Non-Parametric Trend Analyses Of Annual Spring-Overturn Total Phosphorus And Total Dissolved Phosphorus Data In Horse Lake, British Columbia

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Introduction

The B.C. Ministry of Environment, Lands and Parks has recently reviewed long-term water quality time series to identify any potential trends visually. Included in these time series were the data for total phosphorus and total dissolved phosphorus in Horse Lake, British Columbia, recorded at the spring overturn.

This report summarizes the statistical analyses of these apparent trends of total phosphorus and total dissolved phosphorus concentrations at this lake monitoring site.

Background information on each of these sites can be obtained by contacting the B.C. Ministry of Environment, Lands and Parks.

Methods

Exploratory Data Analysis (EDA)

Exploratory data analysis procedures are the `initial look' at a dataset, providing a researcher with tools to select appropriate statistical tests and modeling techniques. Apart from computing basic summary statistics (means, medians, minimums, maximums, number of observations), EDA procedures are best represented by graphical displays of the data. Time series plots were used in the initial data explorations.

Non-Parametric Tests

Non-parametric tests to detect trends in water quality have been used by many others in the past (Yu and Zou, 1993; Walker, 1991; Gilbert, 1987; Hirsch and Slack, 1984). The relative simplicity and minimal data assumptions of these tests make them a popular choice for analysis of water quality time series. Two different non-parametric tests, the *Kendall Test for Trend* and the *Sen slope estimator* were used to detect and determine magnitudes of any trends in the water quality data.

Kendall Test for Trend

To perform this non-parametric test, Kendall's S statistic is computed from the data (see Millard, 1997, or any good introductory non-parametric statistics text for details). The null hypothesis of no trend is rejected when S is significantly different from zero. Hirsch et al. (1982) note that this test is appropriate even in the presence of missing observations, and censored values.

Sen Slope Estimator

This non-parametric statistic calculates the magnitude of any significant trends found. The Sen slope estimator (Sen, 1968) is calculated as follows (Y is the variable of interest; X is the time at which the i^{th} observation was taken) :

$$D_{ij} = \left[\frac{Y_j - Y_i}{X_j - X_i} \right] \text{ for } i < j, \quad X_i \neq X_j$$

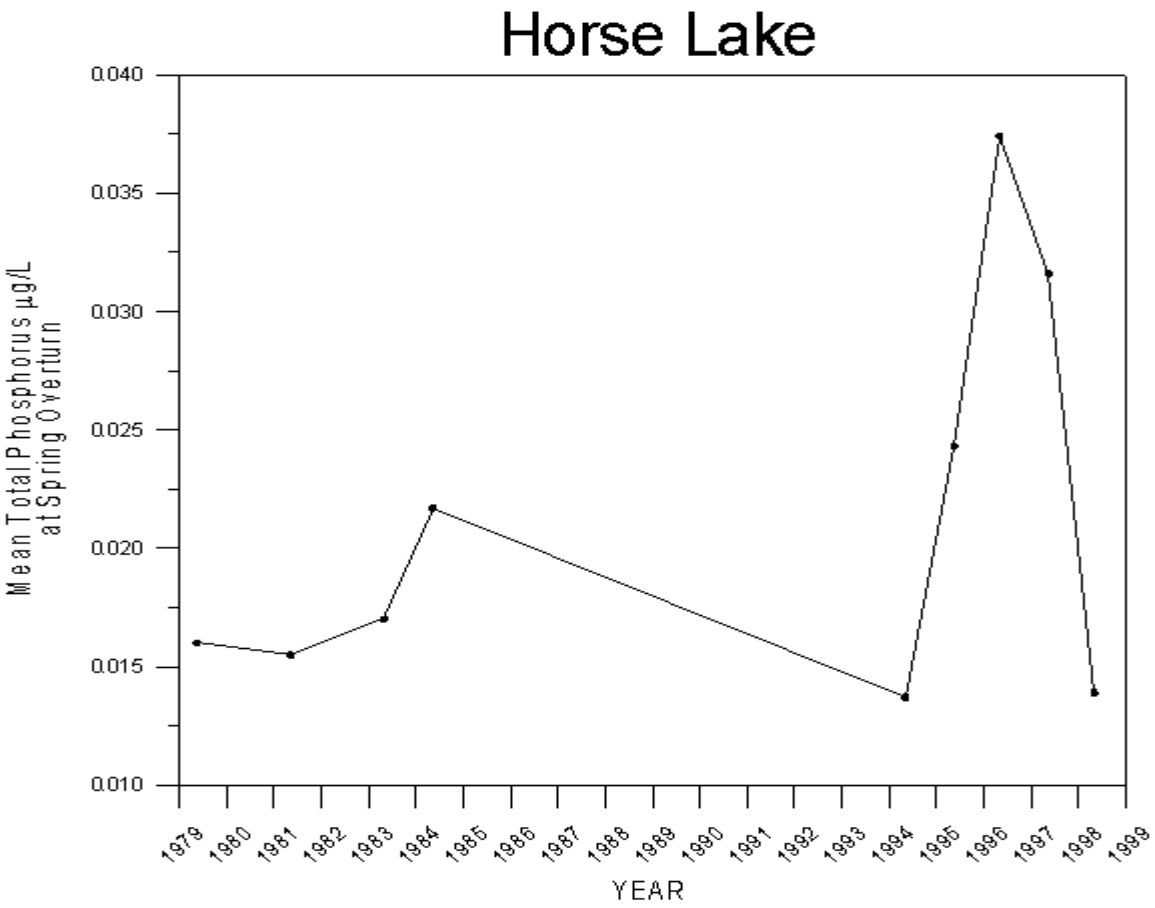
The slope estimate is the median of all D_{ij} values. Hirsch *et al*. (1982) point out that this estimate is robust against extreme outliers. Confidence bounds for this slope estimator are calculated as a simple percentile of the total number of calculated slopes (Gilbert, 1987).

