Statistical Evaluation of Water Quality Measurements

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Abstract

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A statistical analysis of water quality data collected on paired agricultural watersheds was undertaken. The objective of the study was to evaluate trends in water quality. The data sets that were used to determine the changes in water quality were taken from the project "Gestion de l'eau dans le bassin versant de la partie superieure du ruisseau St. Esprit". For the period from 1994 to 1996, the analysed water quality parameter were nitrate, phosphate, ammonium, potassium, total Kjeldahl nitrogen, total phosphorus and suspended sediment.

The data sets were analysed using descriptive statistics, graphical techniques and non-parametric methods to detect trends in the measured water quality parameters. The statistical analyses were undertaken to determine the effects of soil conservation practices and fertiliser management and to compare different sampling strategies.

The analyses showed that there were no detectable changes in water quality over the 3-year period related to the conservation practices. The lack of improvement in water quality might be due to the slow rate of adoption of conservation practices and to climatic variations.

For the non-parametric methods applied, it was possible to show that climatic variations on small watershed affect the results over a short time period (< 5years). The phosphate concentration on the control showed a significant upward trend. The nitrate concentration on St. Esprit showed an upward trend over the 3-year period and then downward trend after a 4-year period of water quality data. This was likely due to the implementation of best management practices.

The statistical analyses showed that weekly sampling on fixed schedule produce the same results as automated sampling based upon flow rate related to a defined discharge. This shows that the more complex and expensive flow weighted sampling scheme is not required to detect trends in water quality.

Résumé

Évaluation statistique des mesures de qualité de l'eau

Une analyse statistique des données de qualité de l'eau recueillies sur deux bassins-versants agricoles a été entreprise. L'objectif de l'étude était d'évaluer des tendances de qualité de l'eau. Les banques de données qui ont été utilisés pour déterminer les changements de la qualité de l'eau ont été dévelopés dans le cadre du projet "Gestion de l'eau dans le bassin versant de la partie supérieure du ruisseau St. Esprit". Pour la période de 1994 à 1996, les paramètres de qualité de l'eau analysés étaient: nitrates, phosphates, ammonium, potassium, azote total Kjeldahl, phosphore total et particules en suspension.

Les banques de données ont été analysées en utilisant des statistiques descriptives, techniques graphiques et des méthodes non paramétriques pour détecter des. tendances dans les paramètres de qualité de l'eau mesurés.

Les analyses statistiques ont été entreprises pour déterminer les effets des pratiques en matière de conservation des sols et de gestion d'engrais sur la qualité de l'eau et pour comparer différentes stratégies de prélèvement.

Les analyses ont montré qu'il n'y avait eu aucun changement detectable de la qualité de l'eau au cours de la période de trois ans. L'absence d'amélioration de qualité de l'eau pourrait être dû à la leteur d'adaptation des pratiques de conservation et aux variations climatiques.

Grâce aux méthodes non paramétriques appliquées, il a été possible de montrer que les variations climatiques dans les bassins versants affectent les résultats sur une courte période de temps (< 5 ans). La concentration en phosphates sur la bassin témoin a montré une tendance à la hausse significative. La concentration en nitrates sur le bassin St. Esprit a montré une tendance à la hausse au cours de la période de trois ans et puis l'évolution à la baisse après une période de quatre ans mesenes de qualité de l'eau. Cela est probablement dû à la mise en place des meilleures méthodes de gestion. Les analyses statistiques ont montré que le prélèvement hebdomadaire selon un hozaire donne les mêmes résultats que l'échantillonnage automatique basé sur du débit. Ceci montré qu'il n'est pas nécessaire defaire des prélérements eu funtcion du debit pour détecter les tendances de la qualité de l'eau.

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Abbreviations and Symbols

α	statistical hypothesis test significance level (alpha)
BMP	best management practice
g	gram
g/l	gram per liter
ha	hectare
H_a	alternate hypothesis
H_0	null hypothesis
kg	kilogram
km	kilometer
mg/l	milligram per liter
mm	millimeter
n	number of data (individual observations) in a data set
NH_4	ammonium
NO_3	nitrate
2*P	a two sided P value from a statistical hypothesis test (actual estimated probability of a Type I error)
PO_4	phosphate
R	precipitation
TKN	total Kjeldahl nitrogen
TP	total phosphorus
U – test	seasonal Wilcoxson-Mann-Whitney test
X –test	Van der Waerden's test for normal scores
Z	standard normal variate (a hypothesis test result)

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1. Introduction

The conversion of land, over many decades, from its natural state to more intensive uses such as agricultural and urban development has been a major factor in the degradation of aquatic and other ecosystems.

The main reason for this degradation is the pollution from man's activities caused by population growth and changing technology. Examples of this trend are the change to intensive agriculture and the increased discharge of effluent from urban and industrial areas. The results of these anthropoid impacts are the eutrophication of lakes and rivers with the results of acidification and excessive growth of aquatic plants due to high nutrient concentrations (such as nitrate, phosphate).

