magnesium, mg/L	11.3	25
Sodium, mg/L	47	93
Potassium, mg/L	2.9	5
Chloride, mg/L	77.6	143
Sulfate, mg/L	19.7	54
Fluoride, mg/L	.35	0.7
Arsenic, µg/L	7.8	20
Cadmium, µg/L	2.2	10
Chromium, µg/L	3.5	20
Cobalt, µg/L	1.2	5
Copper, µg/L	2.4	8
Iron, µg/L	122	270
Lead, µg/L	4.2	13
Manganese, µg/L	10.5	24
Zinc, µg/L	19.6	72
Mercury, µg/L	.07	0.5

[1]Annual mean not to exceed this value. All parameters measured quarterly (October, January, April, and July) except Dissolved Oxygen, Specific Conductance, and pH, which are to be measured daily.

APPENDIX B

Pesticides Allowable Concentration of Zero[1]
(Sampled Semiannually)

Parameter

Aldrin
Lindane
Chlordane
DDD
DDE
DDT
Dieldrin
Endrin
Ethion
Toxaphene
Heptachlor
Heptachlor E
PCB
Malathion
Parathion
Diazinon
Methyl Parathion
2, 4, 5 - T
Silvex
Trithion
Methyl Trithion

[1]Samples to be taken in water column until concentrations in sediment are established.

SUPPLEMENTARY DATA II.--Card image formats of South Florida Water Management District water-quality data set (WCAQW) and discharge data set.

Station number | Date | Orthophosphate Phosphorus | Conductance | Total Kjeldahl Nitrogen | Nitrate | Sample Type Code | Next Sample

```
CAMB0163L3  10478.1445.000  0.000    17.200    6.700 470.000              7.300
CAMB0163L3                   .067      .109
CAMB0163L3    .004    .024   .040      .010    1.200               1.190  1.230
CAMB0163L3                                                        42.100
CAMB0163L3
CAMB0163L3          19.000
CAMB0259L3  11878.1600.000  0.000    18.800    9.100 490.000              7.700
CAMB0259L3                   .016      .041
CAMB0259L3    .004    .004   .020      .010    1.010               1.000  1.020
CAMB0259L3                                                        42.800
CAMB0259L3
CAMB0259L3          19.000
```

Daily discharge (cubic feet per second) in three card per month format with implicit date.

L378011	3	1	0	0	0	0	0	0	1	4	
L378012	4	5	6	10	8	8	5	6	6	69	
L378013	192	194	143	133	118	114	134	132	95	90	95
L378021	0	0	0	0	0	0	0	0	0	0	
L378022	0	0	0	0	0	0	0	0	0	0	
L378023	0	0	0	0	0	0	0	0			
L378031	0	0	0	0	0	0	0	0	0	0	
L378032	0	0	0	0	0	0	0	0	0	0	
L378033	0	0	0	0	0	0	0	0	0	0	0

Data File Name: WCAQW

Content: Water quality data at S-7, S-8, S-9, S-11B, S-12A, S-12D, S-140, L-3, L-28, S-151 for period 1978 through 1982.

Input Format:

(Comment)	Variable Name	Record No.	Columns Begin	Columns End	Field Width	Type
	STATION	1	9	12	4	A
	MONTH	1	18	19	1	F
	DAY	1	20	21	2	F
	YEAR	1	22	23	2	F
(hours, min)	TIME	1	25	28	4	F
(meters)	DEPTH	1	33	40	8	F
(°C)	TEMP	1	41	48	8	F
	DO	1	49	56	8	F
(field measurement)	SPCOND	1	57	64	8	F
	LABCOND	1	65	72	8	F
	PH	1	73	80	8	F
	TURB	2	17	24	8	F
	COLOR	2	25	32	8	F
	OPO4	2	33	40	8	F
	TPO4	2	41	48	8	F
(total dissolved P)	TDPO4	2	49	56	8	F
(dissolved organic P)	DORGPO4	2	57	64	8	F
(particulate P)	PARTP	2	65	72	8	F
(total organic carbon)	TOTORGC	2	73	80	8	F
	NO2	3	17	24	8	F
	NO3	3	25	32	8	F
(NOx + NH4)	INORG	3	33	40	8	F
	NH4	3	41	48	8	F
	TKN	3	49	56	8	F
(dissolved TKN)	TDKN	3	57	64	8	F
(TKN-NH4)	ORGN	3	65	72	8	F
	TOTALN	3	73	80	8	F
	CA	4	17	24	8	F
	MG	4	25	32	8	F
	K	4	33	40	8	F
	NA	4	41	48	8	F
	SIO2	4	49	56	8	F
	SO4	4	57	64	8	F
	CL	4	65	72	8	F
	ALK	4	72	80	8	F
(hardness)	HARD	5	17	24	8	F
(total dissolved: cadmium	TDISSCD	5	25	32	8	F
chromium	TDISSCR	5	33	40	8	F
copper	TDISSCU	5	41	48	8	F
manganese	TDISSMN	5	49	56	8	F
lead	TDISSPB	5	57	64	8	F
strontium	TDISSSR	5	65	72	8	F
zinc)	TDISSZN	5	73	80	8	F
1=discharge, 2=no discharge	DSCH	6	17	24	8	F
sample type	SAMTYP	6	25	32	8	F

Equivalent Fortran Format: (8X,A4,3F2,F4.0,4X,6F8.3/16X,8F8.3/16X,8F8.3/16X, 8F8.3/16X,8F8.3/16X,3F8.3

Note on Sample Type (SAMTYP): delete all observations with SAMTYP = 9. These represent duplicate analyses. All other values represent valued data.

Number of card images: 22,242

SUPPLEMENTARY DATA III.--Listing of TRANSPOSE program written by Sharon Watkins, U.S. Geological Survey.

```
//AG41CAR5 JOB (account number,MATTR,3,10),'MATTRAW',
//  CLASS=T
//* $$DIR <TPA>TALLAHASSEE>STUDIES>HMATTRAW>SFWMD
//  EXEC SAS
//DISCH DD DSN=AG41CAR.QL3.DATA,DISP=OLD,UNIT=ONLINE
//OUTR DD DSN=AG41CAR.FLOW,DISP=OLD,
//  UNIT=ONLINE
//SYSIN DD *
DATA Q;
 INFILE DISCH;
INPUT YEAR1 10-11 MO1 12-13 @15 (V1-V10) (10*6.)
       #2 @15 (V11-V20) (10*6.)
       #3 @15 (V21-V31) (10*6.);
PROC TRANSPOSE PREFIX=Q OUT=QPRIME;
  VAR V1-V31;
    BY YEAR1 MO1;
 PROC MATRIX;
DUMMY=J(1860,1);
  DO I=1 TO 5;
   DO J=1 TO 12;
    DO K=1 TO 31;
     DUMMY((((((I-1)*12)+J-1)*31)+K),1)=K;
    END;
   END;
  END;
OUTPUT DUMMY OUT=DATES (RENAME=(COL1=DATE));
 DATA OUTR.QL3;MERGE QPRIME DATES;
  IF Q1= . THEN DELETE;
  DROP _NAME_   ROW;
PROC PRINT  ;
/*
//
```

SUPPLEMENTARY DATA IV.--Listing of MERGE program written by Sharon Watkins, U.S. Geological Survey.

```
//AG41CAR5 JOB (account number,MATTR,5,10),'MATTRAW',
//  CLASS=S
//*$$DIR <TPA>TALLAHASSEE>STUDIES>HMATTRAW
//  EXEC SAS
//DISCH DD DSN=AG41CAR.FLOW,DISP=OLD
//GLADES DD DSN=AG41CAR.S7.DATA,DISP=OLD
//RAIN DD DSN=AG41CAR.FLOW,DISP=OLD
//MRG DD DSN=AG41CAR.FLOW,DISP=OLD
//SYSIN DD *
DATA ONE;SET RAIN.RF99;
RF7T=LAG(RF1)+LAG2(RF1)+LAG3(RF1)+LAG4(RF1)+LAG5(RF1)+LAG6(RF1)+LAG7(RF1);
RF14T=RF7T+LAG8(RF1)+LAG9(RF1)+LAG10(RF1)+LAG11(RF1)+LAG12(RF1)+
LAG13(RF1)+LAG14(RF1);
RF30T=RF14T+LAG15(RF1)+LAG16(RF1)+LAG17(RF1)+LAG18(RF1)+LAG19(RF1)+
LAG20(RF1)+LAG21(RF1)+LAG22(RF1)+LAG23(RF1)+LAG24(RF1)+LAG25(RF1)+LAG26(RF1)+
LAG27(RF1)+LAG28(RF1)+LAG29(RF1)+LAG30(RF1);
DATA TWO;SET DISCH.QS7;
Q7T=LAG(Q1)+LAG2(Q1)+LAG3(Q1)+LAG4(Q1)+LAG5(Q1)+LAG6(Q1)+LAG7(Q1);
IF Q7T=0 THEN DO;
 Q7T=2;
END;
Q14T=Q7T+LAG8(Q1)+LAG9(Q1)+LAG10(Q1)+LAG11(Q1)+LAG12(Q1)+
LAG13(Q1)+LAG14(Q1);
Q30T=Q14T+LAG15(Q1)+LAG16(Q1)+LAG17(Q1)+LAG18(Q1)+LAG19(Q1)+
LAG20(Q1)+LAG21(Q1)+LAG22(Q1)+LAG23(Q1)+LAG24(Q1)+LAG25(Q1)+LAG26(Q1)+
LAG27(Q1)+LAG28(Q1)+LAG29(Q1)+LAG30(Q1);
DATA THREE;INFILE GLADES;
INPUT ID $ 9-12 MO1 18-19 DATE 20-21 YEAR1 22-23 COND 57-64
#2 PO4 33-40
#3 NO3 25-32 TKN 49-56 TN 73-80
#6;
PROC SORT; BY YEAR1 MO1 DATE;
DATA MRG.MS7; MERGE ONE TWO THREE; BY YEAR1 MO1 DATE;
IF (COND=. & PO4=. & NO3=. & TKN=. & TN=.) THEN DELETE;
OUTPUT MRG.MS7;
/*
//
```

SUPPLEMENTARY DATA V.--Listing of MAXR program with rainfall only independent variable

```
//AG41CAR5 JOB (account number,MATTR,3,10),'MATTRAW',
//  CLASS=C
//* $$DIR <TLH>TALLAHASSEE>STUDIES>HMATTRAW>STEP
//  EXEC SAS
//MRG DD DSN=AG41CAR.FLOW,DISP=OLD,UNIT=ONLINE
//SYSIN DD *
DATA ONE; SET MRG.ML3;
   IF RF7T=0.00 THEN DO;
     RF7T=0.01;
   END;
     IF RF14T=0.00 THEN DO;
       RF14T=0.02;
     END;
       IF RF30T=0.00 THEN DO;
         RF30T=0.03;
       END;
         IF PO4=0.002 THEN DO;
           PO4=0.004;
         END;
LNRF7=LOG(RF7T);
LNRF14=LOG(RF14T);
LNRF30=LOG(RF30T);
INVRF7=1/RF7T;
INVRF14=1/RF14T;
INVRF30=1/RF30T;
LNCOND=LOG(COND);
LNPO4=LOG(PO4);
LNNO3=LOG(NO3);
LNTKN=LOG(TKN);
LNTN=LOG(TN);
DATR=MDY(MO1,DATE,YEAR1);
JULIAN=JULDATE(DATR);
DOY=MOD(JULIAN,1000);
IF MOD(YEAR1,4)=0 THEN DECTIME=1900+YEAR1+(DOY/366);
ELSE DECTIME=1900+YEAR1+(DOY/365);
PROC SORT;
 BY JULIAN;
PROC STEPWISE;
 MODEL LNCOND=LNRF7 LNRF14 LNRF30 RF7T RF14T RF30T INVRF7 INVRF14 INVRF30/
   MAXR STOP=1;
DATA TWO; SET ONE;
PROC STEPWISE;
 MODEL LNPO4=LNRF7 LNRF14 LNRF30 RF7T RF14T RF30T INVRF7 INVRF14 INVRF30/
   MAXR STOP=1;
DATA THREE;SET TWO;
PROC STEPWISE;
 MODEL LNNO3=LNRF7 LNRF14 LNRF30 RF7T RF14T RF30T INVRF7 INVRF14 INVRF30/
   MAXR STOP=1;
DATA FOUR;SET THREE;
PROC STEPWISE;
 MODEL LNTKN=LNRF7 LNRF14 LNRF30 RF7T RF14T RF30T INVRF7 INVRF14 INVRF30/
   MAXR STOP=1;
DATA FIVE;SET FOUR;
PROC STEPWISE;
 MODEL LNTN=LNRF7 LNRF14 LNRF30 RF7T RF14T RF30T INVRF7 INVRF14 INVRF30/
   MAXR STOP=1;
/*
//
```

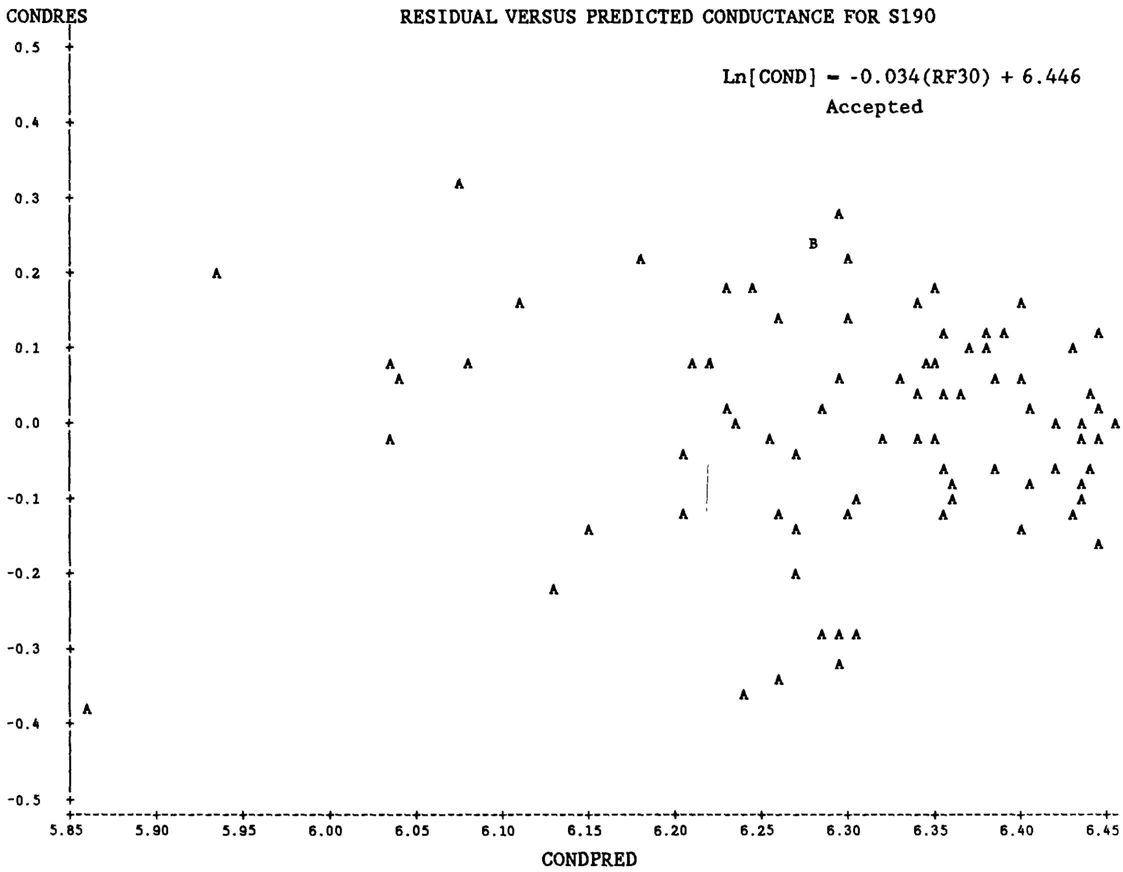
SUPPLEMENTARY DATA VI.--Listing of GLM program with Seasonal Kendall test attached