Results and Discussion

Total Phosphorus

The data set for total phosphorus at Horse Lake during spring overturns spanned 19 years, from 1979 to 1998 (Figure 1).

Figure 1 Time series plot of total phosphorus recorded at the spring overturn in Horse Lake, 1979 - 1998.



Two analyses were conducted on the total phosphorus data. The first analysis was conducted on the subset consisting of the 8 samples available between 1979 and 1997. Non-parametric tests indicated some evidence of an increasing trend, with the Kendall test statistic having a p-value slightly greater than 5 % (see Table 1). The confidence bounds on the Sen Slope estimator include zero which suggests little evidence for this increasing trend (see Table 1). The second analysis was conducted on the full set of available data (9 samples). There was no evidence of any trends with the additional 1998 sample included in the analysis (see Table 1).

Table 1 Non-parametric results for mean spring overturn total phosphorus data in Horse Lake 1979 - 1997/98.

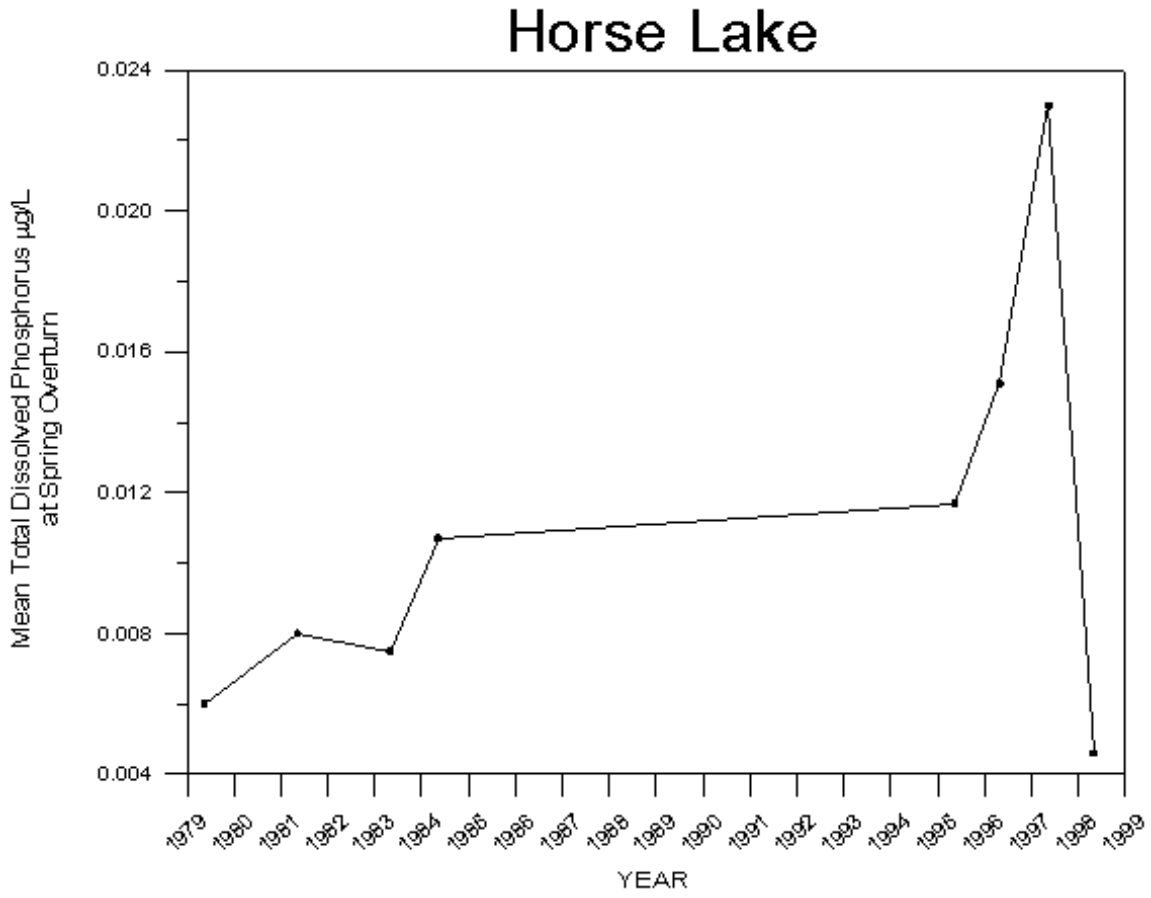
	Total Phosphorus 1979 - 1997		Total Phosphorus 1979 - 1998	
	statistic	***p-value***	***statistic***	***p-value***
Kendall Trend	1.8558	0.0635	0.9383	0.3481