As result of this water pollution, many countries have started programs to improve and protect the quality and quantity of existing water resources. The first major step in this direction was the International Drinking Water Supply and Sanitation Decade in the 1980's. This program was initiated by the General Assembly of the United Nations (Hipel, 1988).

Therefore, it was important to establish procedures to evaluate and control water quality in rivers and lakes. Agricultural practices and their environmental impact became a major research topic. One aspect of such research is to improve the water quality of rivers in intensive agricultural areas. A widely used method to reduce the impact of non-point source pollution to the environment is the application of best management practices.

The problem of non-point source pollution has been recognised in several agricultural regions in North America and Europe in the last twenty years. One-half of all water pollution is derived from non-point sources in the United States, with agricultural sources being most pervasive and important (Chester and Schierow, 1985). It is estimated that approximately 80 % of the N and P loads derived from agricultural sources in Quebec come from non-point sources (MENVIQ, 1988).

With an increasing awareness of the problems related to agricultural pollution, a significant amount of money has been spent to develop and promote best management practices. The most common way to achieve this information is to monitor water quality and evaluate trends. This however takes a long time, typically 10 to 25 years. An alternate technique is to utilise paired watershed studies. Using this method of paired watersheds, it might be possible to detect trends over a much shorter period, because both watersheds experience the same short-term climatic variation.

This dissertation evaluates the trends in water quality on paired agricultural watersheds in Quebec, and evaluates the suitability of different sampling protocols for collected water quality data for trend analyses. The watersheds are located about 50-km north-east of the city Montreal. The watersheds are part of the L'Assomption River basin. The water quality data were collected as part of the project "Gestion de l'eau dans le bassin versant de la partie superieure du ruisseau St. Esprit" (Enright et al., 1998). The water quality data were collected between 1994 and 1996. On the St. Esprit watershed, an agrologist was hired in 1993 to assist the producers in selecting and applying best management practises. However, very few conservation practises were adopted prior to the fall of 1994, and as such, both watersheds were managed in a similar fashion in that year.

1.1 Objectives

The objectives of this thesis were to:

1. Assess the overall annual trends in the water quality parameters ammonium (NH_4), potassium (K), Nitrate-Nitrogen (NO_3), phosphate-phosphorus (PO_4), suspended sediment and total phosphorus (TP) on each of the paired watersheds for the period of 1994-1996

2. Relate the observed water quality trends to observed precipitation, hydrology and adoption of best management practises

3. Compare the suitability of different sampling strategies, based on statistical evaluations.

1.2 Scope

This study evaluates the changes in water quality at the small watershed scale using statistical methods and identifying which statistical methods are suitable for trend evaluation in short-term water quality data sets. Another aspect is to examine the impact of different sampling strategies with respect to the applied statistical methods.

The water quality observations are derived from samples taken from two gauging stations at the outlet of the watersheds. On one watershed best management practises were applied, and the second watershed was used as control. The study was undertaken during the period from January 1994 to December 1996 inclusive. All results recommendations are only applicable to the conditions present in these two watersheds.

2. Literature Review

An important element of environmental deterioration of inland waters is the progressive enrichment of lakes and rivers with nutrients and pesticides resulting in the mass production of algae, and other desirable biotic changes (Tyagi, 1996).

To assess the degree to which environmental degradation has taken place, and if remedial actions have had the desired impact, trend analysis of water quality sets has received considerable attention in the last twenty years (Lettenmaier 1977; Berryman 1988; Hipel 1988; Hirsch 1988). The interest of trend analysis in water quality arises for two reasons. The first is the increase of environmental awareness, with the result of larger sums from public and private funds being spent for the purpose of water quality improvement. The second reason is that there has to be a substantial amount of water quality data collected that is amenable to such analysis.

One major goal of such surface water quality monitoring is the estimation of the magnitude of changes in concentration of various constituents between two periods.

2.1 Non-point Source pollution studies in Quebec

In the last ten years, non-point source pollution has been well documented at the field scale level in Quebec. With an increasing awareness of the problems caused by non-point source pollution the government of Quebec has undertaken a number of projects, on both large and small watersheds, to evaluate the impacts of non-point and point source pollution (Simoneau and Grimard 1989; Boukchina 1992; Asselin et al. 1992; Simoneau 1996; Labarge 1996). Theses projects were undertaken to develop mechanisms to reduce those impacts, known as best management practises.

To evaluate the impact of use of best management practises, two paired watershed studies are established in Quebec (Enright, 1998; Aubin et al. 1995) and in the United States (EPA, 1993).