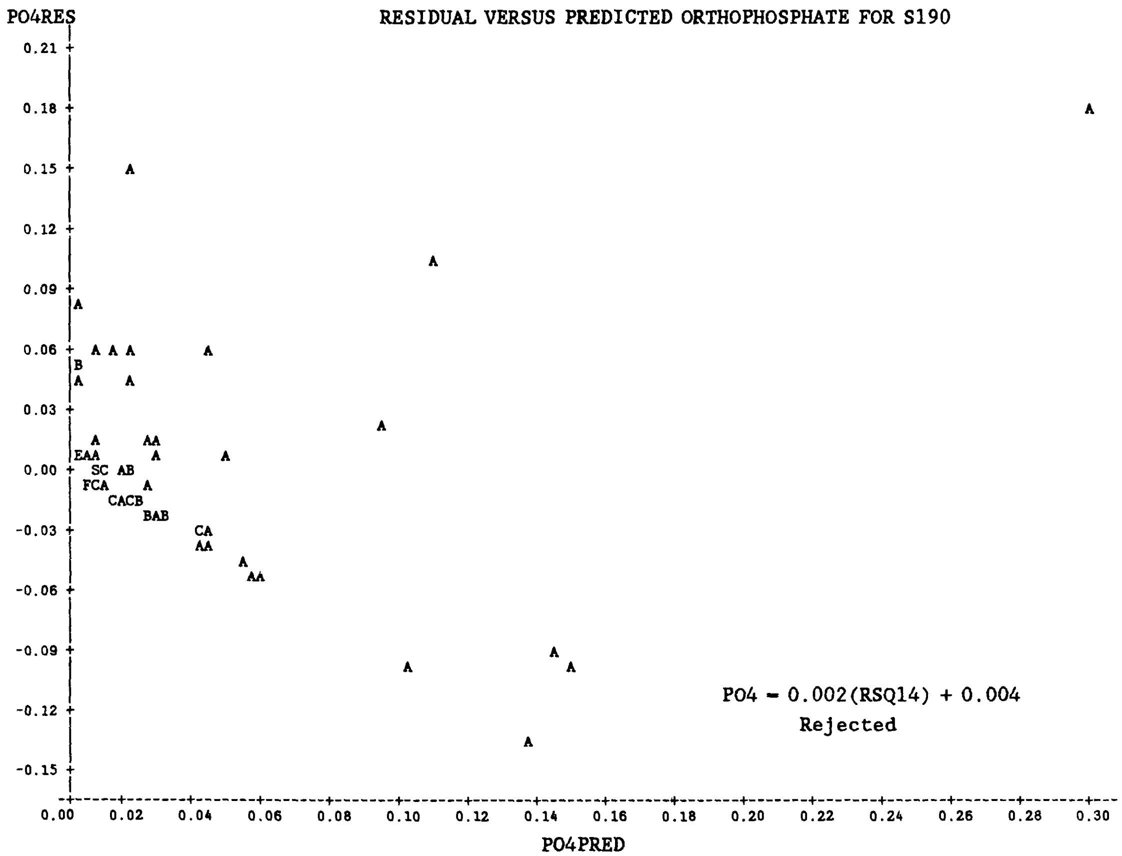
```
//AG41CAR5 JOB (account number,MATTR,3,10),'MATTRAW',
//  CLASS=C
//* $$DIR <TLH>TALLAHASSEE>STUDIES>HMATTRAW>GLM
//PROCLIB  DD DSN=WRD.PROCLIB,DISP=SHR
// EXEC WRDSAS,DSN1=NULLFILE,DSN2=NULLFILE
//MRG DD DSN=AG41CAR.FLOW,DISP=OLD,UNIT=ONLINE
//SYSIN DD *
OPTIONS NOOVP NODATE;
DATA ONE; SET MRG.MS11B;
   IF RF7T=0.00 THEN DO;
     RF7T=0.01;
   END;
     IF RF14T=0.00 THEN DO;
       RF14T=0.02;
     END;
       IF RF30T=0.00 THEN DO;
         RF30T=0.03;
       END;
         IF PO4=0.002 THEN DO;
           PO4=0.004;
         END;
LNCOND=LOG(COND);
RSQ7=RF7T*RF7T;
DATR=MDY(MO1,DATE,YEAR1);
JULIAN=JULDATE(DATR);
DOY=MOD(JULIAN,1000);
IF MOD(YEAR1,4)=0 THEN DECTIME=1900+YEAR1+(DOY/366);
ELSE DECTIME=1900+YEAR1+(DOY/365);
PROC SORT;
 BY JULIAN;
PROC GLM;
  MODEL LNCOND=RF7T;
  OUTPUT OUT=B
    PREDICTED=CONDPRED
    RESIDUAL=CONDRES;
   PROC SEASKEN SEASON=6;
   VAR DECTIME COND CONDRES;
PROC PLOT NOLEGEND;
PLOT CONDRES*DECTIME CONDRES*CONDPRED;
   TITLE1 GLM RESIDUALS VERSUS DECTIME FOR S11B;
PLOT LNCOND*DECTIME='O' CONDPRED*DECTIME='P' / OVERLAY;
   TITLE1 OBSERVED AND PREDICTED CONDUCTANCE VERSUS DECTIME FOR S11B;
DATA TWO; SET ONE;
PROC GLM;
 MODEL PO4=RSQ7;
  OUTPUT OUT=B
    PREDICTED=PO4PRED
    RESIDUAL=PO4RES;
   PROC SEASKEN SEASON=6;
   VAR DECTIME PO4 PO4RES;
PROC PLOT NOLEGEND;
PLOT PO4RES*DECTIME PO4RES*PO4PRED;
   TITLE1 GLM RESIDUALS VERSUS DECTIME FOR S11B;
PLOT PO4*DECTIME='O' PO4PRED*DECTIME='P' / OVERLAY;
   TITLE1 OBSERVED AND PREDICTED ORTHOPHOSPHATE VERSUS DECTIME FOR S11B;
DATA THREE;SET TWO;
PROC GLM;
MODEL NO3=RSQ7;
  OUTPUT OUT=B
    PREDICTED=NO3PRED
    RESIDUAL=NO3RES;
   PROC SEASKEN SEASON=6;
      VAR DECTIME NO3 NO3RES;
PROC PLOT NOLEGEND;
    PLOT NO3RES*DECTIME NO3RES*NO3PRED;
   TITLE1 GLM RESIDUALS VERSUS DECTIME FOR S11B;
PLOT NO3*DECTIME='O' NO3PRED*DECTIME='P' / OVERLAY;
   TITLE1 OBSERVED AND PREDICTED NITRATE VERSUS DECTIME FOR S11B;
DATA FOUR;SET THREE;
   PROC SEASKEN SEASON=6;
    VAR DECTIME TKN;
PROC PLOT NOLEGEND;
PLOT TKN*DECTIME;
   TITLE1 TOTAL KJELDAHL NITROGEN VERSUS DECTIME FOR S11B;
DATA FIVE;SET FOUR;
PROC GLM;
  MODEL TN=RSQ7;
  OUTPUT OUT=B
    PREDICTED=TNPRED
    RESIDUAL=TNRES;
   PROC SEASKEN SEASON=6;
  VAR DECTIME TN TNRES;
PROC PLOT NOLEGEND;
PLOT TNRES*DECTIME TNRES*TNPRED;
   TITLE1 GLM RESIDUALS VERSUS DECTIME FOR S11B;
PLOT TN*DECTIME='O' TNPRED*DECTIME='P' / OVERLAY;
   TITLE1 OBSERVED AND PREDICTED TOTAL NITROGEN VERSUS DECTIME FOR S11B;
PLOT RF7T*DECTIME RSQ7*DECTIME;
/*
//
```

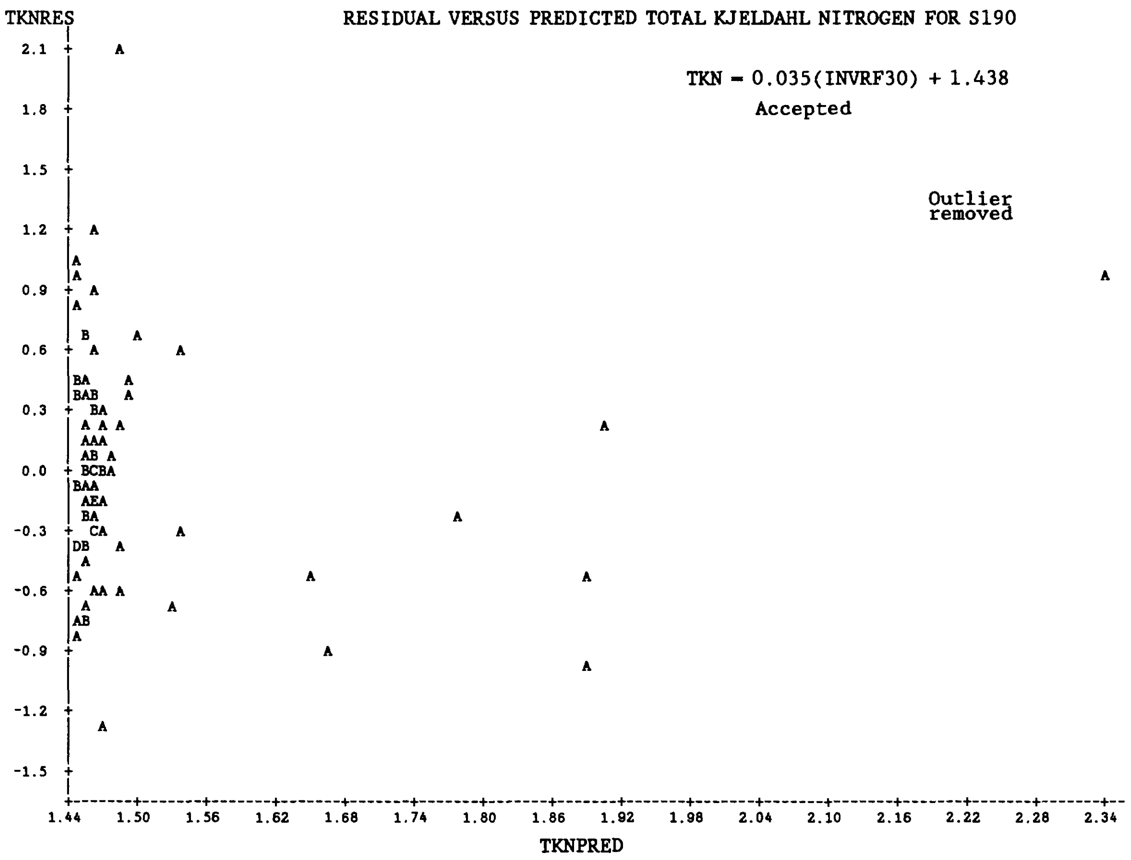
SUPPLEMENTARY DATA VII.—Residual plots for the 30 statistically significant regression models.

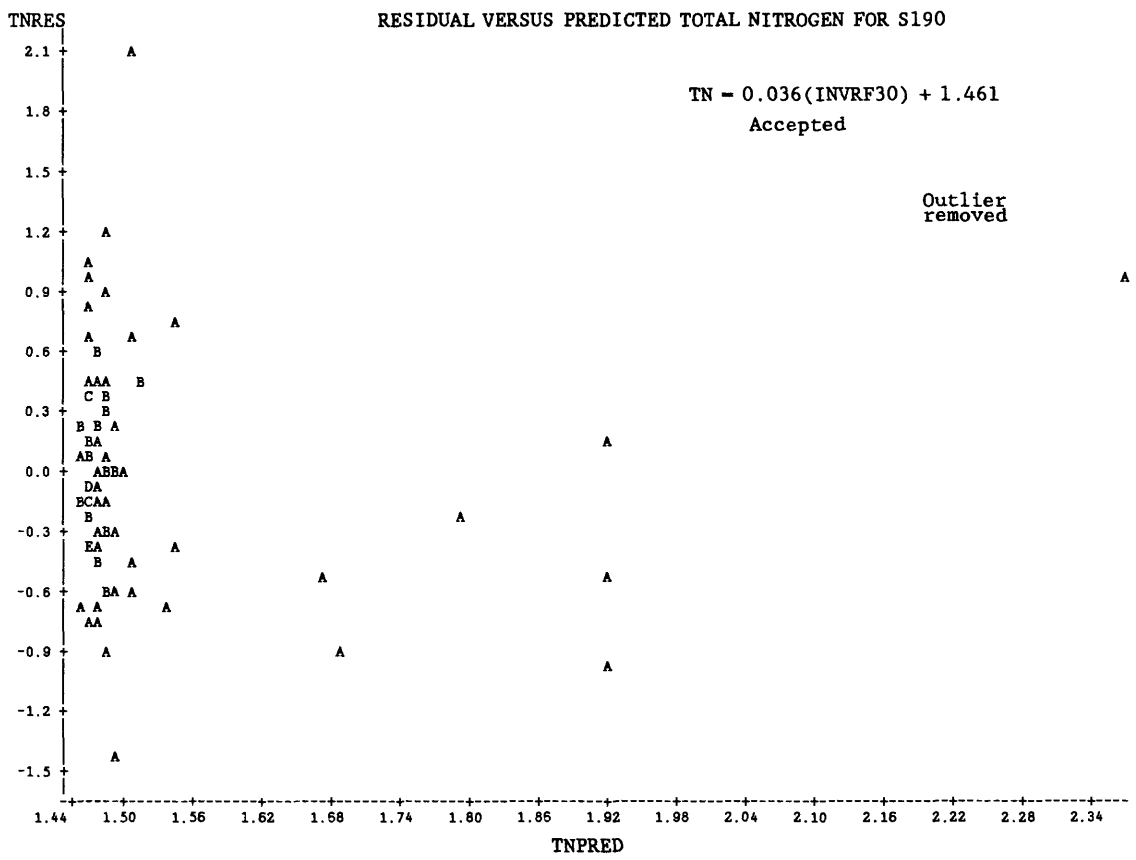
Residual versus predicted:

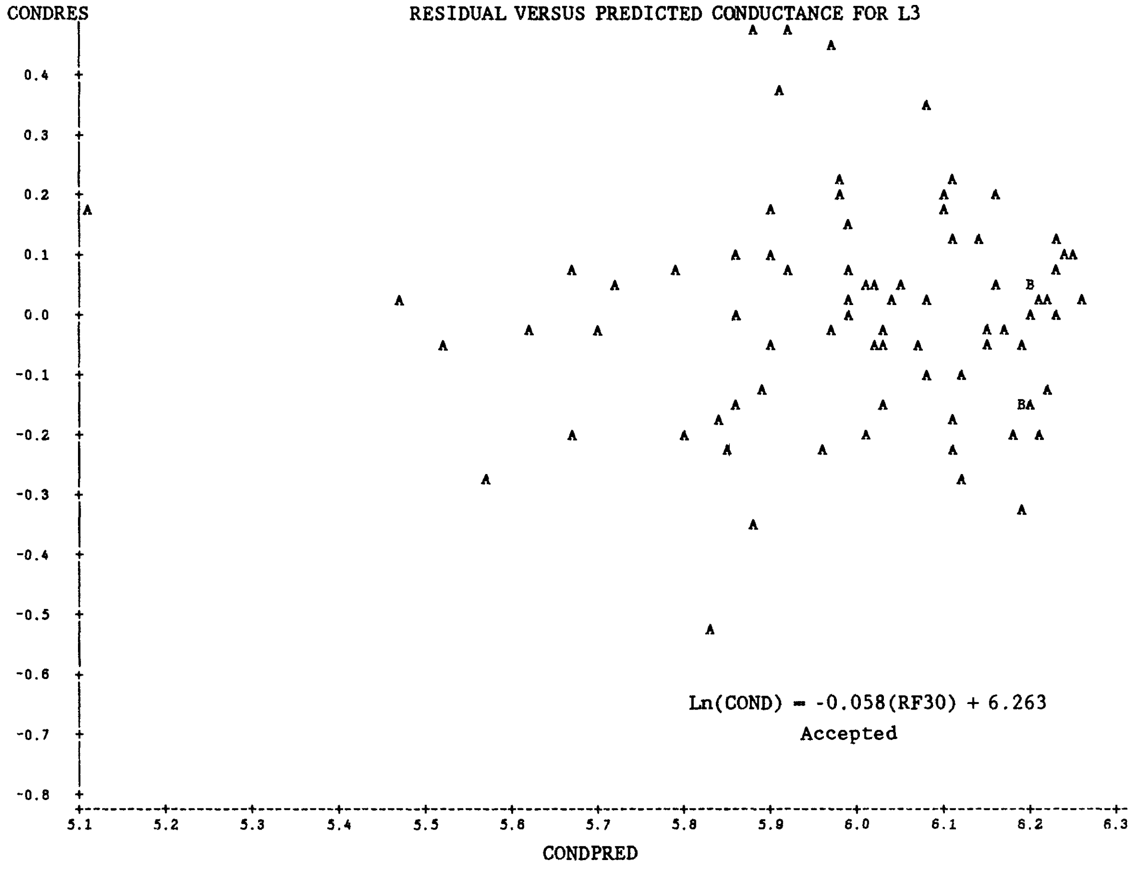
Conductance for S190
Orthophosphate for S190
Total Kjeldahl nitrogen for S190
Total nitrogen for S190
Conductance for L3
Orthophosphate for L3
Total nitrogen for L3
Conductance for S8
Orthophosphate for S8
Nitrate for S8
Total Kjeldahl nitrogen for S8
Total nitrogen for S8
Conductance for S140
Orthophosphate for S140
Conductance for S7
Orthophosphate for S7
Nitrate for S7
Total Kjeldahl nitrogen for S7
Total nitrogen for S7
Conductance for S11B
Orthophosphate for S11B
Nitrate for S11B
Total nitrogen for S11B
Conductance for S9
Orthophosphate for S9
Nitrate for S9
Orthophosphate for S151
Conductance for S12D
Orthophosphate for S12D
Conductance for S12A

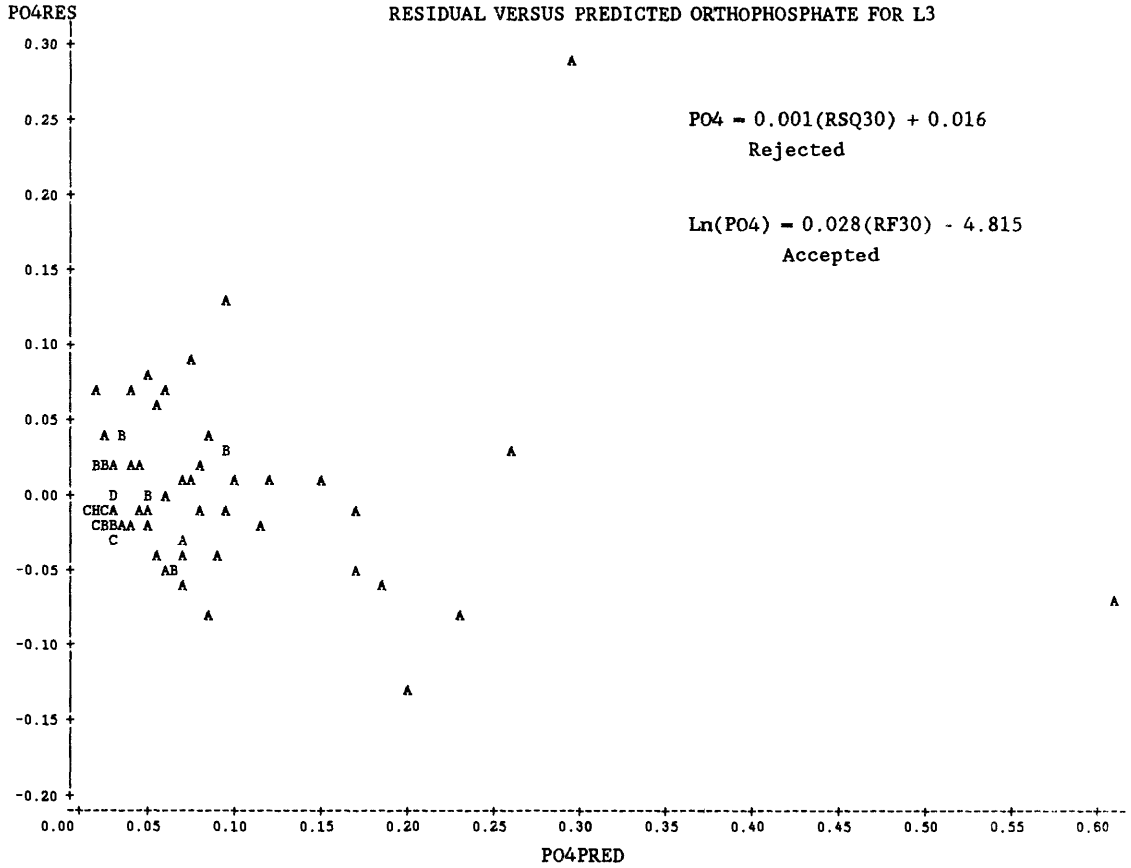

CONDRES
RESIDUAL VERSUS PREDICTED CONDUCTANCE FOR S190
Ln[COND] = -0.034(RF30) + 6.446
Accepted
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
5.85 5.90 5.95 6.00 6.05 6.10 6.15 6.20 6.25 6.30 6.35 6.40 6.45
CONDPRED


PO4RES
RESIDUAL VERSUS PREDICTED ORTHOPHOSPHATE FOR S190
PO4 = 0.002(RSQ14) + 0.004
Rejected
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0.00
-0.03
-0.06
-0.09
-0.12
-0.15
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24 0.26 0.28 0.30
PO4PRED


TKNRES
RESIDUAL VERSUS PREDICTED TOTAL KJELDAHL NITROGEN FOR S190
TKN = 0.035(INVRF30) + 1.438
Accepted
Outlier removed
TKNPRED


TNRES
RESIDUAL VERSUS PREDICTED TOTAL NITROGEN FOR S190
TN = 0.036(INVRF30) + 1.461
Accepted
Outlier removed
TNPRED





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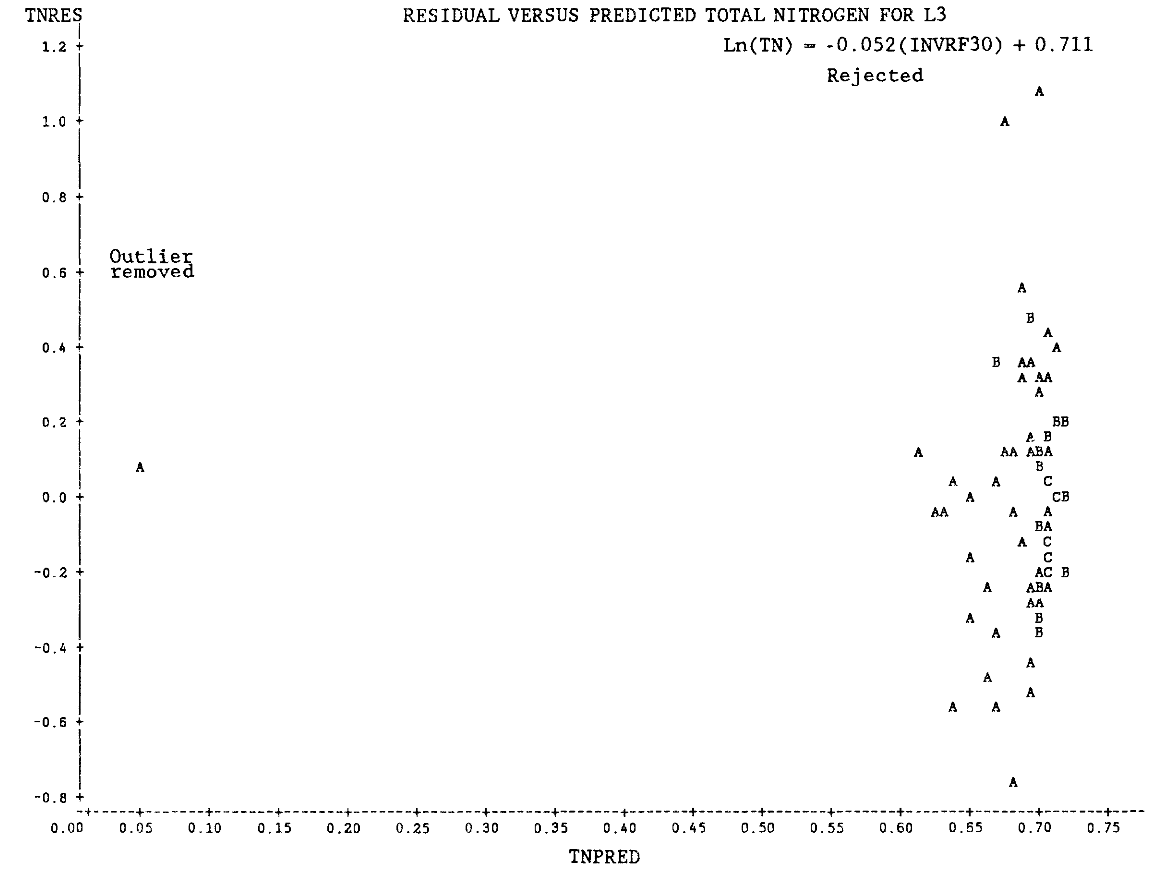
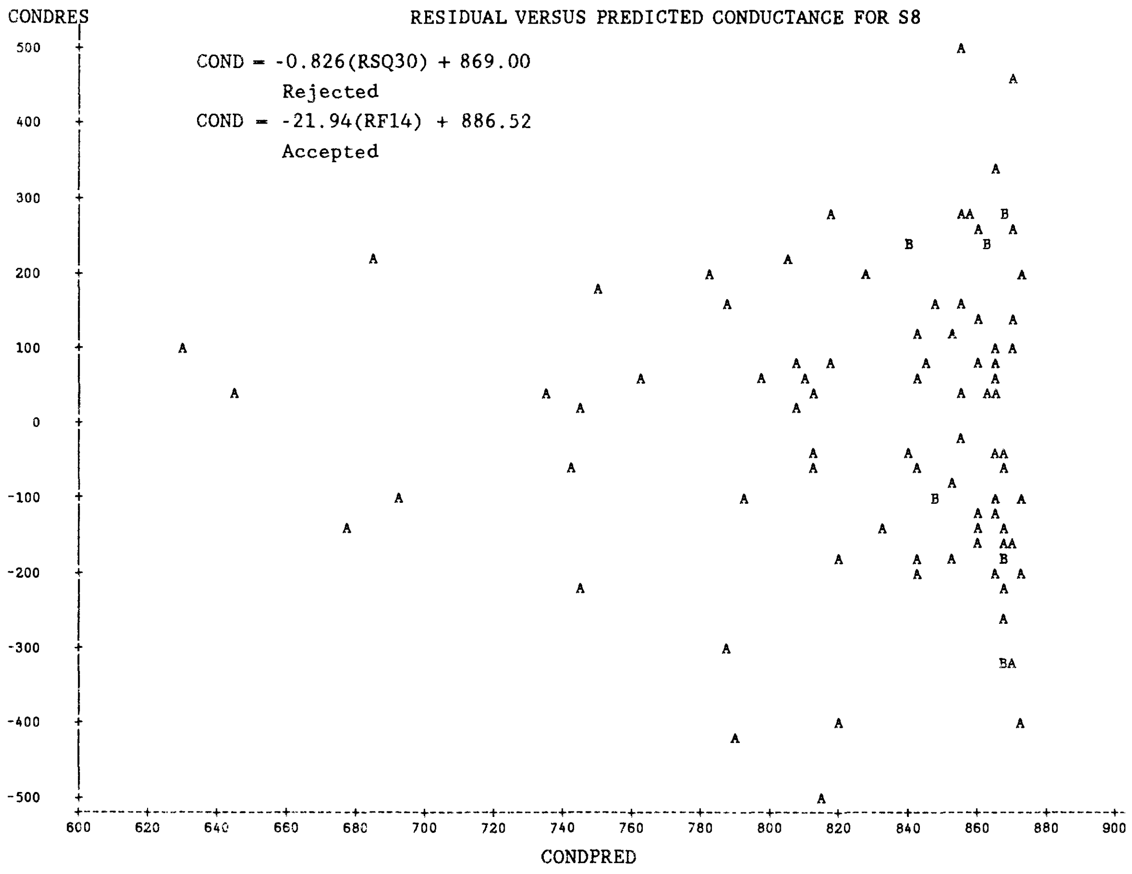
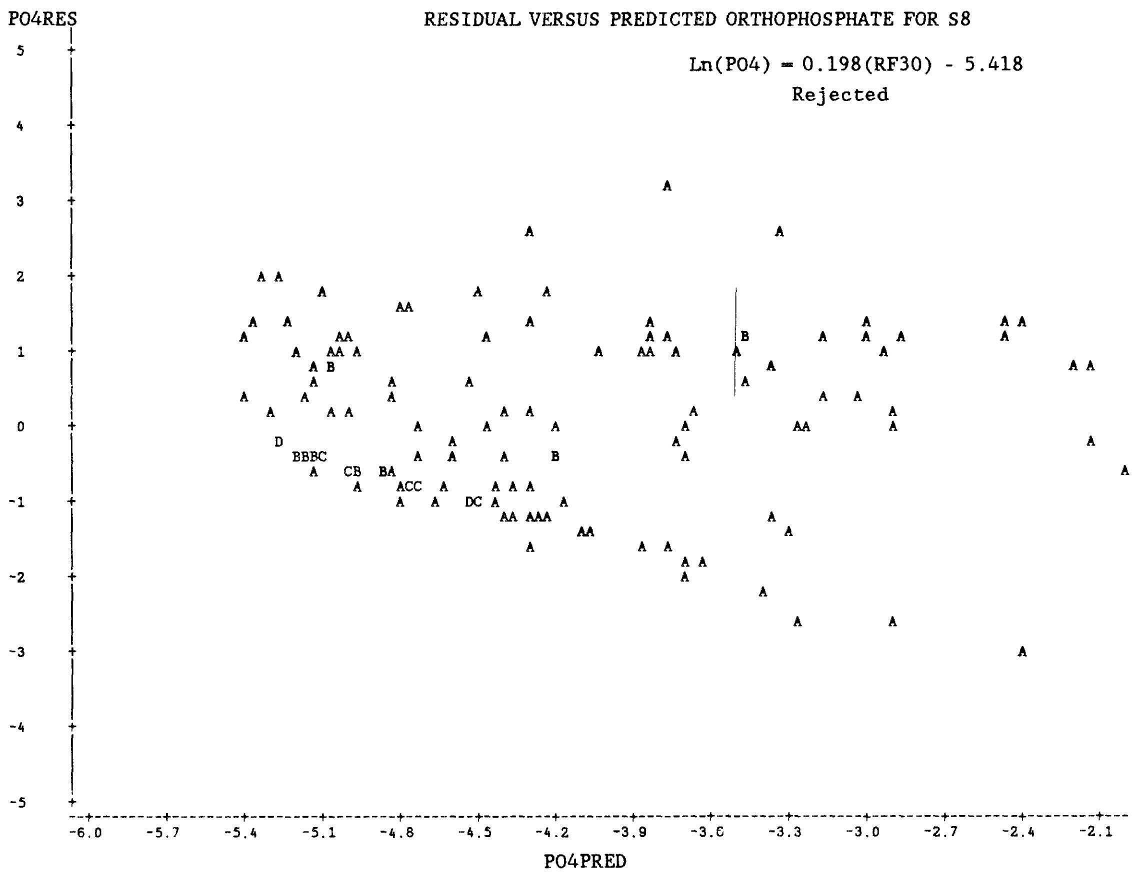
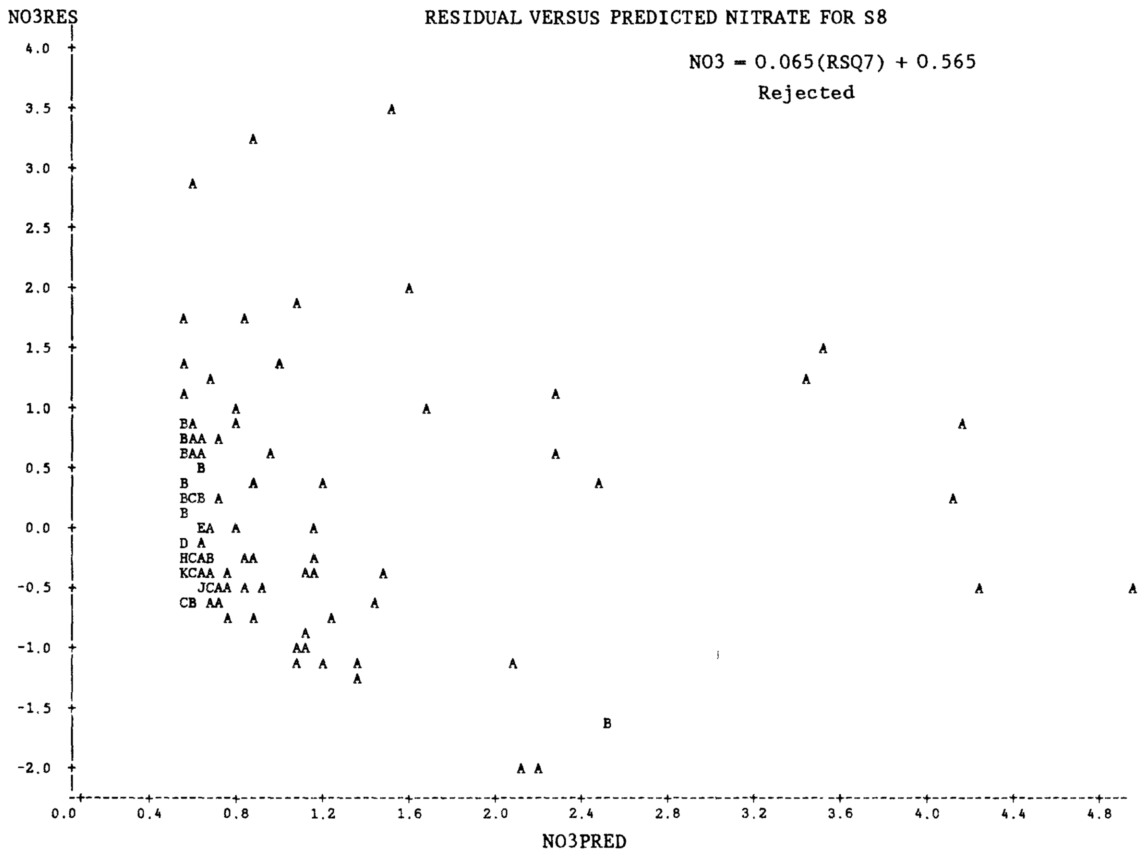

