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S.R. Esterby, A.H. El-Shaarawi
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NWRI Contribution No. 91-02

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S.R. Esterby[1], A.H. El-Shaarawi[2]
L.C. Keeler[1] and H.O. Block[3]

[1] Lakes Research Branch
[2] Rivers Research Branch
National Water Research Institute
Burlington, Ontario L7R 4A6

[3] Water Quality Branch
Western and Northern Region
Calgary, Alberta T2P 2M7

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MANAGEMENT PERSPECTIVE

A major reason for maintaining water quality sampling networks is the detection of changes in water quality over time, i.e., trend detection. Of importance to any analysis for trend, is the inclusion of terms in the model to account for other known sources of variability so that the trend can be detected in as short a time as possible and its magnitude estimated precisely and without bias. Further, the form of the change needs also to be modelled correctly, e.g., a step change or a linear trend. In this report, analysis of specific conductance data from the Bow and South Saskatchewan Rivers, with approximately monthly sampling frequency, are analyzed by a nonparametric method, Kendall's seasonal τ, and by regression methods with seasonal components included in the regression model. Consistent conclusions about the existence of a change in concentration over time and the size of the change were obtained by the methods for a linear change, illustrating the usefulness of nonparametric methods, and, equally important, the applicability of regression methods if an appropriate model is formulated. The regression methods, with the diagnostic tool of residual analysis, were more useful in assessing the form of the change. Indeed, for this set of data, the change was better characterized as lower specific conductance in 1982 and 1983 and not a linear decline over the entire period. The statistical analyses are presented in adequate detail to show the iterative nature required for analysis of data such as found in water quality sampling networks, if the analysis is to do justice to these data sets which represent such a large investment.

PERSPECTIVES DE LA DIRECTION

Le dépistage des changements au niveau de la qualité de l'eau au cours des années, c'est-à-dire le dépistage de la tendance, est une raison importante du maintien des réseaux d'échantillonnage de la qualité de l'eau. Pour toute analyse des tendances, il est important d'inclure des termes dans le modèle qui permettent d'expliquer d'autres sources connues de variabilité de manière que la tendance puisse être décelée le plus rapidement possible, et son ampleur estimée avec précision et sans biais. En outre, la forme du changement doit également être modélisée correctement, par exemple, un changement progressif ou une tendance linéaire. Dans le présent rapport, les données sur la conductivité spécifique des rivières Bow et Saskatchewan Sud, avec une fréquence d'échantillonnage à peu près mensuelle, sont analysées par une méthode non paramétrique, la valeur saisonnière τ de Kendall, et par des méthodes de régression avec des composantes saisonnières incluses dans le modèle de régression. Des conclusions uniformes au sujet de l'existence d'une variation de la concentration au cours des années et l'importance du changement ont été obtenues par les méthodes du changement linéaire, ce qui montre l'utilité des méthodes non paramétriques, et de l'applicabilité tout aussi importante des méthodes de régression si un modèle approprié est formulé. Les méthodes de régression, avec comme outil de diagnostique l'analyse résiduelle, étaient plus utiles pour évaluer la forme du changement. En effet, pour ce jeu de données, le changement était mieux caractérisé comme conductivité spécifique faible en 1982 et 1983, et non pas comme une baisse linéaire pendant toute la période. Les analyses statistiques sont présentées en détails adéquats pour montrer la nature itérative nécessaire pour analyser les données comme celles que l'on obtient dans les réseaux d'échantillonnage de la qualité de l'eau, si l'analyse doit faire justice à ces jeux de données qui représentent un investissement aussi important.

ABSTRACT

The specific conductance data from five sampling stations on the Bow and South Saskatchewan River system, collected between 1978 and 1986, are analyzed for the detection and estimation of temporal trend. The features of the data set pertinent to the choice of statistical methods are the record length, monthly sampling frequency, seasonality and missing data. Nonparametric methods based on Kendall's τ are used to test for the existence of monotonic change, to test for the homogeneity of the trend in different months, and to estimate the size of the change. Plots of the data are shown to be necessary to help interpret the data. The data are also analyzed by regression methods using a model with sinusoidal components for seasonality and either a linear term or yearly means for changes over years. Both the nonparametric and regression methods detected temporal changes for the same four stations. The plots by month and the plots of the estimated yearly means from the regression analysis showed that this was not strictly in the form of a linear decline, and multiple comparison procedures on the yearly mean estimates provided the most informative summary of the changes. Although there were some differences between stations, the common feature was a drop in specific conductance in 1982 and 1983. There was good agreement between the nonparametric methods and the regression model with the linear trend term, not only for detection of change but also in the estimation of the size of the change. This illustrates the usefulness of the nonparametric methods, and equally important, the applicability of regression methods for this type of data if an appropriate model is formulated, that is, a model including seasonal terms, not just simple linear regression, as is commonly done.

RÉSUMÉ

Les chercheurs ont analysé les données sur la conductivité spécifique, recueillies entre 1978 et 1986, dans cinq stations d'échantillonnage sur le réseau des rivières Bow et Saskatchewan Sud, afin de déceler et d'évaluer la tendance temporelle. Les caractéristiques de l'ensemble de données pertinentes au choix des méthodes statistiques sont la longueur record, la fréquence de l'échantillonnage mensuel, la saisonnalité et les données manquantes. Des méthodes non paramétriques fondées sur la valeur τ de Kendall sont utilisées afin de vérifier l'existence de changement monotonique, l'homogénéité de la tendance au cours des différents mois, et pour évaluer l'ampleur du changement. Des tracés graphiques des données semblent être nécessaires pour interpréter les données. Celles-ci sont également analysées par des méthodes de régression à l'aide d'un modèle à composantes sinusoïdales en ce qui concerne la saisonnalité, et un terme linéaire ou des moyennes annuelles, pour les changements survenus au cours des années. Les méthodes non paramétriques et les méthodes de régression ont toutes deux décelé des changements temporels au niveau des quatre mêmes stations. Les tracés graphiques par mois et les tracés des moyennes annuelles estimées et établies par l'analyse de régression, ont montré que le changement n'était pas strictement sous forme de baisse linéaire, et des méthodes de comparaison multiple des estimations de la moyenne annuelle ont fourni le résumé le plus informatif des changements. Même si certaines différences ont été relevées entre les stations, une baisse de la conductivité spécifique en 1982 et 1983, était un élément commun. Les chercheurs ont relevé une bonne concordance avec la tendance linéaire, entre les méthodes non paramétriques et les modèles de régression, non seulement pour le dépistage du changement, mais aussi au niveau de l'estimation de l'ampleur du changement. Ces résultats montrent l'utilité des méthodes non paramétriques, et de l'applicabilité tout aussi importante des méthodes de régression pour ce type de données si un modèle approprié est formulé, c'est-à-dire un modèle incluant des termes saisonniers et non simplement une régression linéaire, comme cela se fait habituellement.

INTRODUCTION

Methods for time trend detection and estimation, suitable for water quality data sets such as that from the Bow and South Saskatchewan Rivers, are considered here. Several features of the data set determine the class of methods which can be used. The record length is moderate (about 10 years) and the sampling interval within the year is long enough so that the presence of serial correlation is unlikely (van Belle and Hughes, 1984, suggest that the interval should be at least two weeks). The sampling and analytical techniques are consistent over the period of interest or the effect of changes can be removed in the statistical analysis. Features, such as seasonality and missing data, are present and must be taken into account.