Sen Slope	0.0025	N/A	0.0018	N/A
Upper CI	0.0051	N/A	0.0039	N/A
Lower CI	-4.211E-4	N/A	-5.850E-4	N/A

Total Dissolved Phosphorus

The data set for total dissolved phosphorus at Horse Lake during spring overturns also spanned 19 years, from 1979 to 1998 (Figure 2).

Figure 2 Time series plot of total dissolved phosphorus recorded at the spring overturn in Horse Lake, 1979 - 1998.



Two analyses were conducted on the total dissolved phosphorus data as well. The first analysis was conducted on the subset consisting of the 7 samples available between 1979 and 1997. Non-parametric tests indicated strong evidence of an increasing trend, with the Kendall test statistic having a p-value significant at the 5 % (see Table 2). The second analysis was conducted on the full set of available data

(8 samples). The addition of the 1998 sample seemed to be significantly lower than previous samples and non-parametric tests supported this in providing no evidence of any trends (see Table 2).

Table 2 Non-parametric results for mean spring overturn total dissolved phosphorus data in Horse Lake 1979 - 1997/98.

	Total Dissolved Phosphorus 1979 - 1997		Total Dissolved Phosphorus 1979 - 1998	
	statistic	***p-value***	***statistic***	***p-value***
Kendall Trend	2.7034	0.0069	1.3609	0.1735
Sen Slope	0.0016	N/A	0.0014	N/A
Upper CI	0.0032	N/A	0.0030	N/A
Lower CI	9.21E-4	N/A	-4.86E-4	N/A

Summary

Trend analyses on total phosphorus and total dissolved phosphorus data collected at Horse Lake during spring overturns revealed two items of note:

· Data for both constituents showed some evidence of increasing trends when analyzed over the years 1979 - 1997 using non-parametric tests for trend; and

· Subsequent analyses that included the additional 1998 sample in both constituent data sets indicated no evidence of any trends.

References

Gilbert, R.O., 1987. Statistical methods for environmental pollution monitoring. Van Nostrand-Reinhold, New York.

Hirsh, R.M. and J.R, Slack, 1984. A nonparametric trend test for seasonal data with serial dependence. Water Resources Research 20: 727-732.

Hirsh, R.M., J.R, Slack, and R. Smith, 1982. Techniques of trend analysis for monthly water quality data. Water Resources Research 18 (1): 107:121.

Millard, S.P., 1997. EnvironmentalStats for S-Plus User's Manual, Version 1.0. Probability, Statistics & Information, Seattle, WA.

Sen, P.K., 1968. On a class of aligned rank order tests in two-way layouts. Annals of Mathematical Statistics 39, 1115-1124.

Walker, W., 1991. Water quality trends at inflows to Everglades National Park. Water Resources Bulletin 27 (1): 59-72.

Yu, Y.S. and S. Zou, 1993. Research trends of principal components to trends of water-quality constituents. Water Resources Bulletin 29(5): 797-806.