The EPA (1993) used data from a study undertaken in Vermont to illustrate a method of analysis for paired watershed data. The purpose of the study was to determine the impact of conventional and conservation tillage on two watersheds with a size of approximately one-hectare. The advantage of this study was the size of the examined watersheds, which allowed a complete control of the applied practises. For studies on small and medium size watersheds, with more than one farmer involved, control over the applied practices is much more difficult to attain. As such, it is much more difficult to identify clearly the point at which practices are adopted. The methodology developed by the EPA compares "total" sediment load, per event, between the two watersheds. It was not a suitable method for the St. Esprit and Desrochers data because of the size of the watershed and the significant baseflow.

As indicated above, a limited amount of research has been conducted, which documents the water quality and quantity on small and medium size watersheds in Quebec, compared to the area of the province Quebec. Enright et al. (1997) stated that the lack of data on small and medium size agricultural watersheds limits the adoption of hydrologic and water quality models for targeting high priority pollution problems.

Another problem related to this lack of data is the difficulty to apply statistical methods to determine the changes in water quality on a short-term base.

In addition, one should be aware of the fact that most studies of trend detection in water quality that were undertaken so far rely on large rivers basin. Further, the recommended statistical methods to evaluate changes are usually applied to time series longer than ten years. In this study, an attempt to adapt these for small sized watersheds has been undertaken.

An overview of existing methods for evaluating such water quality changes is given in the next sections.

2.2 Overview of Trend Analysis Methods

Nature rarely evolves in a straightforward pattern. When change occurs, it is invariably the result of one or more casual influences, none of which is itself likely to behave in a linear fashion nor produce a pure linear trend in the affected water quality variable.

Therefore, researchers developed different approaches to detect trends in water quality over the last twenty years. These approaches are based on existing mathematical theorems and algorithms that include descriptive, graphical, parametric and nonparametric points of departure. Hence, we have to make an internal differentiation of those methods.

Most researchers in the field distinguish between exploratory and confirmatory data analysis. These concepts were first introduced by Tukey (1997). As Aroner (1997) stated, an understanding of these concepts is fundamentally important to selecting the appropriate method of data analysis.

The exploratory data analysis techniques can be divided in graphical representation and descriptive statistics. The main goal of these techniques is to summarise the sampling data, derive an understanding of the behaviour of the explored population and describe the features of that sampled population.

The exploratory analysis should be robust, so that the information gained is not too sensitive. Tentative or unavoidable assumptions are made about the underlying population (Aroner, 1997). The exploratory analysis should not be used to reach confirmed conclusions, for instance about a tested hypothesis of the sampled population.

The second category of techniques to analyse water quality data is the confirmatory technique. The main aspect of this technique is to test hypotheses advanced regarding populations. This could be the test for the hypothesis of a step trend or a linear trend. It should be emphasised at this point, that these hypotheses should not be made based on the results of an exploratory analysis. The exploratory analysis does not provide us with a significance level at which we can accept or reject the observed trend.

In general, the performance of a confirmatory procedure is higher than for an exploratory procedure. Typically, there are more assumptions associated with a confirmatory procedure.

It should be pointed out that certain assumptions have to be made before statistical procedures and hypothesis tests can be performed. These are:

- random sampling
- independence between observations within a sample (paired sample)
- independence between observations within a sample and between sample sets (unpaired samples)
- stationary of the mean and variance
- a population unit is measured without error

Unfortunately, the reality is that environmental data commonly exhibit the following characteristics

- Outliers
- Seasonality (the mean changes over time)
- Small sample sizes from extremely variable populations with low signals to noise ratios
- Limit of detection values (LOD)
- Variability changes over time

- Missing observations (from a time series)
- Greater variability at higher concentrations
- Asymmetrical, skewed, non normal distributions
- Measurement uncertainty

The above characteristics tend to be the rule, rather than the exception.

In order to provide engineers with a useful algorithm to solve problems in the field of trend analysis in water quality, Aroner (1997) suggested the following protocol:

1. Specify an appropriate hypothesis to be tested; this will usually constitute the alternate hypothesis (H_a); the null hypothesis (H_0) is usually that there is no trend or no change over time.
2. Identify the type of trend analysis (step or monotone trend) and the associated time periods appropriate for that hypothesis.
3. Select analysis techniques (data aggregation, the specific trend test(s) to be applied, exogenous factors if any suitable for the hypothesis and the sample data distribution, seasonality, missing observations, serial correlation).
4. Select a decision making rule - what level of risk of false conclusion is acceptable.

The following sections will provide a short description of the more recently used exploratory and confirmatory methods of trend analysis.

2.3 Graphical Methods

Graphical methods for analysing trends in water quality are classified as exploratory methods.

The graphical presentation of data sets is one of the most important tools to describe the behaviour between two or more environmental variables in time, frequency and spatial domains. Graphical presentation allows us to interpret statistical results, for example a time series plot with an estimated trend. In addition, it helps to ensure that statistical assumptions are satisfied by revealing distribution, seasonality and constant mean behaviour and variability. Some of the mostly common used graphical displays are

- Q-Q Plot
- Time series line or scatter plot
- Seasonal, annual and longitudinal Box - plots
- Probability plots
- Bar graphs
- Spatial displays

One of the most important and applicable graphical methods are described below.