There is considerable interest in the use of nonparametric techniques in testing for trend in water quality data sets, due partly to the paper of Hirsch et al. (1982) which illustrated the use of a blocked Kendall's τ, called the seasonal Kendall test for trend by these authors. An alternative to τ is Spearman's rank correlation coefficient, ρ_s, which has also been used in testing for trend in water quality data (e.g., Lettenmaier, 1976; El-Shaarawi et al., 1983). These procedures involve testing the hypothesis of randomness using a statistic that is powerful for the alternative of a trend. Hirsch et al. (1982) note that the form of the trend is general, that is, a monotonic change over time including both gradual and sudden changes.

The reasons for using nonparametric techniques are their robustness to nonnormality and extreme values and the ease with which values below the detection limit can be handled. In addition, both ρ_s and τ compare favourably to the parametric alternative, the regression slope estimator for β, when the normality assumption is met, in that they both have asymptotic relative efficiency of about 0.98 relative to β (Conover, 1980). ρ_s is slightly more powerful than τ, but τ converges to normality faster (van Belle and Hughes, 1984). In the presence of ties, the variance of ρ_s is unchanged and thus ρ_s is easier to use than τ (Taylor, 1987). Values below the detection limit are treated as ties in the nonparametric methods and hence limitations on the usefulness of these techniques are just those due to the presence of ties. An additional important point to note is that, in general, nonparametric techniques are no longer nonparametric in the presence of serial correlation, and Hirsch et al. (1982), through simulation, show that the seasonal Kendall test is not robust to serial correlation.

The procedure described by Hirsch et al. (1982) accounts for seasonality through blocking, either months or seasons, and can be calculated in the presence of missing values, e.g., not all months were measured every year. Implicit to this procedure, is the assumption that the trend is the same for all months or seasons. Van Belle and Hughes (1984) give a modification that permits a test of homogeneity of trend as well as a test for trend. If homogeneity exists then a measure of average trend such as the seasonal Kendall τ can be used, otherwise only tests within individual months or seasons or within sets of homogeneous months or seasons are appropriate. The measure of average trend used in the seasonal Kendall test is actually a weighted average of the τ's in the individual months. The results of a limited Monte Carlo study (Taylor, 1987) show that this weighted average is only slightly less powerful than the optimally weighted average, an example of which is the measure of average trend used by van Belle and Hughes.

Regression methods can also be used for trend testing and estimation with data sets such as described above. Unequal spacing of observations and missing data values can be handled by these methods. However, for these and methods such as the seasonal Kendall test, the interpretation of the results need always be done in view of how much information is missing due to gaps in the record.

In this chapter, specific conductance data from the five stations on the Bow and South Saskatchewan Rivers collected between 1978 and 1986 are analyzed by methods based on Kendall's τ and by regression methods. Prior to these analyses, the specific conductance data from each station was analyzed by the methods of the previous chapter. No change in specific conductance due to change of laboratory in 1983, was detected.

STATISTICAL METHODS

Methods Based on Kendall's τ

Kendall's τ, calculated on a sample $y_1, y_2, \ldots, y_n$, with y_i the measurement in year i, is given by

$$\tau = \frac{S}{\frac{1}{2}n(n-1)} \tag{1}$$

where $$S = \sum_{i<k}\sum \operatorname{sgn}(y_k - y_i) \tag{2}$$

and

$$\operatorname{sgn}(y_k - y_i) = \begin{cases} 1 & \text{if} \quad y_k \; y_i \\ 0 & \text{if} \quad y_k = y_i \\ -1 & \text{if} \quad y_k \; y_i. \end{cases} \tag{3}$$

Since the y's are ordered in time, S is the difference between the number of pairs where the measurement in a later year is larger than the measurement in a earlier year minus the number of pairs where the later measurement is smaller. Either S or τ may be used in testing for trend.

Consider data collected over m years at a particular station and let y_{ij} be the measurement on a water quality variable in the jth month of year i, where there are measurements in month j in n_j years. Thus the total number of measurements is

$$n. = \sum_{j=1}^{12} n_j.$$

If seasonality can be characterized by higher values in certain months of each year, to prevent seasonality from obscuring the trend, the trend statistic can be computed separately for each month. An average trend statistic is obtained from these monthly values. Hirsch _et al_. (1982) use

$$S = \sum_{j=1}^{12} S_j \tag{4}$$

where S_j, the statistic for month j, is given by

$$S_j = \sum_{i<k}\sum \operatorname{sgn}(y_{kj}-y_{ij}). \tag{5}$$

The test for trend consists of testing the null hypothesis, H_0, that the measurements in month j are random and identically distributed for j = 1,2,...,12, against the alternative that for at least one month the $\underline{y}_j$ are not identically distributed. The variance of S_j is

$$\operatorname{var}(S_j) = n_j(n_j-1)(2n_j+5)/18 \tag{6}$$

and in the presence of ties

$$\operatorname{var}(S_j) = \{n_j(n_j-1)(2n_j+5) - \sum_t t(t-1)(2t+5)\}/18 \tag{7}$$

where t = number of y_{ij} involved in a tie. The test of the null hypothesis is based upon

$$Z = \begin{cases} \dfrac{S-1}{[\operatorname{var}(S)]^{\frac{1}{2}}} & S>0 \\ 0 & S=0 \\ \dfrac{S+1}{[\operatorname{var}(S)]^{\frac{1}{2}}} & S<0 \end{cases} \tag{8}$$

where Z is approximately N(0,1), −1 and +1 are continuity corrections, and

$$\operatorname{var}(S) = \sum_{j=1}^{12} \operatorname{var}(S_j). \tag{9}$$

The test for homogeneity of trend used by van Belle and Hughes (1984), is given by

$$X^2_{\text{homog.}} = \sum_{j=1}^{12} Z_j^2 - 12\,\bar{Z}_{\cdot}^2 = \sum_{j=1}^{12} (Z_j - \bar{Z}_{\cdot})^2 \qquad (10)$$

which has approximately a X^2 distribution with m-1 degrees of freedom. The Z_j are given by

$$Z_j = S_j/(\mathrm{var}(S_j))^{\frac{1}{2}} \qquad (11)$$

and

$$\bar{Z}_{\cdot} = \sum_{j=1}^{12} S_j/12. \qquad (12)$$

The corresponding test for trend is

$$X^2_{\text{trend}} = m\,\bar{Z}_{\cdot}^2 \ \sim X^2_{(1)}. \qquad (13)$$

Hirsch et al. (1982) give a nonparametric estimator of slope, B, where B is the median of all d_{ikj} where

$d_{ikj} = (y_{kj} - y_{ij})/(k-i)$ for all pairs $1 \le i < k \le n_j$ for a given j

and j = 1,2,...,12.

The above procedures are based on one measurement per month or season. If there is more than one measurement per month or season, which is likely to be the case if season is defined by combining months, several alternatives are possible (van Belle and Hughes, 1984). These include treating the values for the month within a year as ties in time, using a mean or median (if the number of values is approximately constant each year) or selecting a single value in a consistent way over all years.