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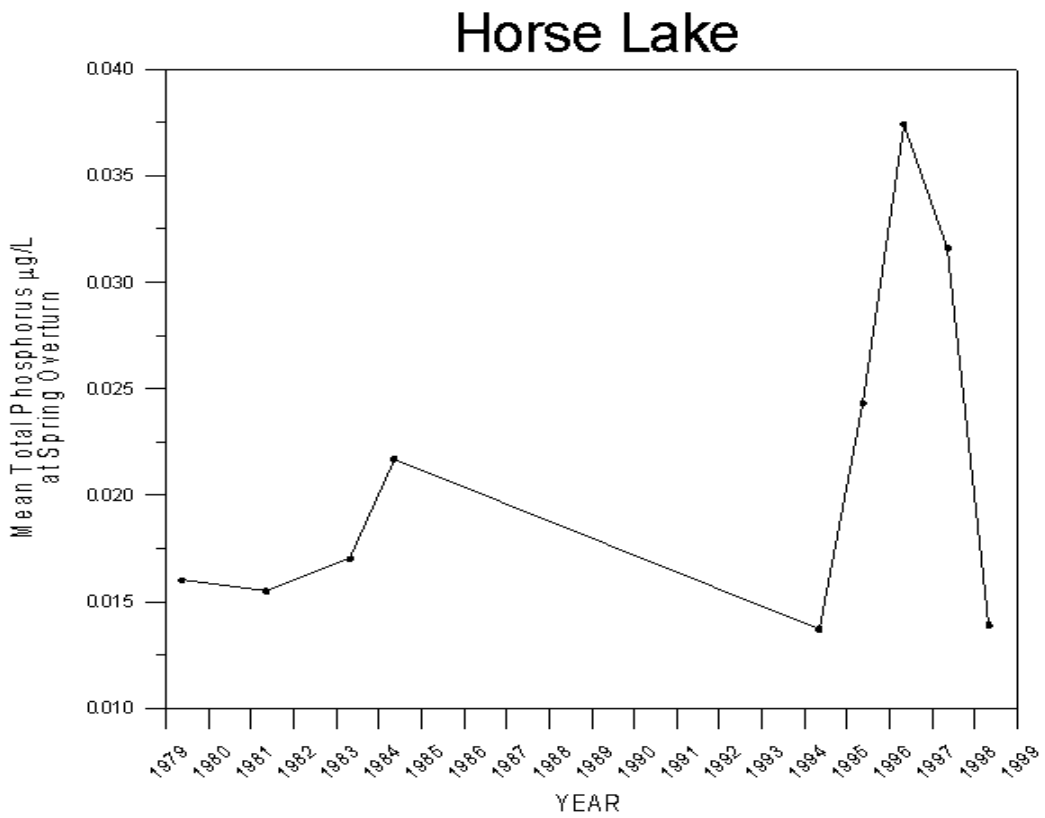

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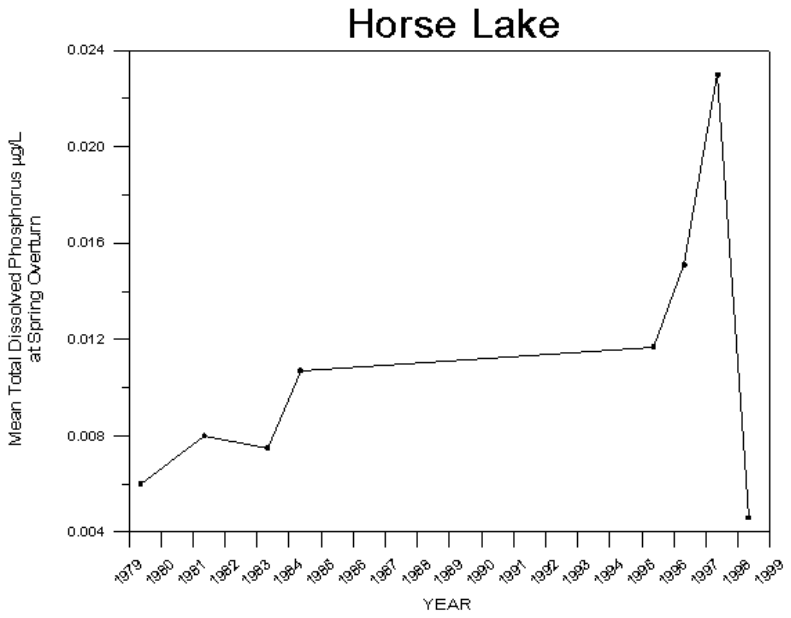

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