TNRES
RESIDUAL VERSUS PREDICTED TOTAL NITROGEN FOR L3
Ln(TN) = -0.052(INVRF30) + 0.711
Rejected
Outlier removed
TNPRED

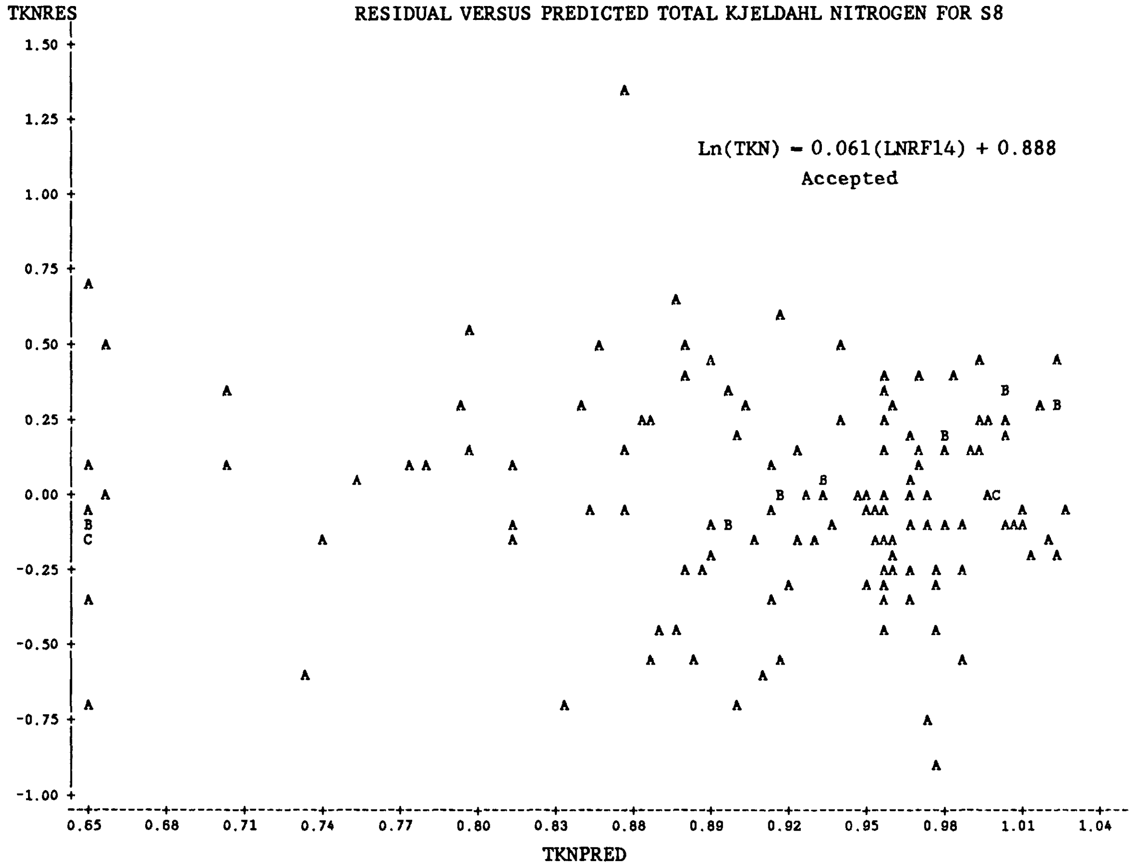

CONDRES
RESIDUAL VERSUS PREDICTED CONDUCTANCE FOR S8
COND = -0.826(RSQ30) + 869.00
Rejected
COND = -21.94(RF14) + 886.52
Accepted
CONDPRED

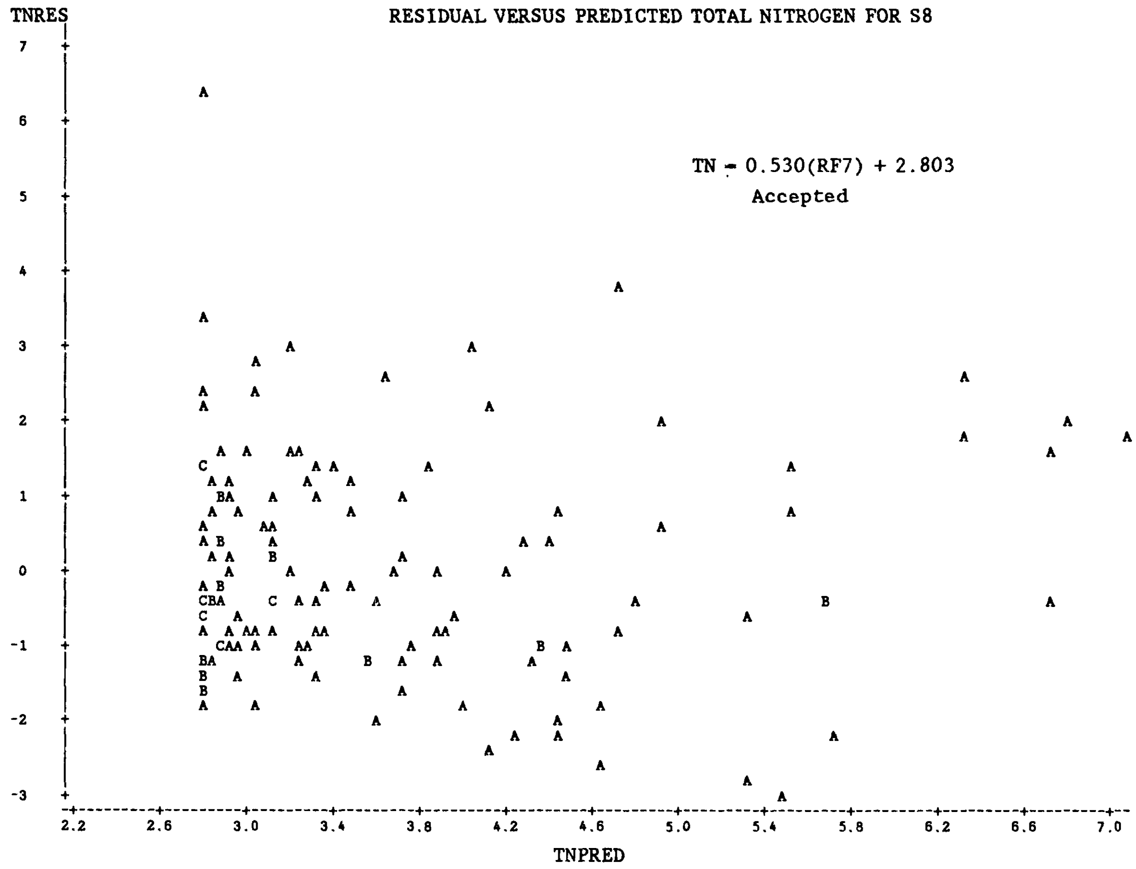


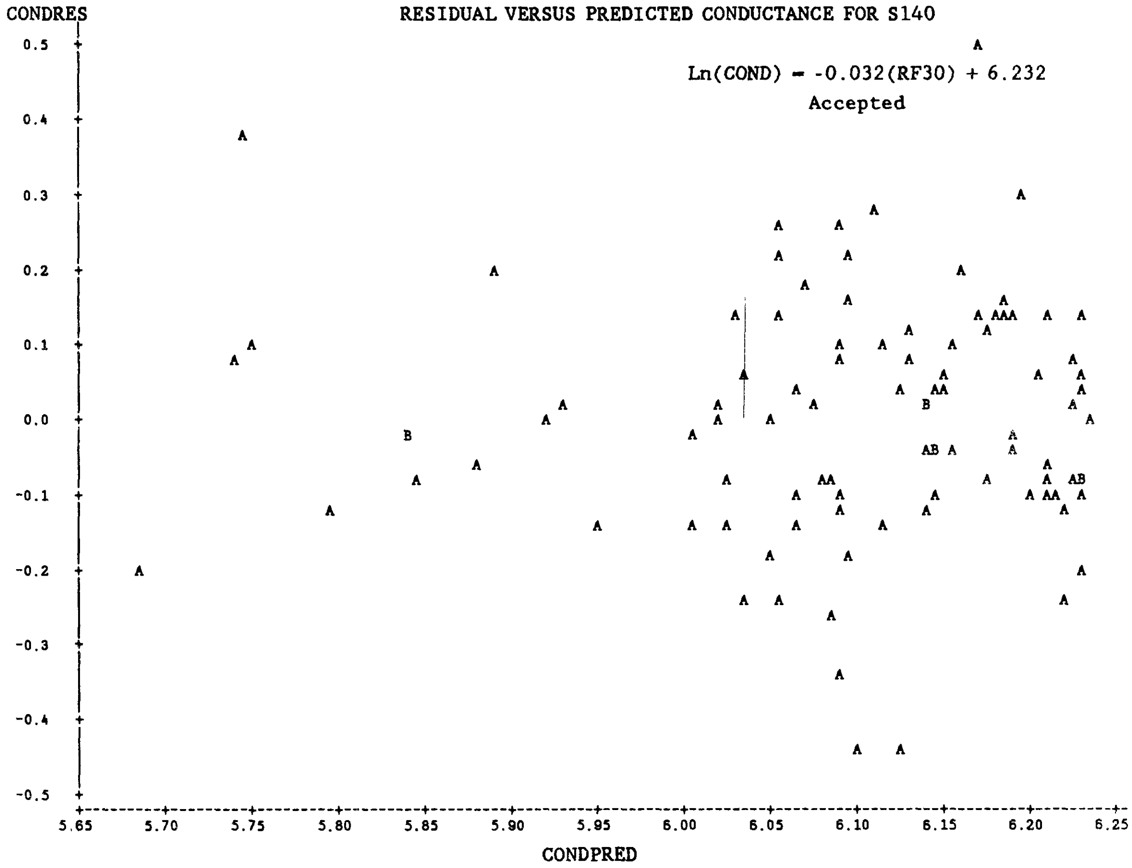
PO4RES
RESIDUAL VERSUS PREDICTED ORTHOPHOSPHATE FOR S8
Ln(PO4) = 0.198(RF30) - 5.418
Rejected
PO4PRED