Regression Methods

The analysis is similar to that of the previous chapter except that the terms corresponding to different year means are reduced to a polynomial in i, and no method or laboratory terms are included. Thus the model assuming seasonality and a linear time trend is

$$y_{is} = \mu + \beta_i + (\beta_{11} \cos \omega\, t_{is} + \beta_{12} \sin \omega\, t_{is}) + \varepsilon_{is} \qquad (14)$$

where the terms are as defined in equation (1) in the previous chapter, except that

y_{is} = water quality variable on day s of year i

and β = slope of the time trend over years.

ANALYSIS OF THE SPECIFIC CONDUCTANCE DATA

The results of the seasonal Kendall trend test are given first. Since these results alone provide little information about the nature of changes over time, a more complete analysis of the data is also described.

Tests Using Kendall's τ and Corresponding Plots

The p values in Table 1 show that there is strong evidence against the null hypothesis for stations BE0013 and BH0017, weaker evidence for stations BA0011 and BN0001 and none for station AK0001. The negative sign of S indicates a decline in specific conductance with time for the first four stations in Table 1, but no notion of the form of change is given.

An important first step in any analysis is to plot the data. A plot which displays the data in the way in which it enters the analysis in the seasonal Kendall test is shown for stations BA0011 and BH0017 in Figure 1. The statistic S is the sum of the statistics S_j for each month (Table 2), where a large $|S_j|$ is indicative of change over time. From Figure 1, the form of the change of specific conductance in a given month between 1978 and 1986 can be seen, as can the degree of consistency between months.

The test of homogeneity described by van Belle and Hughes (1984) was used to quantify the assessment of consistency (Table 3), and, using either a normal approximation (i.e., replace S by S_j in equation (8), or Table 1 of Kendall (1970)), the null hypothesis for each month was tested (Table 2). The latter was used here merely to indicate for which months the evidence against randomness was greatest, so that the form of the change in these plots could be noted. If heterogeneity between months is detected, the individual tests are required (see van Belle and Hughes for further discussion).

The conclusions that can be drawn from the tests of hypotheses are that there are indications of changes in the specific conductance over the period 1978 to 1986 at all stations except AK0001, but the strength of evidence varies. Heterogeneity of trend was not detected. From the plots of the months for which significance at a level of 0.10 or less was found, there is a general pattern of lower specific conductance around 1982 to 1983 relative to the earlier years, at least. This appears in other plots (e.g., BA0011, January), but for some months there is just a general scatter (e.g., BA0011, May).

Regression Analysis

The analysis of the specific conductance data by the methods of Esterby et al. (1989), after removal of the laboratory terms which were found not to differ significantly from zero, gave the models shown on the left in Table 4. From the significance probabilities alone, the yearly seasonal terms, $\{\Delta S_i\}$, for BE0013 and BH0017 would have been excluded from those shown in Table 4. However, the residual plots showed lack of fit in some years without these terms, and hence they have been retained in all models. The significance probability of 0.04 for the runs test for station BE0013 is due to a poor fit of the seasonal cycle. At this station only, there is a sharp drop in specific conductance between two adjacent sampling periods, May and June for most years, followed by low specific conductance for several summer months. Despite this, the percentage of variation is comparable to that of the other stations. In some years there are narrow peaks in the AK0001 record, and these, plus some closely spaced additional measurements in 1984 and 1985, are the reason for the poorer fit and the low probability for the runs test.

To fit a trend term, the yearly means $\{\mu_i\}$ are replaced by a polynomial in years. Curvature in the form of a quadratic did not remove significantly more of the variation than the linear term in the models shown on the right side of Table 4. The reduction in 100 R^2, the residual plots and the runs test indicate inadequacy of these models. The model with yearly means and the model with a trend term in years are compared for BA0001 and BH0017 in Figure 3. The inadequacy of the linear trend in years is very clear from the residual plots. The band of residuals for each station resembles the corresponding pattern of means in Figure 2. The plots of the data and fitted models show that with the linear trend term, the entire seasonal cycle is displaced, which results in sequences of residuals of the same sign and hence too few runs (see p runs, Table 4).

Having fitted the model on the left of Table 4, rather than testing for a linear trend in years, a more appropriate next step would be to plot the estimates of the yearly means from these models (Figure 2). It thus becomes clear that testing for differences between years or sets of years, using a multiple comparison procedure, will be more informative. A drop in specific conductance in 1982 at all stations and low specific conductance in 1978, except at station BA0001, are the consistent features in the plots. Since the yearly means were estimated from a model with other terms and the number of observations per year are unequal, multiple comparison procedures requiring equal variances are not applicable. The method of Scheffé (Scheffé, 1959) or a Bonferroni procedure (Miller, 1981) can be used. Testing for significant differences between all pairs of years using the method of Scheffé provides few significant differences (Table 5), partly because the probability is $1-\alpha$ ($\alpha = 0.05$ in Table 5) that all contrasts, not just the differences between means actually computed, will be within their respective intervals. To compare groups of years, the Bonferroni t statistics will be less conservative. The interesting differences between groups of years, as determined from Figure 2, have been tested using both the Scheffé and Bonferroni methods. The means for these groups and the differences between these means are given in Table 6. Confidence intervals for the differences between groups of years can also be calculated. For example, the 95 percent confidence interval for the mean difference between years 1982 to 1986 and 1978 to 1981 at station BE0013 is 22.5 ± 16.3.

The nonparametric estimator of the slope, B, and the linear regression slope estimator are shown in Table 7, for the purposes of illustration. There is good agreement, but the regression slope estimator is always slightly smaller. Hirsch *et al*. (1982) remarked that this is always the case with skewed data such as they used, where the estimates were -0.014 and -0.005 for β from simple linear regression and the nonparameter slope estimator. Note that the normality assumption in regression consists of the assumption that the errors, ε_i, are a random sample from a single normal distribution, i.e., $\varepsilon_i \sim N(0,\sigma^2)$. In the regression analysis of the present paper, much of the skewness of the original data has been accounted for by fitting the seasonal cycle. If a simple linear regression model is fitted to the data, i.e.,

$$y_{is} = \mu + \beta i + \varepsilon_{is}$$

instead of the model of equation (14), then only for station BH0017 was the slope found to be significantly different from zero (see footnote Table 7). The largest 100 R^2 was 5.23 for station BH0017, and the runs test indicated too few runs ($p<0.0001$) for all stations. Unlike the results quoted by Hirsch et al., the point estimators of slope are not very different from the three estimators but the failure to account for seasonality in the simple linear regression analysis leads to very different conclusions due to inflated error variance estimates.

DISCUSSION

The use of the seasonal Kendall trend test for a monotonic trend has been illustrated on the five Bow and South Saskatchewan River stations. A test for homogeneity of trend over months and a nonparametric slope estimator have also been calculated for these stations. An alternative analysis is a regression analysis based on a model which includes a yearly seasonal cycle and the change over years in a form appropriate for the particular data set, and this has been performed for the five stations. The nonparametric methods detected a change over years for the same stations as did the regression analysis but were otherwise non-informative. At the very least, plots of the data should be done when using the Kendall seasonal test for trend, and a useful form of plot was given here. Thus the seasonal Kendall trend test detected a nonconstancy in specific conductivity over the years but more analysis was necessary to specify the form of the nonconstancy. This is in agreement with the introductory comments of Hirsch et al. (1982), on the use of the test.