2.3.1 Box - Whisker Plot

Box plots have become a standardised and popular method to graphically present data. They were first introduced by McGill et al. (1978). Box-and-whisker plots can be employed as an important exploratory data analysis tool in intervention studies (Hipel, 1988). If the date of intervention, which will improve or degrade water quality, is known, the box-and-whisker graph can be constructed for each season before and after the time of intervention and a graphical comparison can be made.

Box-and-whisker graphs are based upon the five number summary (Tukey, 1977). For a given data set, the five number summary consists the minimum and maximum value, the median and the two extreme quartiles. These quartiles are also called "hinges"(Hipel et. al, 1988) and can be determined by using the 25^{th} and 75^{th} percentiles of the data set. The most convenient manner to display this information is on a seasonal or monthly basis.

2.3.2 Q - Q Plot

Another tool to visually detect trends in water quality time series is the Q-Q plot method. Bartlett et al. (1978) stated that this method is useful when two sets of data are compared. Q-Q plots are based on the percentiles of two given seasons. These percentiles are plotted against each other. If the distributions are nearly the same, the points of the two data sets being compared will lie together nearly along the straight line Y = X. Q-Q plots are useful to get an overview of the behaviour of a water quality data time series.

2.4 Nonparametric tests for trends

In order to lessen the number of underlying assumptions required for testing a hypothesis, such as a specific kind of trend in a data set, researchers developed nonparametric tests (Hipel, 1988).

A nonparametric test can be considered as method for testing a hypothesis whereby the test does not depend upon the form of underlying distribution of the null hypothesis. In the literature, the nonparametric tests are also referred to as distribution free methods.

Hipel (1988) pointed out that, the term nonparametric should be confined to describing distribution free tests for which there are no parameters. In practice, it has been interpreted as standing for the set of all distribution free methods.

In order to give engineers guidance to choose the proper nonparametric method for testing water quality data for trends, Berryman et al. (1988) provided a summary of applicable methods. An extract of this summary can be found in Table 2.1. He also classified the statistical methods and verified their power to detect trends. The results are shown in Table 2.2

Table 2.1 Nonparametric tests for trend detection in water quality series

Trend type	Test	No. of Stations	N Minimum*
Monotone	Spearman	1	20
	Kendall	1	9
	Intrablock for persistent data	1	120 (ten years, 12 month)
Step	Mann -Withney	1	201
	Intrablock	1	12
Homogeneity of monthly trends	Chi-square	1	120 (ten years, 12 month)

* ten observations are needed to conduct a test with $\alpha = 0.05$ and five are required with $\alpha = 0.1$

Table 2.2 Power of nonparametric tests for trend

Type of trend	Test	Power
Monotone	Intrablock test	0.955
	Kendall	0.96
	Spearman	0.98
Step	Wilcoxson - Mann - Whitney	0.955
	Van der Waerden	1

The four most common nonparametric tests used to detected trends in water quality are described in the following sections. It will also include the description of a relatively new test, the van der Waerden' s X - test, which is a powerful test to detect trends.

2.4.1 Seasonal Kendall Test

The seasonal Kendall test is a particular application for Kendall's test for correlation (Kendall and Gibbons, 1990) and Mann's nonparametric test for randomness. It was first introduced by Hirsch et al. (1982) and since this time, it became a standard application in water quality analysis. One advantage of this test is the possibility to evaluate water quality measurements over a period of 2 years.

The seasonal Kendall test for trend detection is an adaptation of the seasonal Mann - Kendall test that is described in the next section. The seasonal Kendall test is divided in two types.

The first one is the seasonal Kendall test without correction for correlation. This modification of the test should be used on data pairs within the same season. This season could be a one-month or a three-month period. To perform this seasonal Kendall test without correlation, the intermediate statistics, S_i, are calculated for each season and then summed across all seasons, to give the global statistic, S' .

Hirsch et al. (1982) used equation 2.1 to calculate the variance of the global statistic, S'

$$Var(S') = \sum_{i=1}^{h} Var(S_i) = \sum_{i=1}^{h} \left\{ n_i(n_i-1)(2n_i+5) - \sum_{j=1}^{p} \left[t_j(t_j-1)(2t_j+5) \right] \right\} \quad (2.1)$$

where h = the number of seasons

n = the number of data in the i th season

t = the extent of any given tie (Aroner, 1997)

For n greater 10, the large sample statistic should be computed (Hirsch et al., 1982). Z is defined as the standard normal variate N (0,1).

$$Z = \begin{cases} \dfrac{S'-1}{[Var(S')]^{1/2}} & \text{if } S' > 0 \\ 0 & \text{if } S' = 0 \\ \dfrac{S'+1}{[Var(S')} & \text{if } S' < 0 \end{cases} \quad (2.2)$$

Thus in a two sided test for trend, the null hypothesis H_0 should be accepted if $|Z| \le z_{\alpha/2}$ where $F_N(z_{\alpha/2}) = \alpha/2$, F_N being the standard normal cumulative distribution function and α being the size of significance level for the test. Hence, a positive Value of S indicates an 'upward trend' (increasing values with time), and a negative value of S indicates a 'downward trend' (Hirsch et al., 1982). The value of 1 which is used in equation 2.2 is a "continuity correction" to improve the approximation of Z.