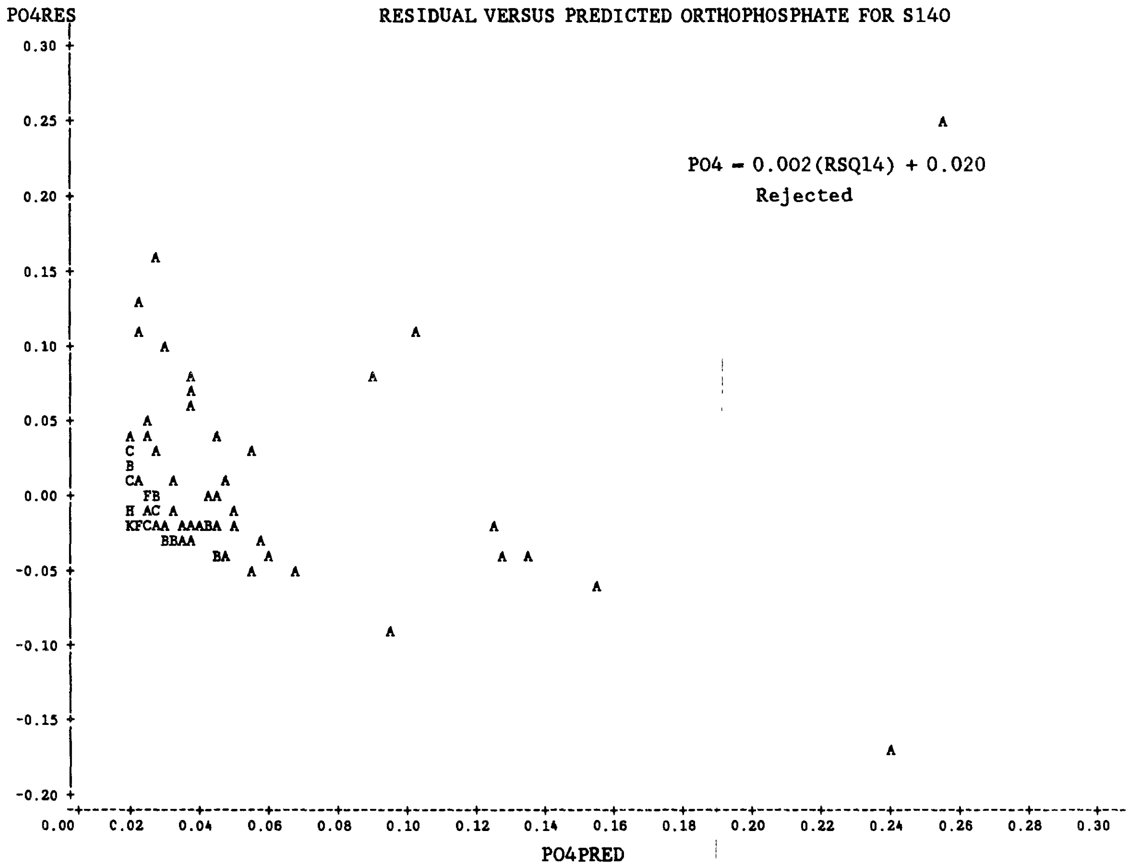


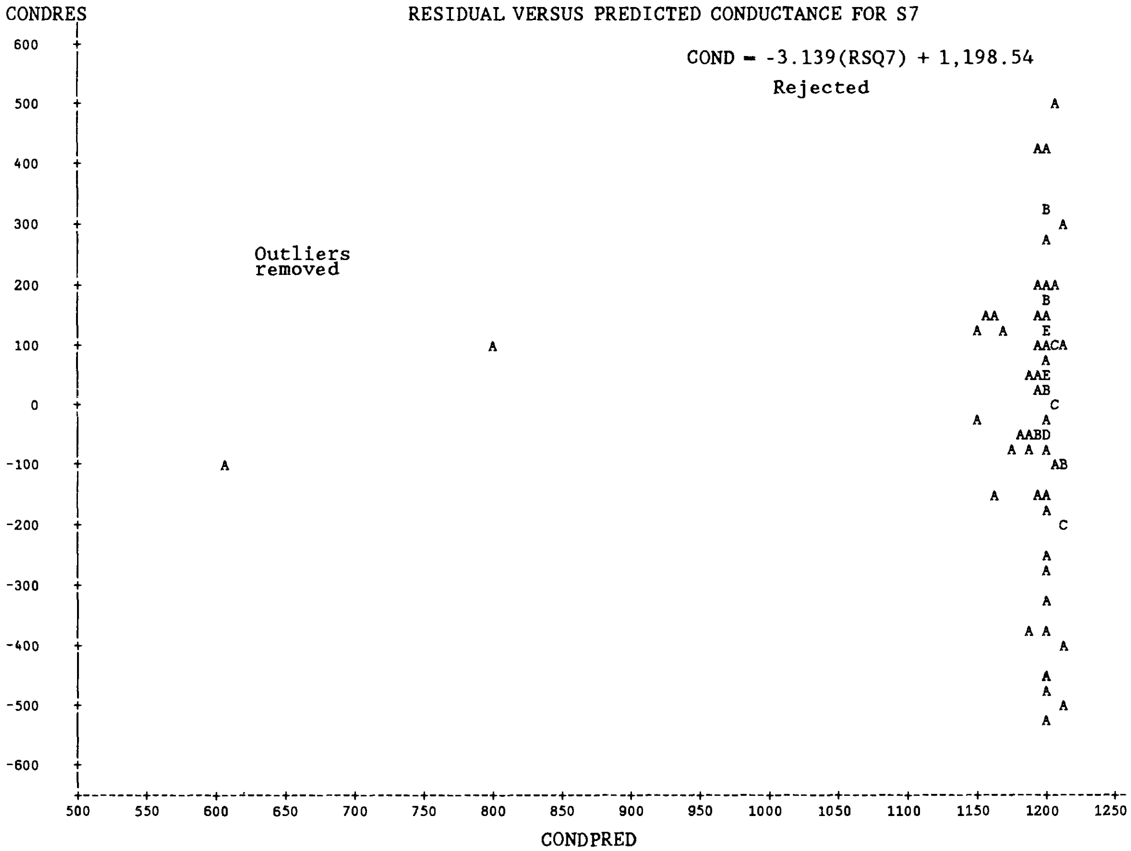
NO3RES
RESIDUAL VERSUS PREDICTED NITRATE FOR S8
NO3 = 0.065(RSQ7) + 0.565
Rejected
NO3PRED