There were difficulties in fitting the seasonal cycle for stations BE0013 and AK0001, which could possibly be circumvented by an appropriate modification to the model. But, in view of the agreement with the nonparametric methods for detection of trend and estimation of slope, the regression method did not seem to give erroneous conclusions because of the poorer fit for these stations.

The test for homogeneity of trend determines whether the standardized statistics, calculated from the data of individual months, differ from the average statistic by more than expected under the null hypothesis of random samples, identically distributed for a given month. No heterogeneity was detected for the five Bow and Saskatchewan River stations. To illustrate the performance of this test on a set of data with more highly significant trend statistics for individual months, the tests for trend and homogeneity were calculated for 11 years of total phosphorus data from the Niagara-on-the-Lake station on the Niagara River (Table 8 and Figure 4). Again, heterogeneity of trend was not detected. Thus, calculation of the monthly statistics is useful even when the test for homogeneity does not provide a low significance probability.

To perform the above tests, the median of the observations in a given month were taken. Except for three cases, the number of days in the month on which measurements were made was at least 17. Although unequal numbers will affect the power of the test (van Belle and Hughes, 1984), it would seem that at the very least a summary statistic, such as the median, should be used rather than choosing an individual value by date or at random, when so much data is available. The other alternative is to treat multiple observations in a month as ties in time.

The seasonal Kendall trend test is based on some arbitrary choice of season. The natural choice for the Bow and South Saskatchewan stations was the month, since that was the frequency of sampling. The choice of season is important because the test follows the change over years within a season. From the regression analysis of this data set, it was found that, of the terms entering the model, seasonality accounted for the highest percentage of variability, and that there were differences in the time at which the specific conductivity peaked (e.g., at BA0011 the spring maximum was estimated to occur in January for three years, February for five years, and March for one year). This could increase the scatter over years, since for some years, the peak (for example) might be reached in a different month. Other considerations in the definition of season (van Belle and Hughes, 1984) are the removal of serial correlation by amalgamation (e.g., taking the mean of closely spaced values in an interval of fixed length such as a month), and difficulty of deciding how to handle multiple observations within a season (discussed above).

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TABLE 1: Kendall seasonal test for trend for specific conductance data.

Station	n.	S	$[var(S)]^{\frac{1}{2}}$	Z	p
BA0011	105	-65	31.94	-2.07	0.04
BE0013	101	-95	30.28	-3.17	0.002
BH0017	105	-101	31.95	-3.19	0.001
BN0001	106	-60	32.37	-1.89	0.06
AK0001	108	-27	33.21	-0.84	0.40

n. is the total number of measurements over the nine years.

The p values are for two-tail tests corresponding to the N(0,1) variate Z defined in equation (8).

TABLE 2: S_j for each month and station calculated from specific conductance data.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
BA0011	-4	0	-10	7	-2	1	-12	-3	4	-12	-18*	-16
BE0013	-11	-11	-12	-2	-4	-7	3	0	-5	-10	-21**	-15
BH0017	-10	-3	4	-16	-6	-18*	-6	-14	-10	-3	-6	-13
BN0001	-10	-6	-16	-3	-6	-14*	14	-9	0	0	2	-12
AK0001	-6	-6	-12	-22**	8	12	-6	4	9	-4	6	-10

*, ** indicate significance at level of 0.10 and 0.05, respectively. Table 1 of Kendall (1970), or in the case where ties are present, the normal approximation with the continuity correction, was used.

TABLE 3: p value for χ^2 testing trend and homogeneity of trend for specific conductance data.

Station	Trend	Homogeneity of Trend
BA0011	0.04	0.68
BE0013	0.001	0.84
BH0017	0.002	0.95
BN0001	0.06	0.63
AK0001	0.42	0.34

χ^2 for trend and homogeneity have 1 and 11 degrees of freedom, respectively.

TABLE 4: Comparison of models with yearly means and with trend in year.

	Yearly Mean					Trend in Year				
	p for Terms					p for Terms				
Station	$\{\mu_i\}$	S	$\{\Delta S_i\}$	100 R^2	p Runs	β	S	$\{\Delta S_i\}$	100 R^2	p Runs
BA0011	0.0004	*	0.05	80.1	0.08^{tm}	0.01	*	0.09	73.7	0.39^{tm}
BE0013	0.005	*	0.61	81.1	0.04^{tf}	0.005	*	0.63	78.9	0.03^{tf}
BH0017	*	*	0.30	77.1	0.24^{tf}	0.001	*	0.58	63.8	$*^{tf}$
BN0001	*	*	0.07	82.1	0.25^{tf}	0.05	*	0.27	73.1	0.01^{tf}
AK0001	0.01	*	0.06	72.7	0.07^{tf}	0.20	*	0.12	66.7	0.003^{tf}

p is the significance probability and refers to the test associated with the indicated set of terms in the model or to the runs test.
* p 0.0001.

tf,tm too few or too many runs.

$\{\mu_i\}$, S, $\{\Delta S_i\}$, β are yearly means, single seasonal cycle, yearly seasonal cycle and slope for linear trend in years, respectively.

TABLE 5: Results of pairwise comparison of estimated yearly means using Scheffé method.

Station	Year Mean in Increasing Order with Significant Differences at the 0.05 Level								
	1	2	3	4	5	6	7	8	9
BA0011	82	83	85	84	86	80	79	78	81
	162.4	164.6	169.5	170.9	172.2	176.1	176.8	177.7	181.5
BE0013	84	83	85	82	86	78	79	80	81
	280.5	283.4	284.3	284.8	292.7	304.1	306.3	308.4	311.4
BH0017	83	84	82	78	85	86	79	81	80
	282.1	284.0	291.4	293.6	295.1	298.1	323.5	323.9	325.6
BN0001	82	78	83	86	85	84	81	79	80
	355.4	364.0	367.3	372.3	373.9	378.4	384.0	397.9	415.8
AK0001	78	86	82	85	83	81	84	79	80
	377.7	386.3	389.9	396.5	399.2	401.8	409.0	432.3	440.2

Yearly means are those estimated from the models in the left side of Table 4.

Underlined years are not significantly different.

TABLE 6: Tests for significant differences between the estimated means for the indicated groupings of years.

Station	Mean for Indicated Years with Significant Differencs at 0.05 Level 1	2	3
BA0011	82,83	84,85,86	78,79,80,81
	163.5	170.9	178.0
BE0013	82,83,84,85,86	78,79,80,81	
	285.1	307.6	
BH0017	78,82,83,84,85,86	79,80,81	
	290.7	324.3	
BN0001	78,82,83	79,80,81,84,85,86	
	362.2	387.1	
AK0001	78,81,82,83,84,85,86	79,80	
	394.3	436.3	

The means are arithmetic means of the year effects shown in Table 5.

Underlined years are not significantly different based upon Scheffé's method. A Bonferroni t-test, which equals an ordinary t test for all stations except BA0011, resulted in all the differences indicated in the table being significantly different from zero at the 0.05 level.

TABLE 7: Estimate of slope from model in Table 4, β, and nonparametric slope estimator, B.