The second method of computing the seasonal Kendall test is with correction for correlation. Hirsch and Slack (1984) presented this modification of seasonal Kendall test without correction for correlation introduced in 1984 and made the attempt to account for serial correlation between adjacent seasons. This means that the independence is still assumed between the subsequent years within the same season. For instance a June observation for one year is assumed to be an independent observation from a June observation another year. The test is known as the covariance sum method (Aroner, 1997). Hirsch (1984) recommends using this type of test only for data sets longer than ten years.

The modified equation is given below

$$Var\ (S') = \sum_{i=1}^{h} Var\left(S_i\right) + \sum_{u=1}^{h}\ \sum_{v=1}^{h} Cov_{u \neq v}\left(u, v\right) \quad (2.3)$$

It should also be mentioned that Aroner (1997) suggested that this test should be applied only to a time series, where a significant serial correlation has been identified. The term serial correlation means the correlation between different observations with trend and seasonality removed. A more detailed description of the seasonal Kendall test with correlation can be found at Hirsch and Slack (1984).

2.4.2 Mann-Kendall Test

Although it is not mentioned in the previous section, that Kendall developed the Kendall' s test for correlation in 1938 and Mann 1945 described a nonparametric method for randomness against time that constitutes to be a particular application of Kendall' s test.

The null hypothesis H_0 is that for each of the m seasons the n observations are independent and identically distributed while the alternative hypothesis H_a is there is a monotone trend (Hipel, 1988). The test for S can be formally given by Hipel (1988)

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_{jg} - x_{kg}) \qquad (2.4)$$

where g= 1,2.....,m

Under H_0 as stated above the distribution of S is normal $n \rightarrow \infty$, and the variance, Var (S) can be given by

$$Var(S) = \left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} \left[t_j(t_j - 1)(2t_j + 5) \right] \right\} / 18 \qquad (2.5)$$

where t_j = the number of observations in a given tie. If no ties are present the summation term drops out (Aroner, 1997). As for the seasonal Kendall test, the large sample statistic Z should be computed as shown in equation 2.5.

Hipel (1988) proposed this test to evaluate the changes in water quality in the Lake Erie study. He applied the test to detect monthly changes in chloride concentrations over a period of 10 years. He concluded that the Mann - Kendall test is an appropriate method to detect trends in water quality series.

2.4.3 Spearman's Rho

The Spearman's Rho test is a non-seasonal test and can be considered as an adaptation of the non-parametric Spearman rank correlation test. It determines the randomness against a monotone trend. Marasculio and McSwenny (1977) generated the computational equation 2.6,

$$R_O = \frac{1/6(n^3 - n) - \sum_{i=1}^{n}(d_i^2) - T}{\sqrt{1/6(n^3 - n) - T}} \qquad (2.6)$$

where n = number of data

d_i = the paired difference in ranks, r_{i1} - r_{i2} between two points in the time series

T = $(1/12)\Sigma_j(t_j^3 - t_j)$ and t_j = the number of tied observations in a given tie.

As Van Belle and Hughes (1984) determined the relative power of nonparametric tests and concluded that, the Spearman test is more powerful than the Mann - Kendall test. Aroner (1997) reported that the non-seasonal Spearman's test is not as flexible as the Seasonal Kendall test with increasing sample sizes. It should be mentioned that the test does not acknowledge missing observations.

All three of the tests described above are considered as tests for monotone trend detection, but as stated above, water quality data does not change in a straight line. Therefore, it was necessary to find methods that use a different approach. Therefore, Hirsch (1984, 1991) tested methods for step trend analysis to evaluate water quality measurements. Two of the most prominent tests are described below.

2.4.4 Wilcoxson - Mann - Whitney Test

Hirsch (1991) suggested step trend procedures should only be used in two cases. The first case is when the record(s) being analysed are naturally broken into two distinct periods with a relatively long time gap between them. The other is when there is a known event that occurred at a specific time during the record and is likely to have resulted in a change in water quality. The record should be divided in a "before" and "after" period.

The Wilcoxson - Mann - Whitney test, also known as the U - test, can be considered as the non-parametric alternative to the parametric "t-test for the difference of two means". This test is preferred for any data exhibiting seasonality. Aroner (1997) computed the test as described below.