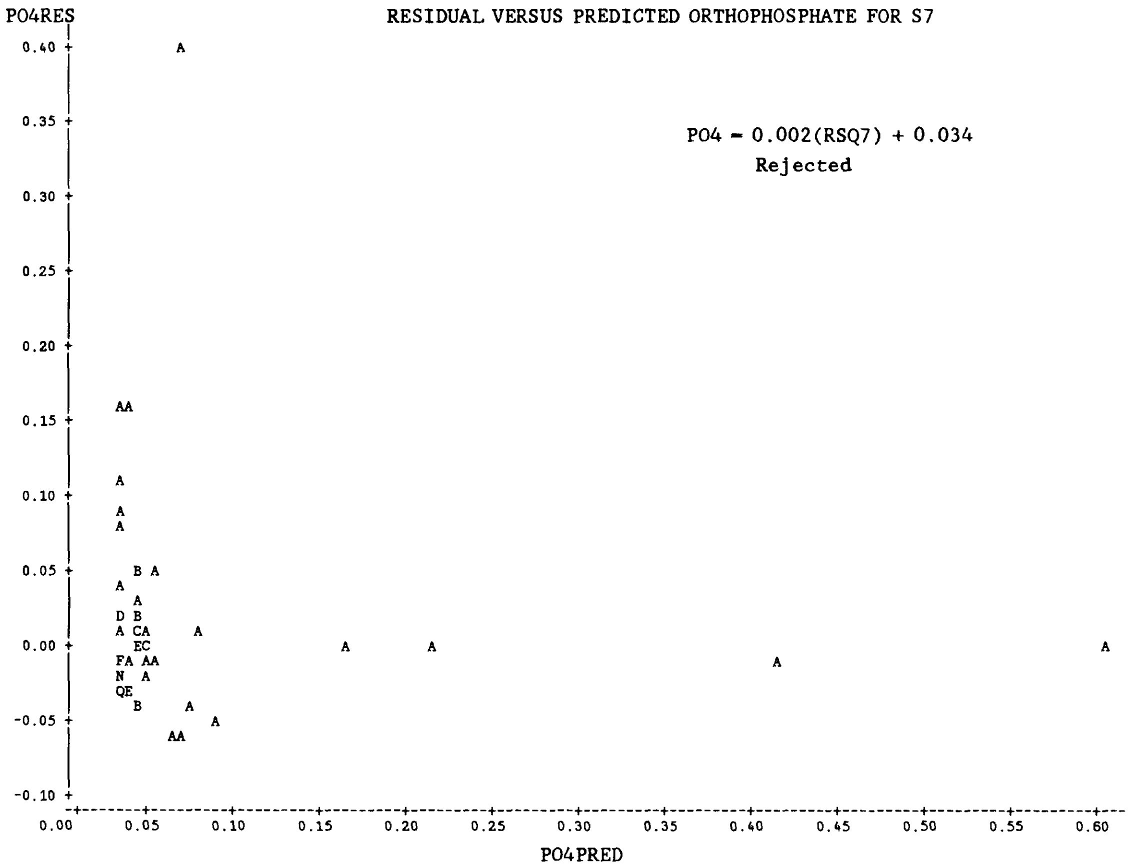

TKNRES
RESIDUAL VERSUS PREDICTED TOTAL KJELDAHL NITROGEN FOR S8
Ln(TKN) = 0.061(LNRF14) + 0.888
Accepted
TKNPRED

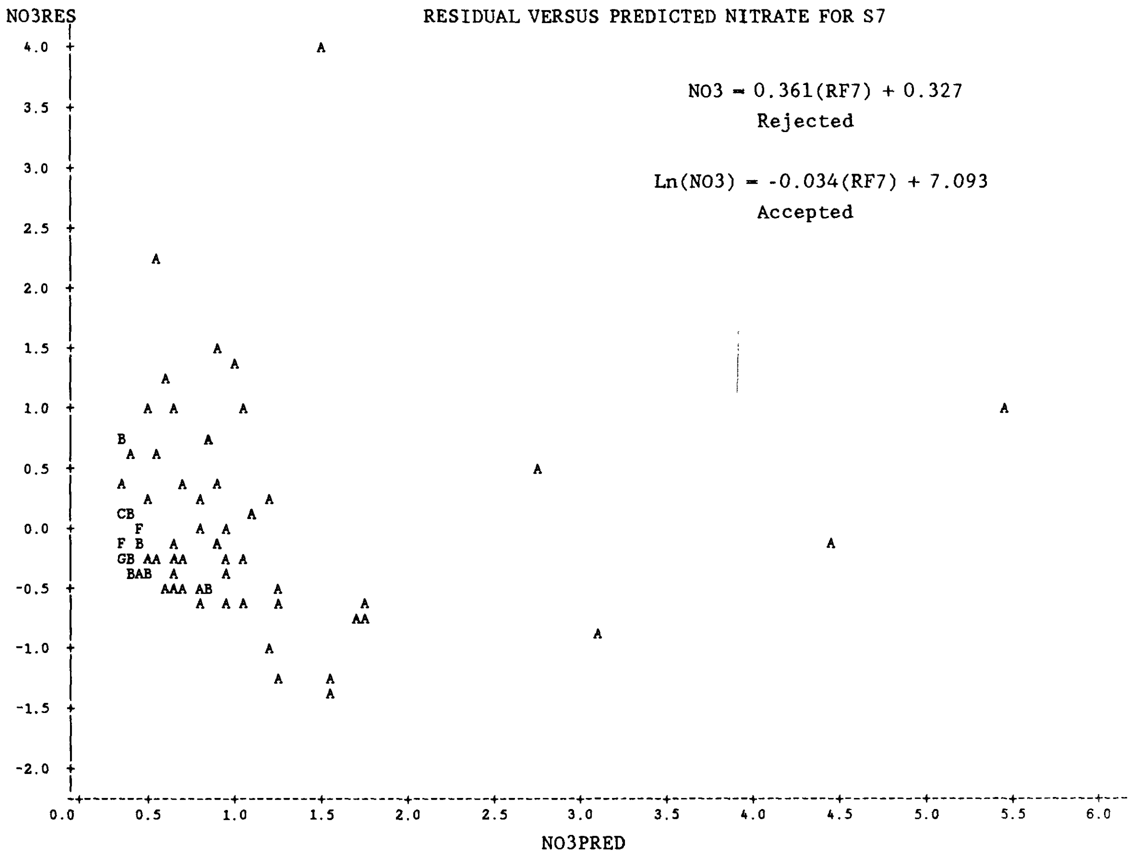

TNRES
RESIDUAL VERSUS PREDICTED TOTAL NITROGEN FOR S8
TN = 0.530(RF7) + 2.803
Accepted
TNPRED

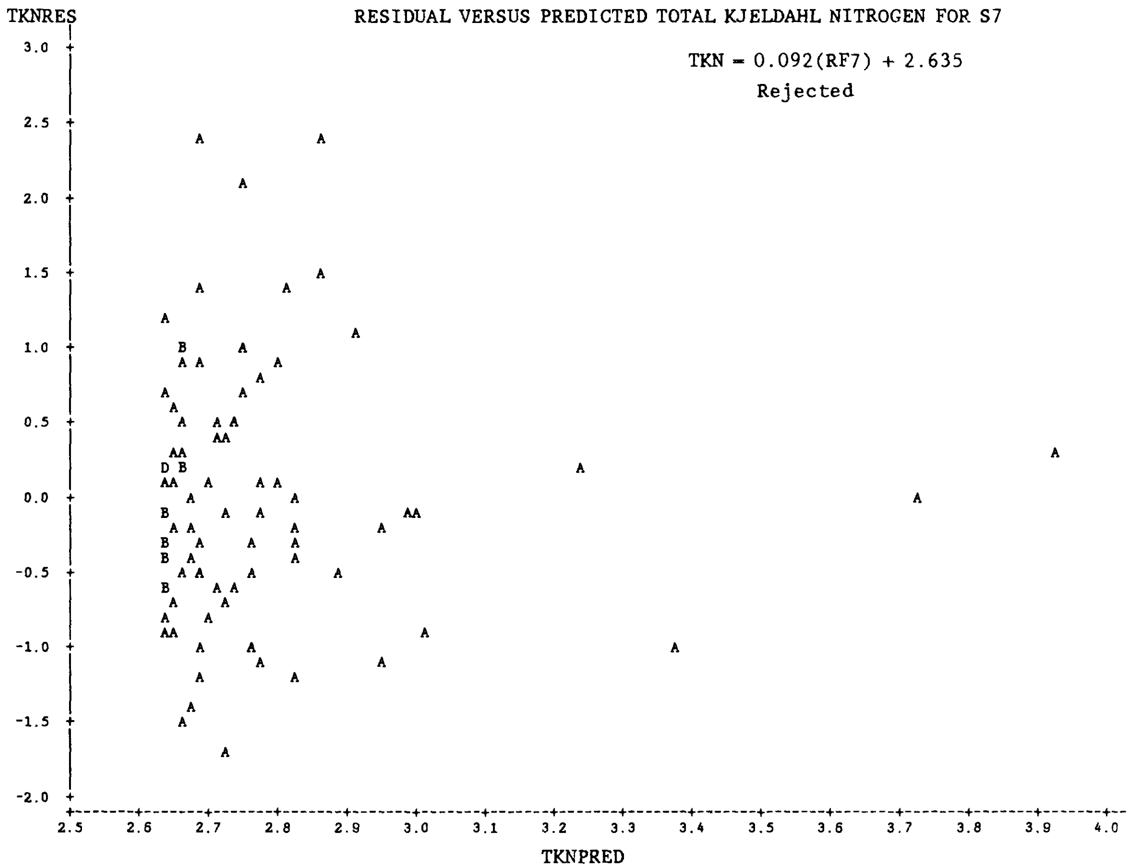

CONDRES
RESIDUAL VERSUS PREDICTED CONDUCTANCE FOR S140
Ln(COND) = -0.032(RF30) + 6.232
Accepted
CONDPRED

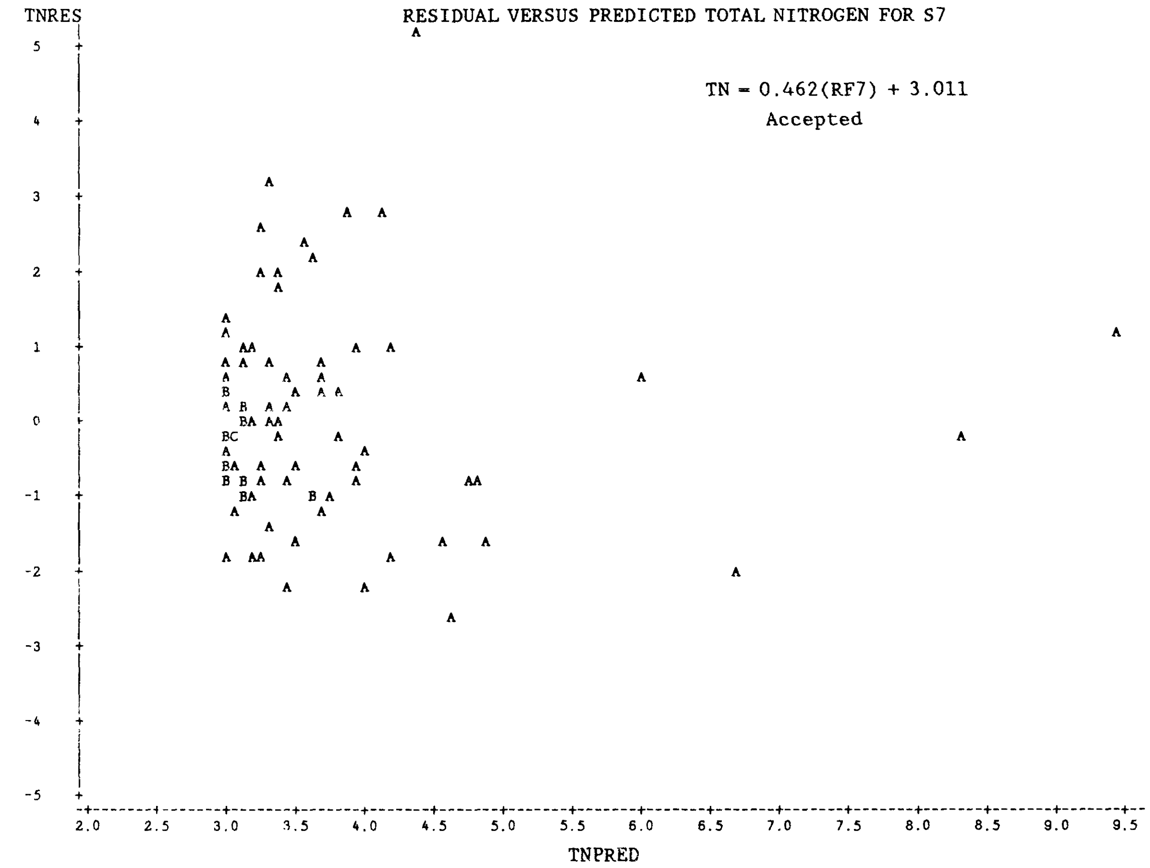

PO4RES
RESIDUAL VERSUS PREDICTED ORTHOPHOSPHATE FOR S140
PO4 = 0.002(RSQ14) + 0.020
Rejected
PO4PRED

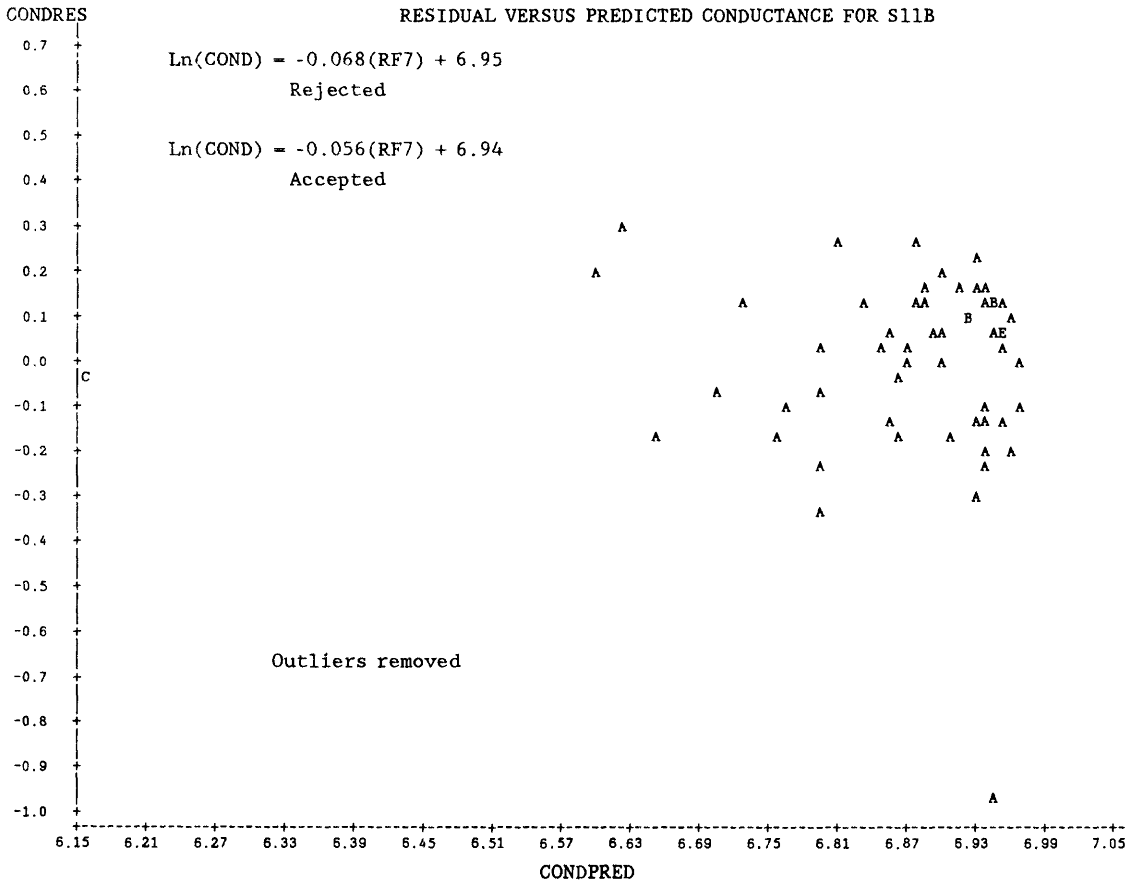

CONDRES
RESIDUAL VERSUS PREDICTED CONDUCTANCE FOR S7
COND = -3.139(RSQ7) + 1,198.54
Rejected
Outliers removed
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
CONDPRED

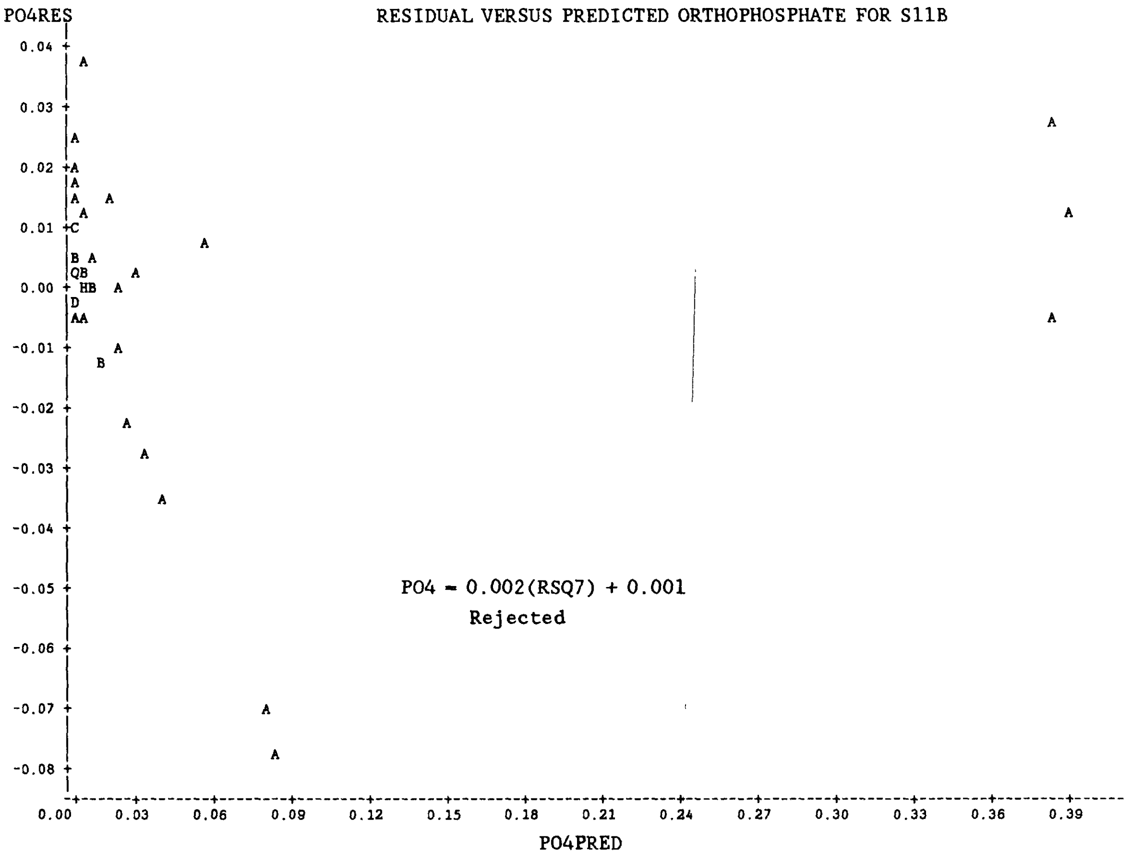

PO4RES
RESIDUAL VERSUS PREDICTED ORTHOPHOSPHATE FOR S7
PO4 = 0.002(RSQ7) + 0.034
Rejected
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
PO4PRED

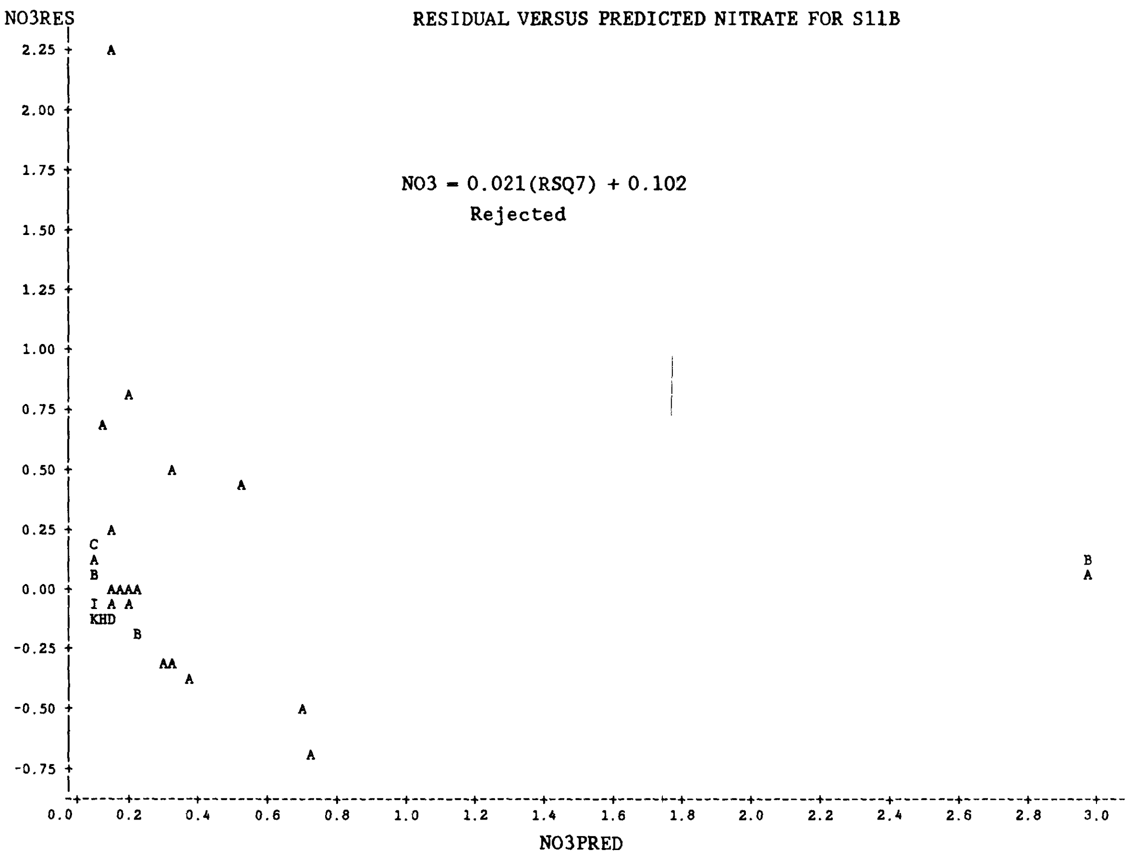

NO3RES
RESIDUAL VERSUS PREDICTED NITRATE FOR S7
NO3 = 0.361(RF7) + 0.327
Rejected
Ln(NO3) = -0.034(RF7) + 7.093
Accepted
NO3PRED