	Regression Model		
Station	$\hat{\beta}$	95% Confidence Interval	Nonparametric Slope Estimator, B
BA0011	-1.2	-2.1, -0.3	-1.0
BE0013	-3.3	-5.6, -1.0	-3.0
BH0017	-3.3	-5.3, -1.3	-3.0
BN0001	-2.4	-4.8, 0.0	-2.0
AK0001	-2.2	-5.6, 1.2	-1.9

The simple linear regression model for BH0017 gave a 95% confidence interval for the slope of (-6.2, -0.6) centered at -3.4, with p = 0.02. The p values associated with the test of zero slope for the other stations ranged from 0.16 to 0.32.

TABLE 8: Nonparametric slope estimates and tests for trend and homogeneity of trend using Niagara River total phosphorus data.

Time Interval	Slope Estimate, B mg L^{-1} yr^{-1}	p, Trend Test
January	-0.0001	0.93
February	-0.0004	0.42
March	-0.0010	0.18
April	-0.0008	0.18
May	-0.0001	0.81
June	-0.0007	0.02
July	-0.0010	0.002
August	-0.0009	0.01
September	-0.0008	0.005
October	-0.0005	0.02
November	-0.0005	0.12
December	-0.0002	0.94
Over all months	-0.0006	0.0001

The p value for the test for homogeneity, of trend on 11 df equals 0.38.

FIGURE CAPTIONS

Figure 1. Specific conductance at stations BA0011 and BH0017 plotted for each month.

Figure 2. Plot of estimated yearly mean specific conductance for each station from the model on the left in Table 4.

Figure 3. Comparison of the models with yearly mean and with linear trend in year for stations BA0011 and BH0017.

Figure 4. Total phosphorus at the Niagara-on-the-Lake station plotted for each month.

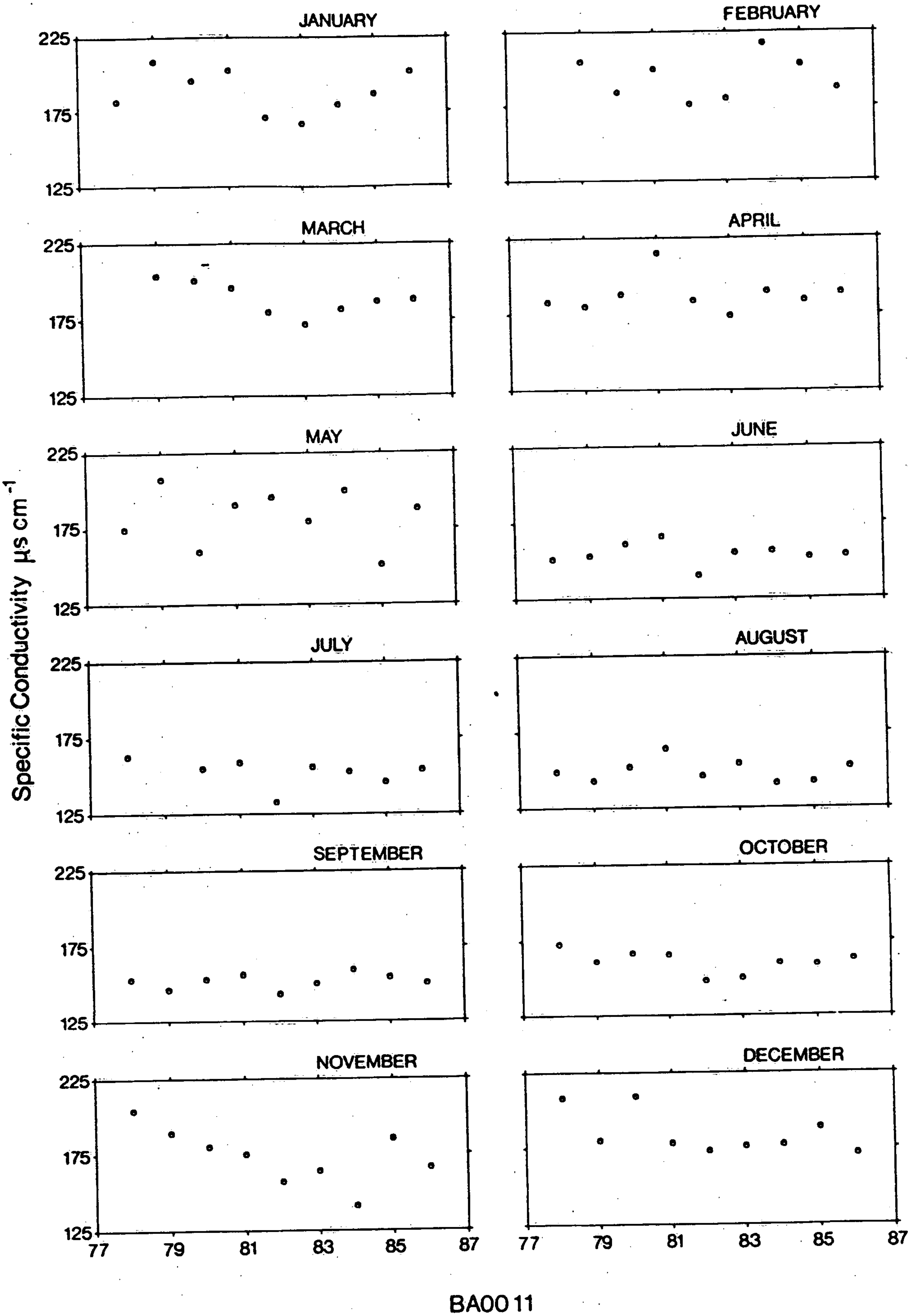

JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
225
175
125
Specific Conductivity µs cm -1
77
79
81
83
85
87
BA00 11