The first step is to combine the two samples and jointly ranked the observations from the smallest to the largest value. Under the null hypothesis H_0 of no difference in central tendency, one can expect the average combined rank of each sample to be identical. To compute this statistic one can use the equation 2.7.

$$W = \sum_{i=1}^{n_1} R_i \tag{2.7}$$

where n_1 = the number of data in the first sample

R_i = ranks of sample 1 within the combined sample.

For large sample ($n > 9$) W should be approximately normal, so one computes the approximation for Z as

$$Z = \frac{W \pm 0.5 - E(W)}{[Var(W)]^{\frac{1}{2}}} \tag{2.8}$$

where the 0.5 improves the normal approximation. The variance of W, can be computed as

$$Var(W) = \frac{n_1 n_2}{12}(n_1 + n_2 + 1)\left[1 - \sum_{s=1}^{S} \frac{t_s^3 - t_s}{N^3 - N}\right] \tag{2.9}$$

where n_2 = the number of data in the second (independent) sample

$N = n_1 - n_2$

t_s = the number of ties in any tied group

Siegel (1956) estimated the power of the Wilcoxson - Mann - Whitney test with 0.955. Therefore, it can be assumed that the test is less powerful than the monotone trend analysis methods (Table 2.2).

2.4.5 Van der Waerden Test (X-Test)

Van der Waerden' s test for trend detection in time series may be considered as one of the most powerful test for trend detection (see Table 2.2). It was originally introduced by van der Waerden in 1971. It is like the U-test a rank test and can be used to determine trends between two samples.

Van der Waerden' s normal scores test is one of three forms of tests for independent samples. Crawford (1983) recommended this test for trend detection in water quality data. Unfortunately, the properties of the test have not been rigorously evaluated yet, but Aroner (1997) considered its performance as excellent. The test can be computed as:

$$X = \sum_{i=1}^{n} \Psi\left(\frac{Rg(x_i)}{n_1 + n_2 + 1}\right) \qquad (2.10)$$

where n_1 = the number of data in the first sample

n_2 = the number of data in the second (independent) sample

$Rg(x_i)$ = the rank from x_i by $i = 1,......,n$

Ψ = the quantile $q = y$

Marasculio and McSwenny (1977) reported the normal scores test after van der Waerden is best for distributions with thin tails.

The use of this method for trend detection of water quality data is not completely proved yet, therefore it will not be used in this study.

2.5 Summary

For determination of environmental trends in water quality data sets, distribution-free methods are widely used. An independent observation of whether environmental conditions are improving or deteriorating should be at least as important as evaluating current conditions.

Trend analysis should not be undertaken without a clear understanding of how the results can be used and interpreted. Hence, the appropriate hypothesis, analysis method(s) and time periods should be carefully selected, to provide adequate tools to determine the effectiveness of environmental management activities.

It should be pointed out that water quality for example does not increase in the same time as it deteriorates. Therefore, it is quite important to measure the impact of environmental management activities over a longer period.

Another factor is an understanding of the capabilities of existing trend analysis methods and their relative power as compared to each other. Hence, it is quite important not to rely only on one method. One can choose from at least two different approaches, the parametric and the nonparametric.

If the nonparametric approach is chosen, one should be aware of the fact that not all-environmental time series exhibit seasonality. If there is no seasonality, a seasonal test like the seasonal Kendall will suffer a loss of power against its non-seasonal counterparts.

It is important to choose between monotone or step trend analysis. As shown in Table 2.2, the monotone trend analysis methods are more powerful than their step trend counterparts. Therefore, the monotone trend analysis methods are the standard tools for detecting trends. The step trend methods should only be used if a distinct before and after period can be identified. The limit between those two periods could be the implementation of soil conservation practices or fertiliser management, as well as a reduced output from agricultural industries.

Taking all the facts described above into account it is necessary to follow certain steps to detect trends in water quality times series. They might be summarised as:

1. Decide if a parametric or a nonparametric approach should be used, depending of the distribution of the data.
2. For non-normal distributed data, select appropriate nonparametric tests, based on the amount of data available.
3. State a null hypothesis and an alternative hypothesis to determine trends (upward, downward, no trend).
4. Compare the results of the used methods with another (overall trend versus trend between specified seasons).
5. Relate the detected trends to possible impacts of environmental changes.

3. Materials and Methods

3.1 Site Description

3.1.1 St. Esprit Watershed

The St. Esprit watershed is situated approximately 50-km north-east of Montreal in the north-west of the village of St. Alexis de Montcalm, and was selected as the intervention watershed, on which conservation practices would be applied.

An adjacent watershed, the Desrochers, was selected as a control. The principal watercourse, the Ruisseau St. Esprit drains an area of 26.1 km^2. Approximately 64 % of this area are in agricultural production. Approximately 50 % of the agricultural area are tile drained (Enright et al., 1995). In the study area, there are approximately 28 farms, and 19 of these farms are involved wholly or partially in livestock production, with an average animal density of 0.8 animal units per hectare (Enright et al., 1997).