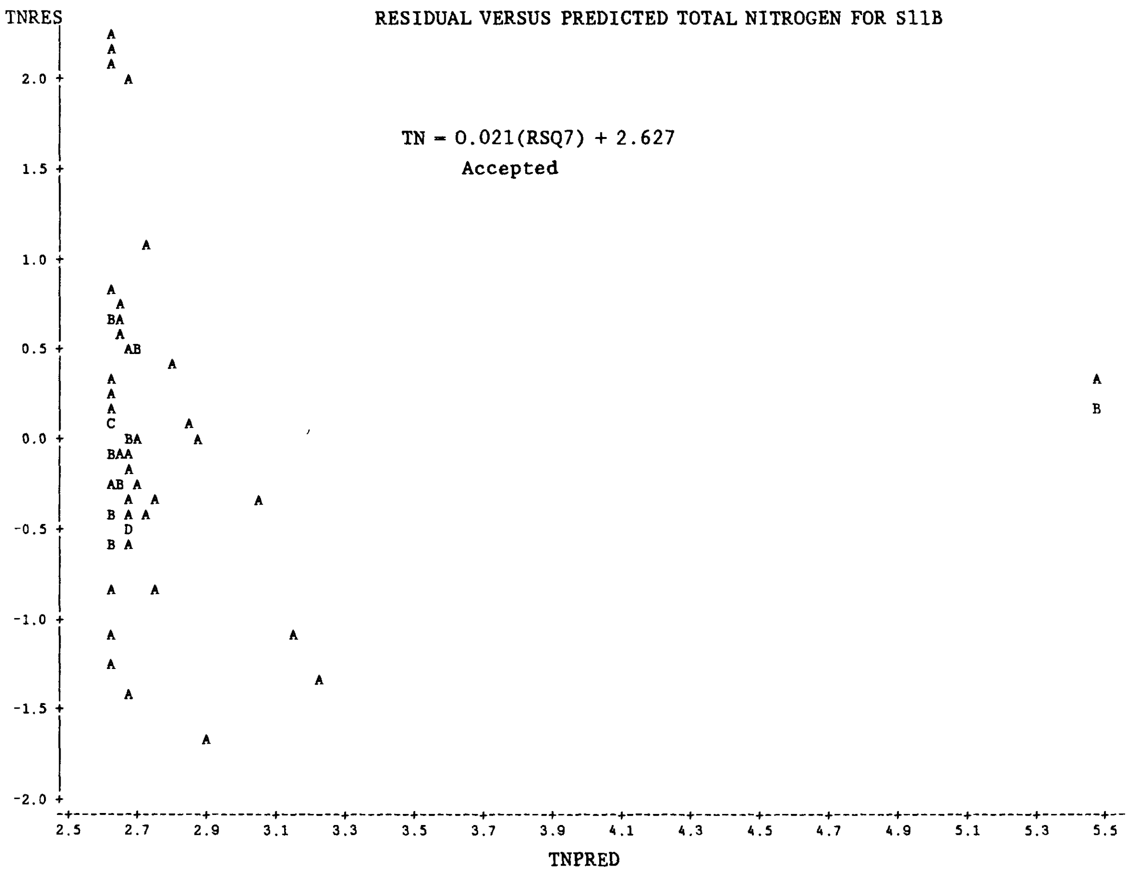

TKNRES
RESIDUAL VERSUS PREDICTED TOTAL KJELDAHL NITROGEN FOR S7
TKN = 0.092(RF7) + 2.635
Rejected
TKNPRED

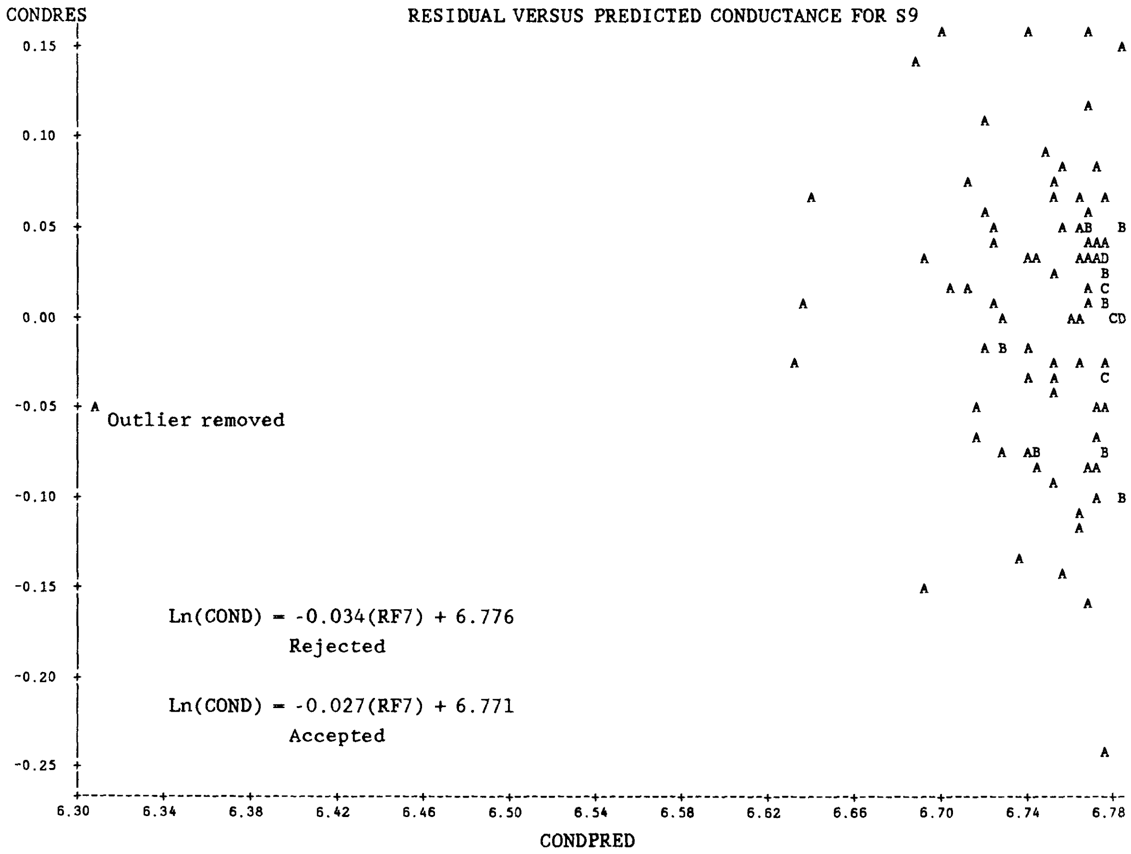

TNRES
RESIDUAL VERSUS PREDICTED TOTAL NITROGEN FOR S7
TN = 0.462(RF7) + 3.011
Accepted
TNPRED

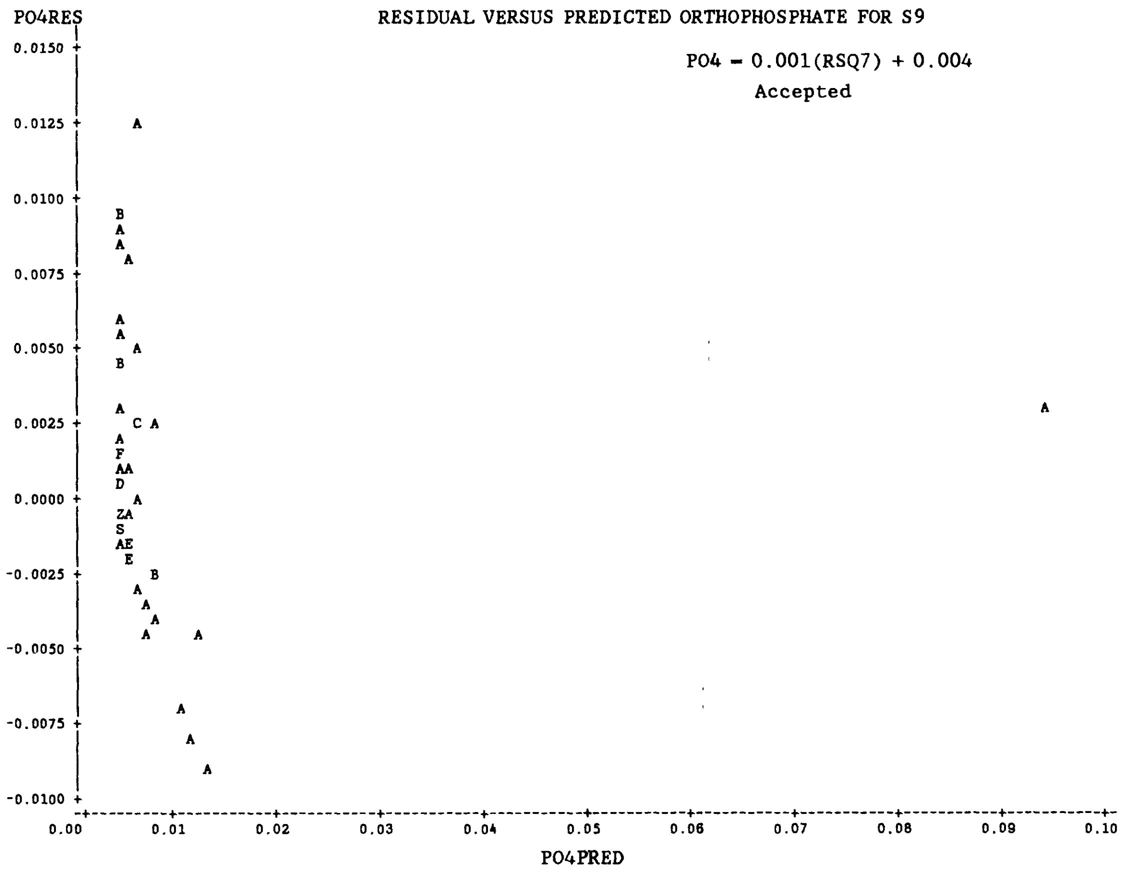

CONDRES
RESIDUAL VERSUS PREDICTED CONDUCTANCE FOR S11B
Ln(COND) = -0.068(RF7) + 6.95
Rejected
Ln(COND) = -0.056(RF7) + 6.94
Accepted
Outliers removed
CONDPRED