FIGURE 1

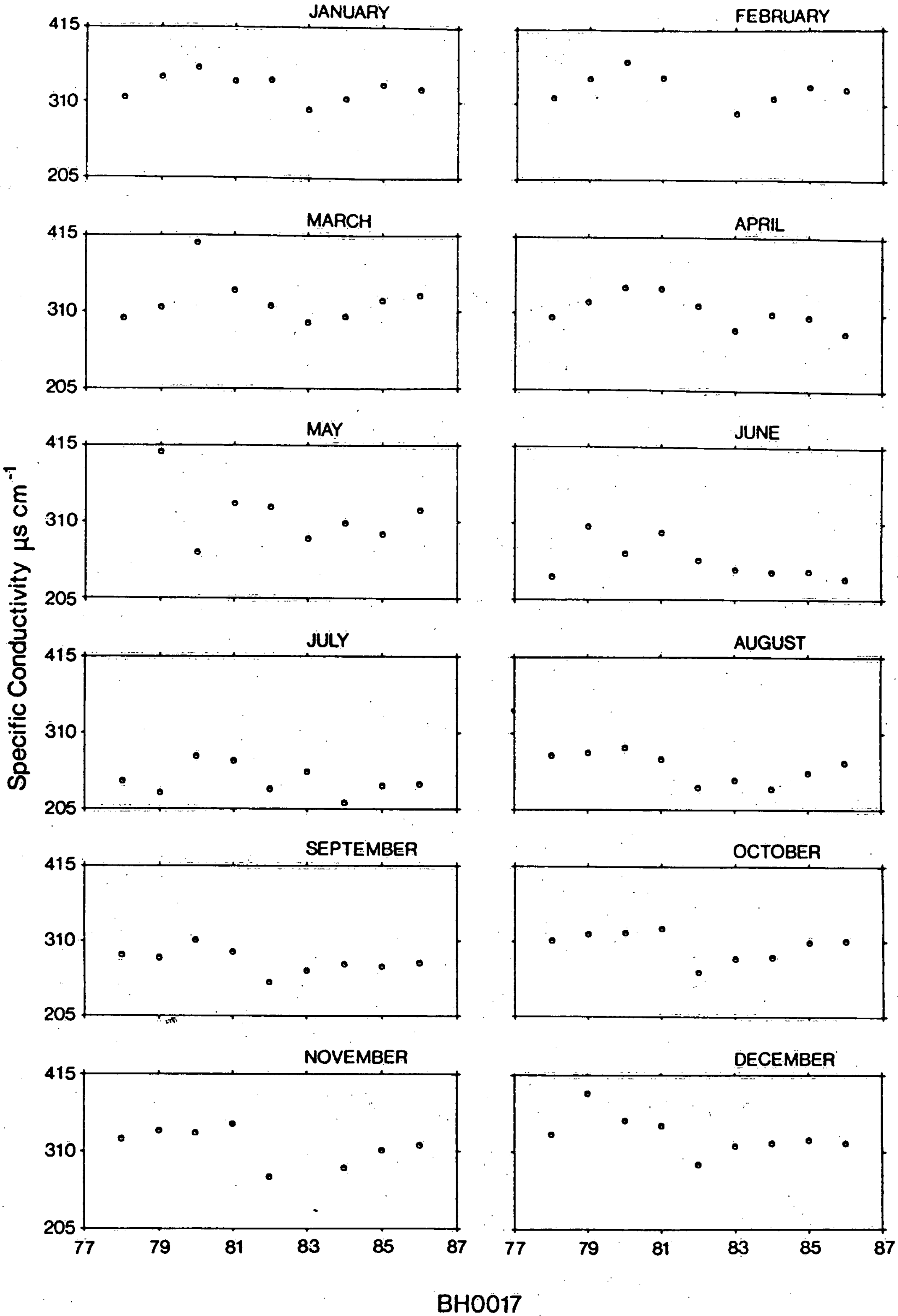
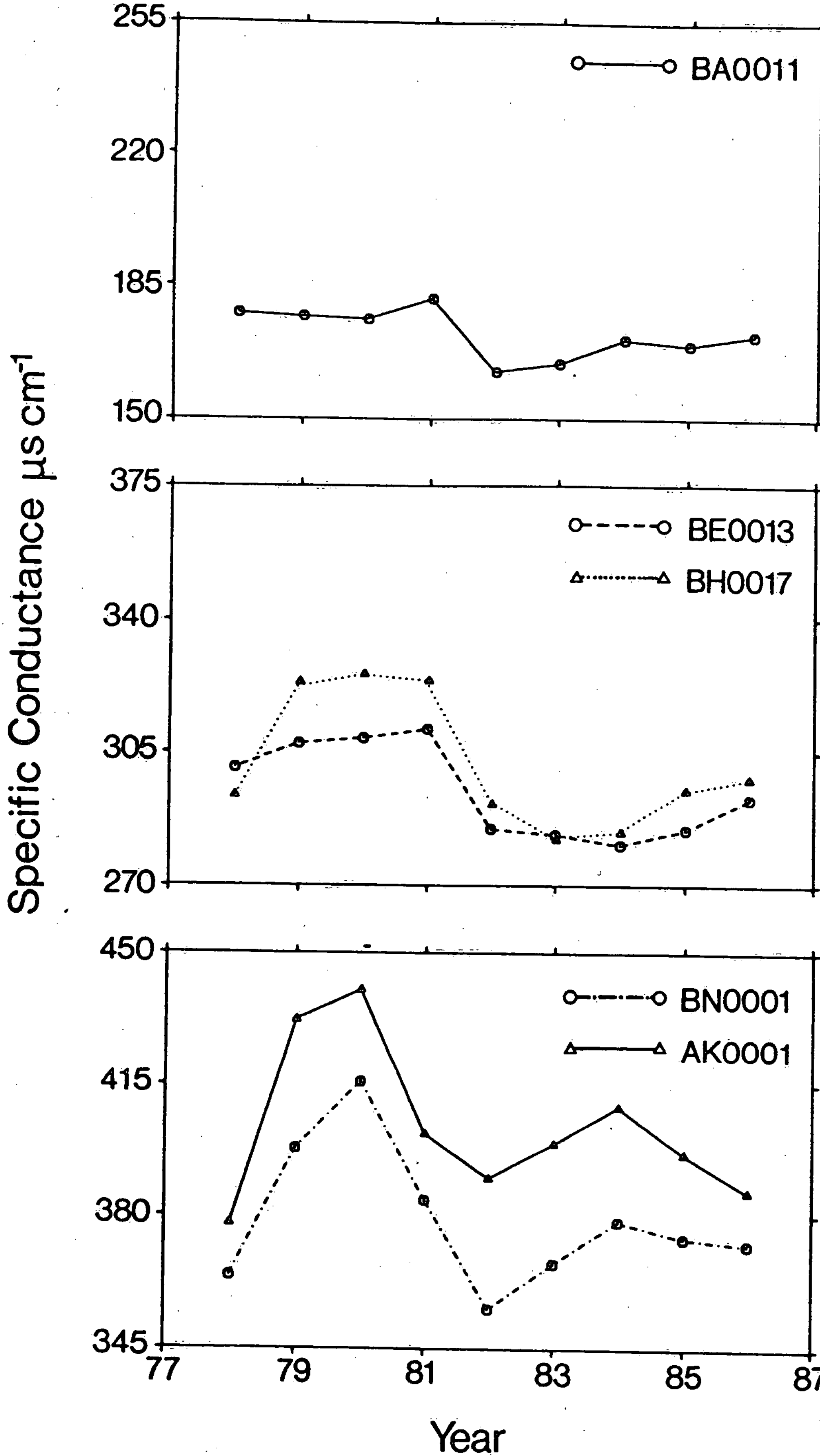