The agricultural land use is listed in Table 3.1. All data presented in section 3.11 and 3.12 were taken from Enright et al. (1998). The non-cropped area is covered by forest (25.2 %). The remaining land coverage is residential area (4.97%) and 6.1 % of unused area. The population in this area is approximately 800 people (Enright et. al, 1997).

With respect to the soil texture, most of the soils on the study watershed can be characterised either as very light or heavy soils. The textures of the dominant soil classes are listed in Table 3.2.

The main channel has a length of 9 km to the watershed outlet. The average annual precipitation in the area is 998 mm and average annual potential evapotranspiration is 489 mm (MEF, 1995).

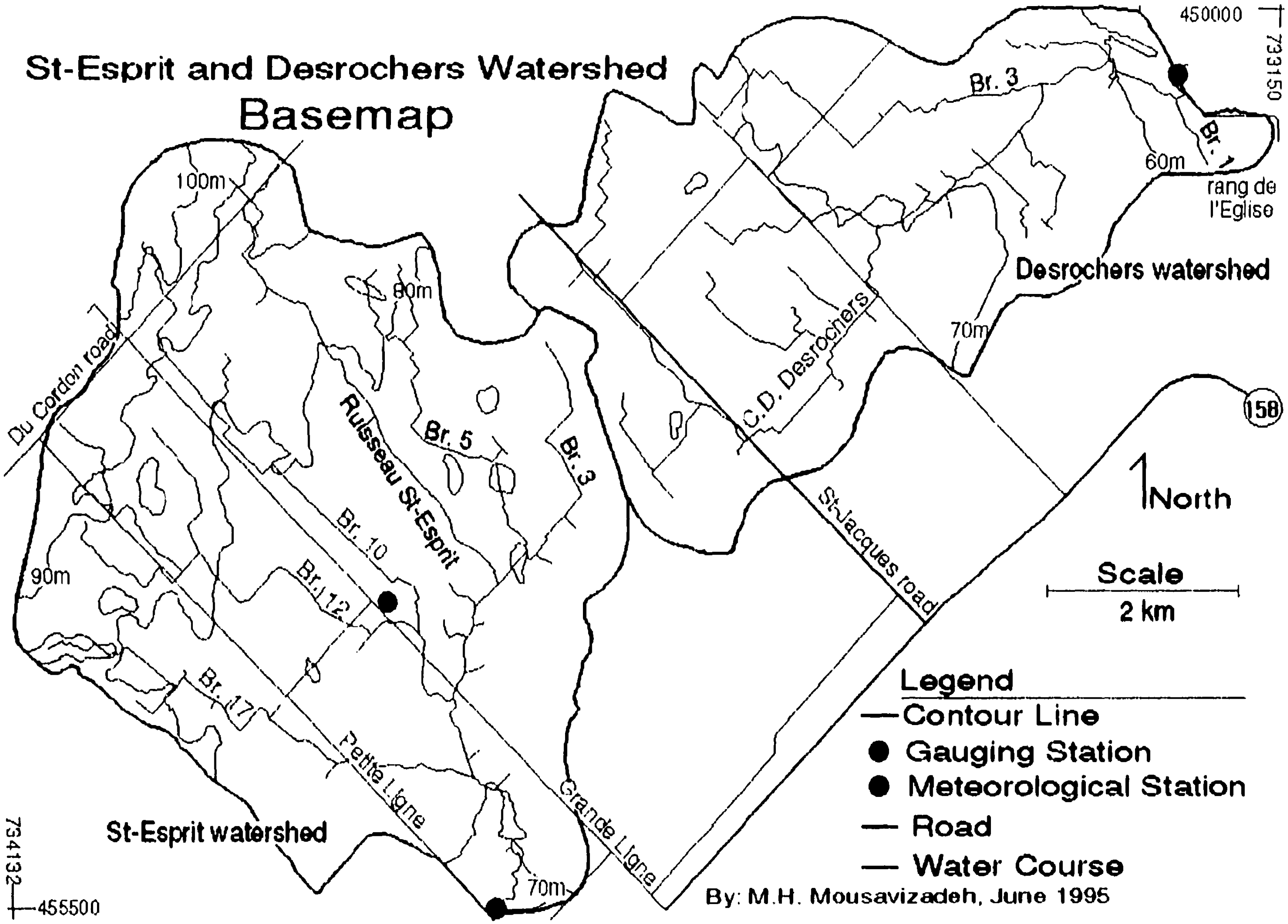


Figure 3.1 Layout of the St. Esprit and Desrochers watersheds

Table 3.1 Agricultural land use - St. Esprit watershed

Crop	Area(%)	Area (km^2)
Corn	23.9	6.26
Cereal	13.3	3.47
Soya	3.3	0.86
Vegetable	3.1	0.82
Hay	11.2	2.94