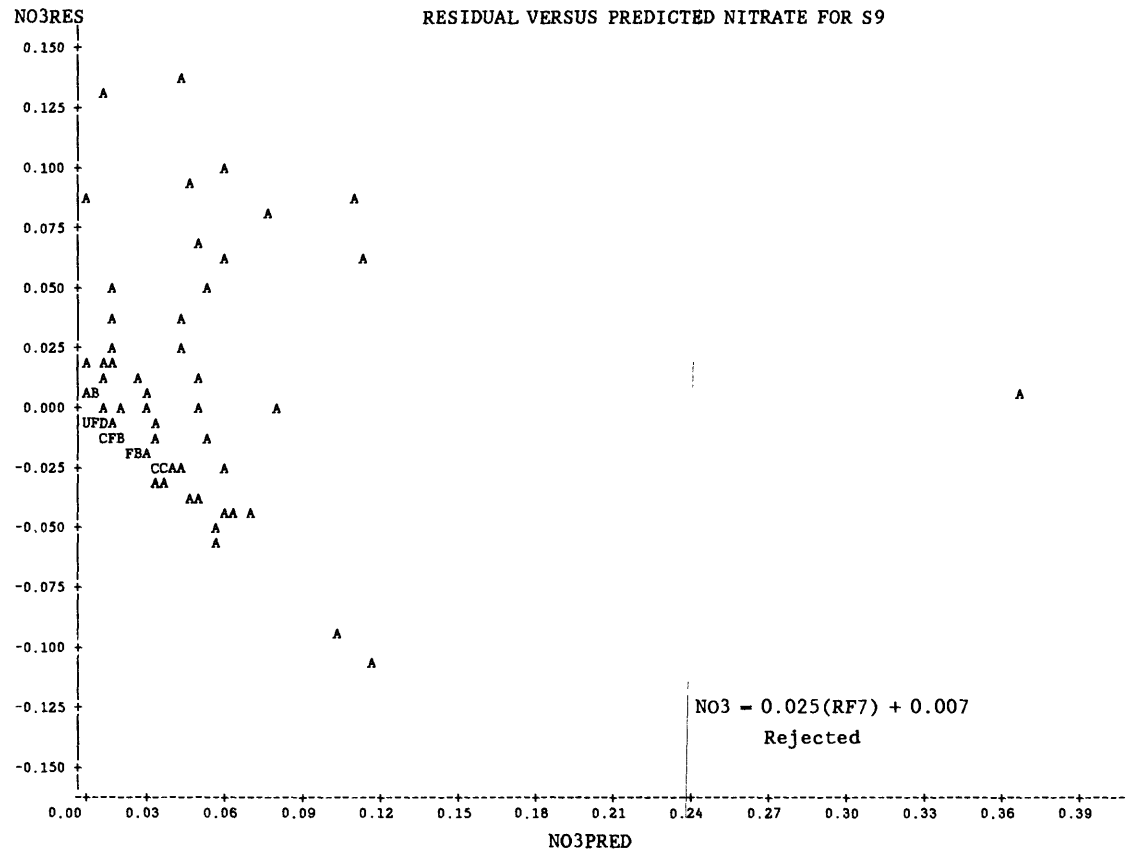

PO4RES
RESIDUAL VERSUS PREDICTED ORTHOPHOSPHATE FOR S11B
PO4 = 0.002(RSQ7) + 0.001
Rejected
PO4PRED

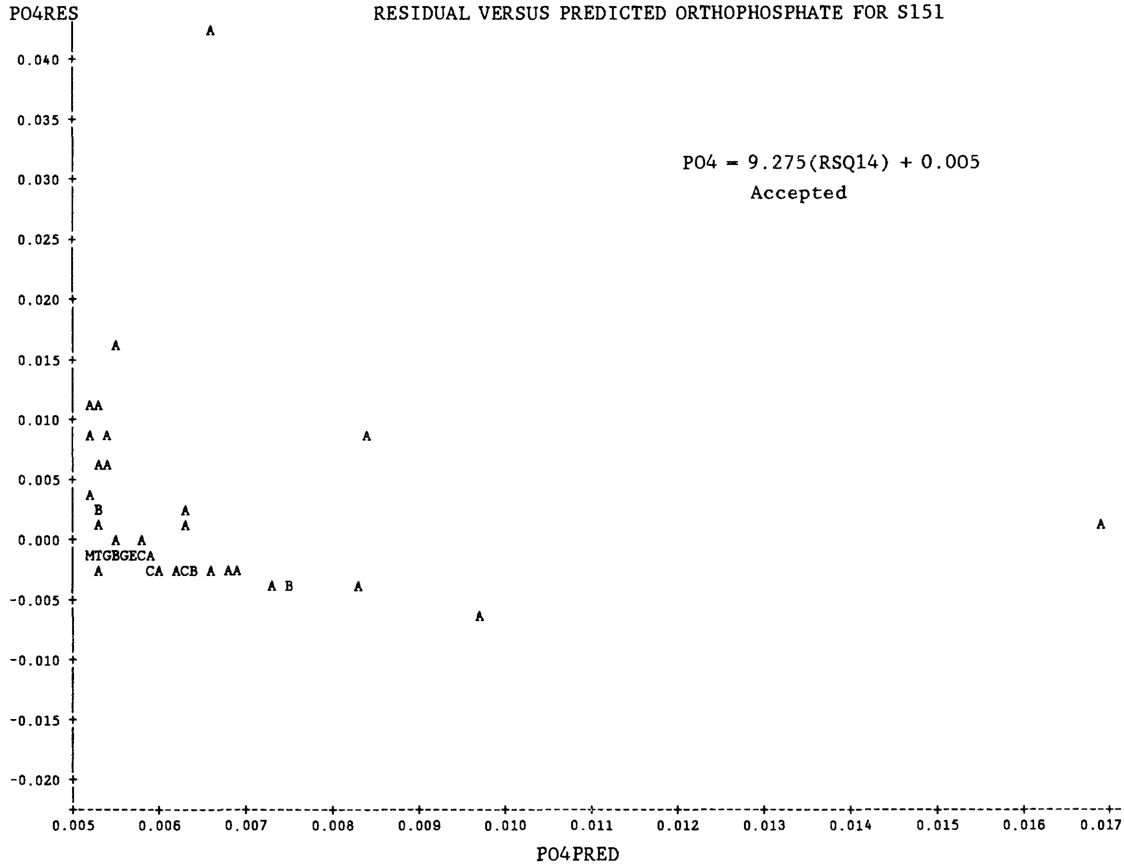

NO3RES
RESIDUAL VERSUS PREDICTED NITRATE FOR S11B
NO3 = 0.021(RSQ7) + 0.102
Rejected
NO3PRED

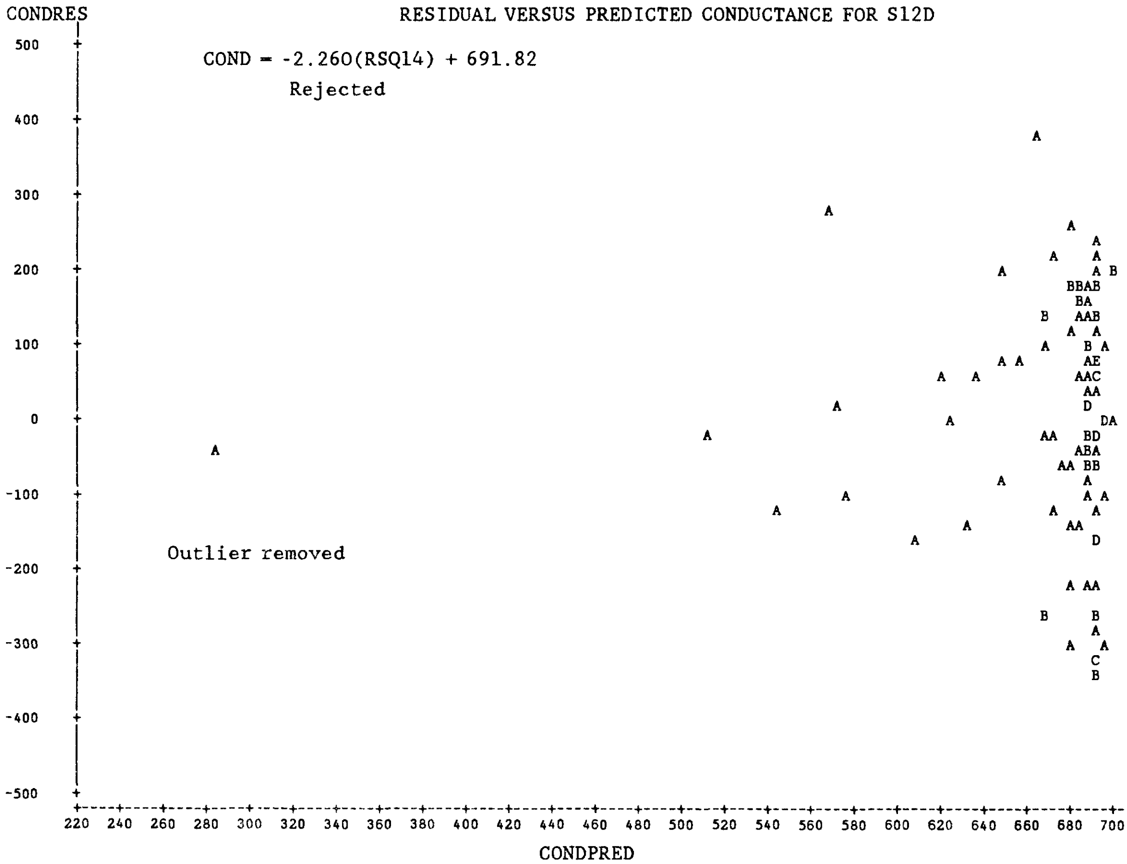

TNRES
RESIDUAL VERSUS PREDICTED TOTAL NITROGEN FOR S11B
TN = 0.021(RSQ7) + 2.627
Accepted
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
4.7
4.9
5.1
5.3
5.5
TNPRED

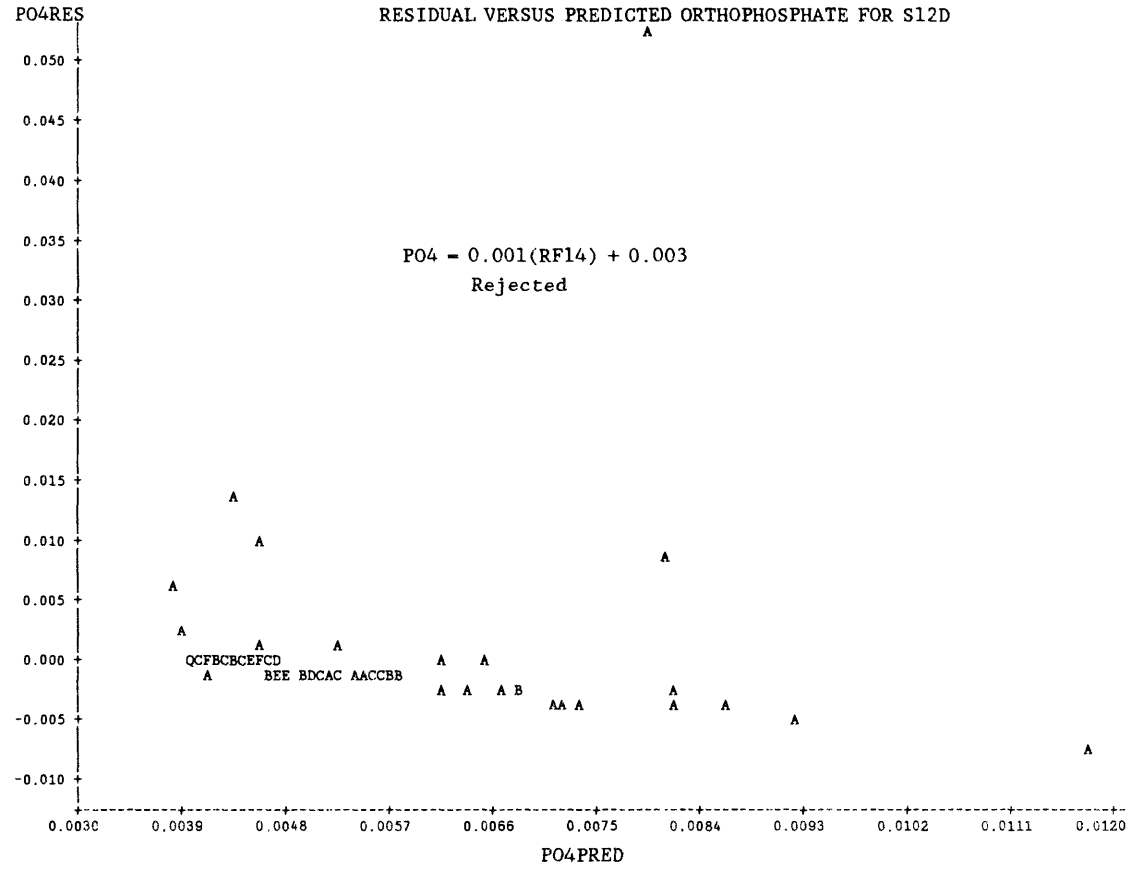

CONDRES
RESIDUAL VERSUS PREDICTED CONDUCTANCE FOR S9
Outlier removed
Ln(COND) = -0.034(RF7) + 6.776
Rejected
Ln(COND) = -0.027(RF7) + 6.771
Accepted
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
6.30
6.34
6.38
6.42
6.46
6.50
6.54
6.58
6.62
6.66
6.70
6.74
6.78
CONDPRED

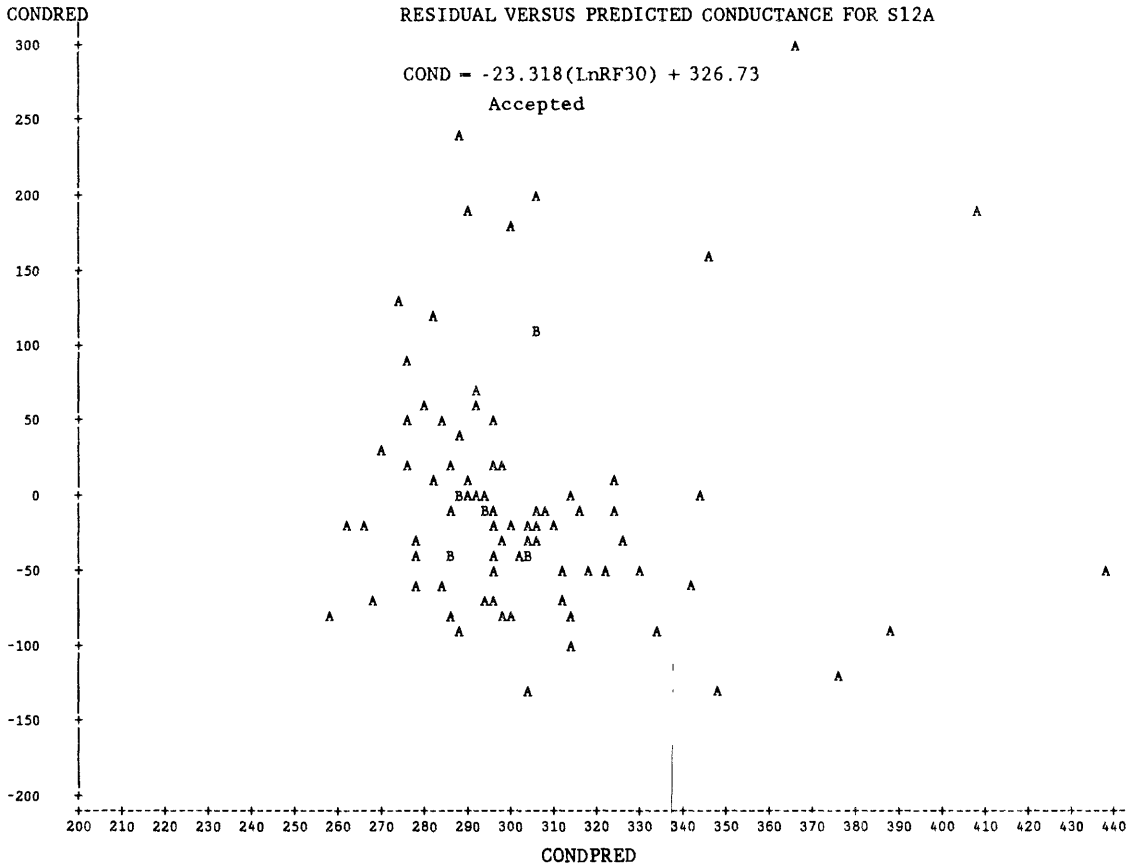

RESIDUAL VERSUS PREDICTED ORTHOPHOSPHATE FOR S9
PO4RES
PO4PRED
PO4 = 0.001(RSQ7) + 0.004
Accepted


RESIDUAL VERSUS PREDICTED NITRATE FOR S9
NO3RES
NO3PRED
NO3 = 0.025(RF7) + 0.007
Rejected


PO4RES
RESIDUAL VERSUS PREDICTED ORTHOPHOSPHATE FOR S151
P04 = 9.275(RSQ14) + 0.005
Accepted
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
0.005 0.006 0.007 0.008 0.009 0.010 0.011 0.012 0.013 0.014 0.015 0.016 0.017
PO4PRED


CONDRES
RESIDUAL VERSUS PREDICTED CONDUCTANCE FOR S12D
COND = -2.260(RSQ14) + 691.82
Rejected
Outlier removed
500
400
300
200
100
0
-100
-200
-300
-400
-500
220 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540 560 580 600 620 640 660 680 700
CONDPRED


RESIDUAL VERSUS PREDICTED ORTHOPHOSPHATE FOR S12D
PO4RES
PO4 = 0.001(RF14) + 0.003
Rejected
PO4PRED


RESIDUAL VERSUS PREDICTED CONDUCTANCE FOR S12A
CONDRED
COND = -23.318(LnRF30) + 326.73
Accepted
CONDPRED