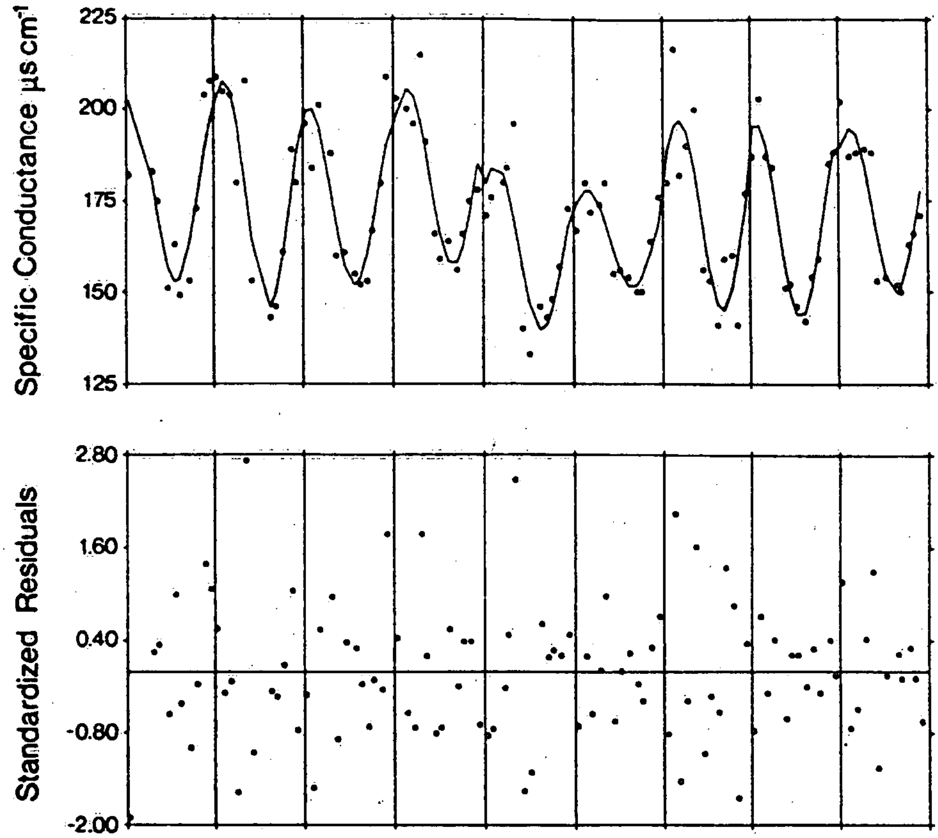
FIGURE 1 (continued)



255
220
185
150
BA0011
375
340
305
270
BE0013
BH0017
450
415
380
345
BN0001
AK0001
77
79
81
83
85
87
Specific Conductance µs cm-1
Year

FIGURE 2

BA0011
Model with
yearly means



BA0011
Model with linear
trend in year

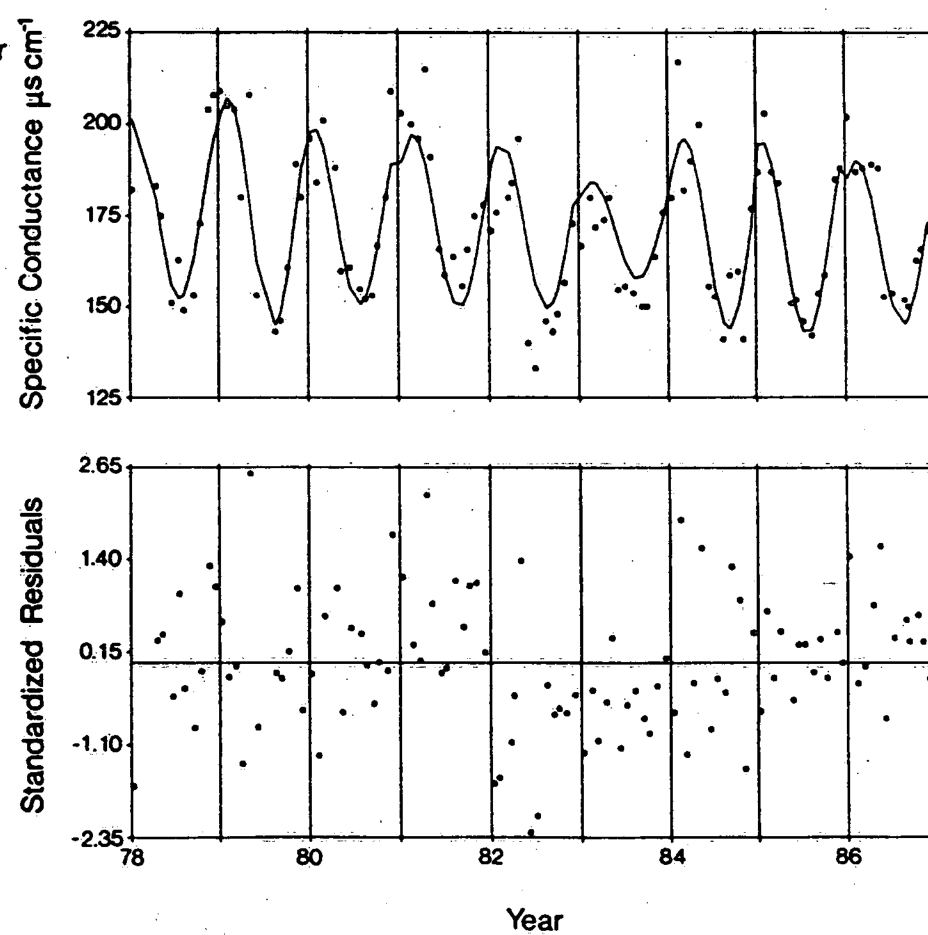
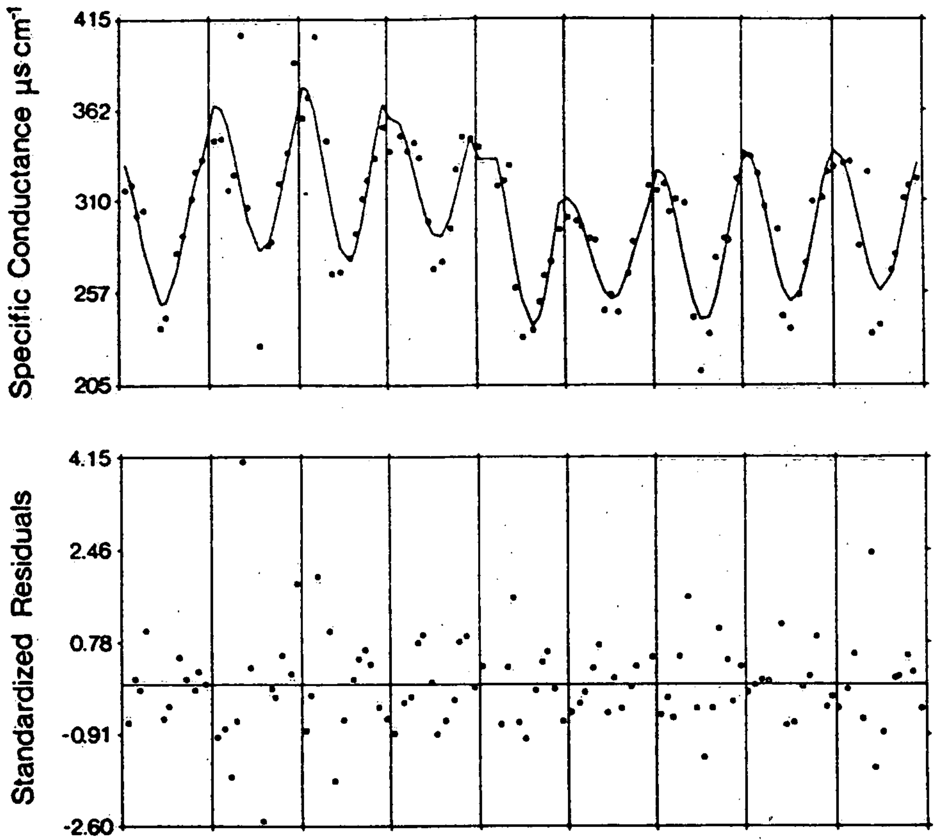


FIGURE 3

BH0017
Model with
yearly means



BH0017
Model with linear
trend in year

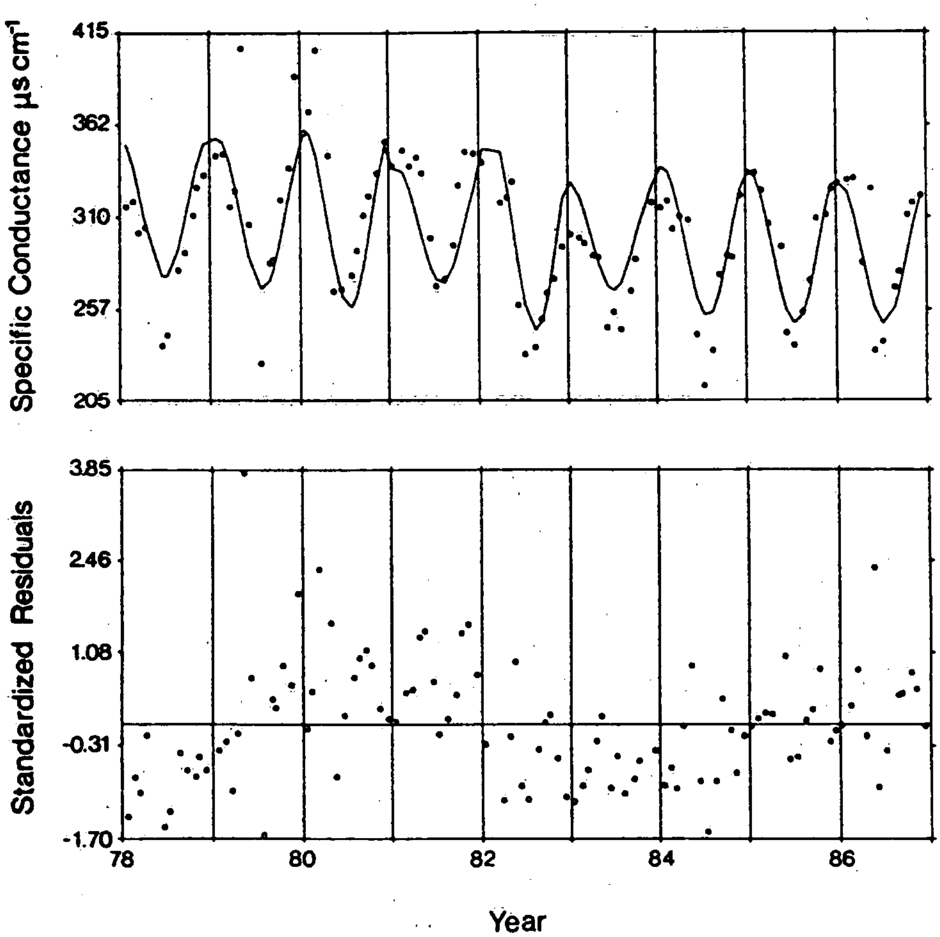


FIGURE 3 (continued)

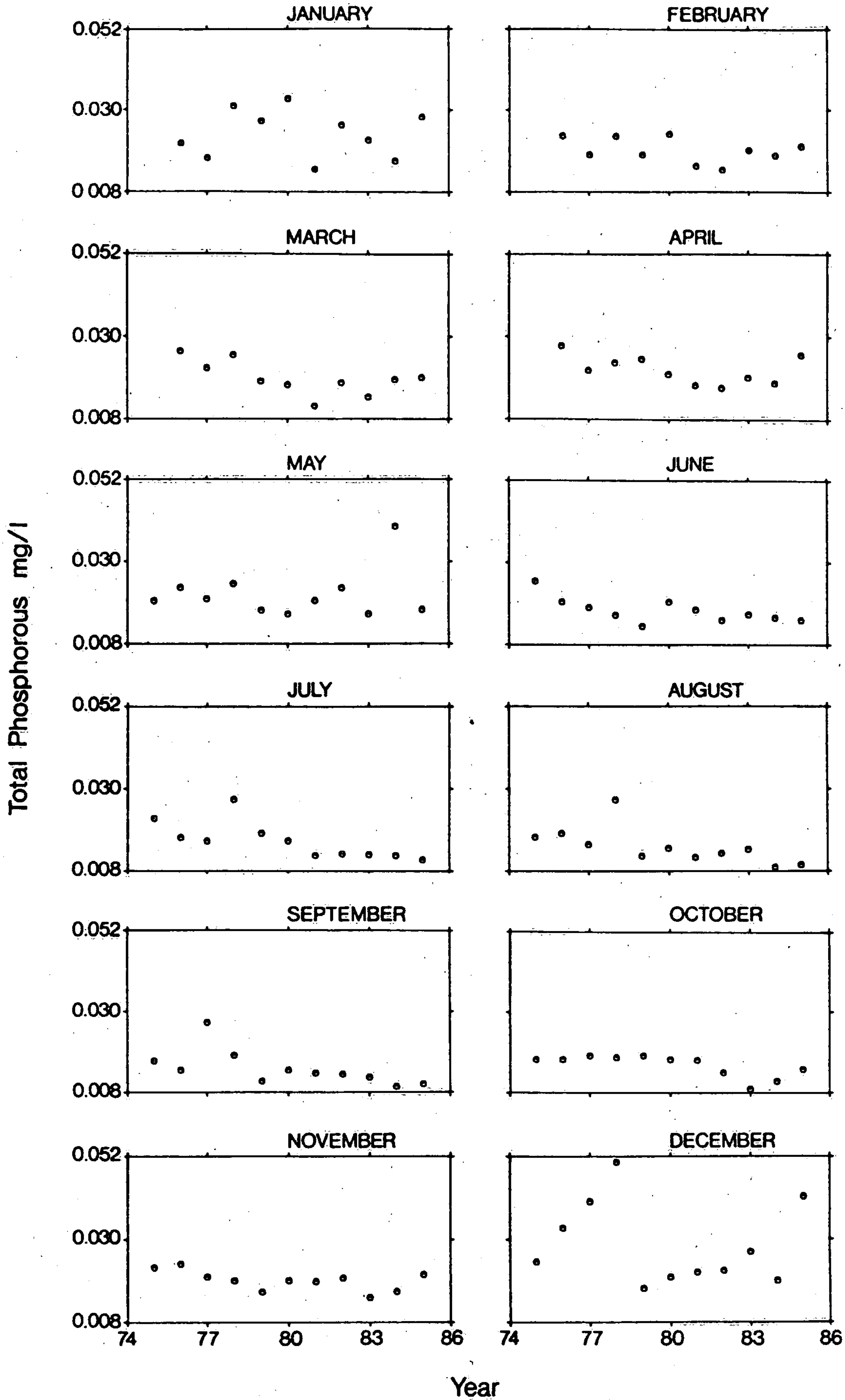

JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
0.052
0.030
0.008
Total Phosphorous mg/l
74
77
80
83
86
Year

FIGURE 4

NATIONAL WATER RESEARCH INSTITUTE
P.O. BOX 5050, BURLINGTON, ONTARIO L7R 4A6

Environment Canada Environnement Canada

Canada

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX
C.P. 5050, BURLINGTON (ONTARIO) L7R 4A6