Table 3.2 Soil classes in the St. Esprit watershed

Soil class	Area (%)	Area (km^2)
Sand	8.2	2.14
Loamy sand	5.6	1.46
Fine loamy sand to sand	0.1	0.03
Sandy loam	33.4	8.71
Fine sandy loam	3.2	0.84
Loam	3.4	0.88
Loam to sandy loam	2.1	0.54
Sandy clay	1	0.26
Silty clay loam	2.3	0.6
Clay loam	14.1	3.67
Clay to clay loam	9.1	2.37
Clay	17.5	4.57
Light soils	50	13.05
Medium Soils	6	1.82
Heavy soils	43	11.22

The annual average temperature is 5.2 °C (MEF, 1995). Hence, the climate is temperate. The topography can be characterised as flat to rolling, with an average slope of 0 % to 3 %.

3.1.2 Desrochers Watershed

This watershed covers an area of approximately 17.9 km^2. Of this area, approximately 79 % or 14.14 km^2 is in crop production. The non-cropped area covers approximately 6 % (1.07 km^2) and approximately 14 % (2.6 km^2) of the watershed is forested. The land use is shown in Table 3.3. Approximately 60 % of the cropped area is tile drained (Papineau, 1997).

The soils in the Desrochers watershed vary from light to heavy with the majority of the crop production taking place on medium soils.

Table 3.3 Agricultural land use on the Desrochers watershed

Crop	Area (%)	Area (km^2)
Corn	36	6.44
Cereals	9	1.61
Soya	4	0.71
Vegetables	9	1.61
Hay	18	3.22

Table 3.4 Soil classes in the Desrochers watershed

Soil class	Area (%)	Area (km^2)
Sand	2.3	0.4
Sandy surface	1	0.18
Fine loamy sand to sand	3.6	0.64
Sandy loam	4.5	0.79
Fine sandy loam	7.5	1.32
Sandy clay loam	3.2	0.56
Loam	8.5	1.5
Loam to sandy loam	28.8	5.07
Loam to clay	14.7	2.59
Silty clay loam	5.5	0.97
Clay loam	2.9	0.51
Clay to clay loam	2.2	0.39
Clay	14.5	2.55
Light soils	***22***	***3.87***
Medium Soils	***53***	***9.33***
Heavy soils	***25***	***4.4***
Total	**100**	**17.6**

A summary of the different soil classes found on the watershed is shown in Table 3.4.

The main channel in the Desrochers watershed is approximately 5 km long. The landscape topography is similar to St. Esprit and can be described as flat to rolling, with a slope of 0 % to 3 %.

3.2 Data Collection

3.2. 1 Instrumentation

At the end of 1993 and the beginning of 1994, gauging stations at the outlets of the St. Esprit and Desrochers watersheds were established by the Department of Agricultural and Biosystems Engineering of McGill University (Figure 3.1).

A meteorological station was established in the St. Esprit watershed in March 1994. The MEF also maintains a meteorological station in St. Jacques de Montcalm, located just south of the two watersheds.

The instrumentation for the gauging stations is housed in a small sampling shelter (1.8m x 2.4-m). The construction of the gauging stations is similar. Therefore, only the St. Esprit station is described. The gauging station of the St. Esprit watershed is located at the upstream side of a bridge and adjacent to the control section. To keep the station running, the building was supplied with AC power and heat.

The water level in the stream is measured using a Druck 950 pressure transducer water level sensor. This was a submersible pressure transducer, which was installed on the streambed. In addition, an ultrasonic water level sensor (UDG01) was mounted over the control section. To collect the information from both sensors, a Campbell CR10 datalogger was used. It was possible to remotely monitor the datalogger via modem.

An independent FLOW-LOG datalogger was installed as a backup water level recording system. This FLOW-LOG sensor was mounted on a small cement slab on the streambed. This system measured the water level and velocity. The measurements were uploaded to the Campbell CR 10 datalogger.

A rating curve was developed for the river at the control section. To develop this rating curve it was necessary to measure the stream velocity at different water levels at the control section. A propeller meter (OSS-PC1) was used to measure the velocity. After these measurements were taken, the results were used to create the rating curve. This curve was then programmed into the logger. The water level in the stream was measured every 10 seconds and used to calculate the average discharge over 15-minute intervals.

An American Sigma 800 SL automated water sampler was also installed at the gauging station. The intake line for the sampler was placed over the control section. The automated sampler was refrigerated and contained a 24 bottle carousel.

A flow weighted sampling strategy was designed to obtain an adequate representation of the parameter concentrations during surface runoff events. A predetermined value of accumulated flow had to be reached before the sampler was activated. This threshold value was variable and depended on the seasons (different flow regimes in spring, summer and fall). In addition, individual samples on a weekly basis were taken manually to verify the automated samples for quality control purposes. An extensive discussion on the rating curve development and sampling strategy can be found in Enright et al. (1995). In general, the majority of auto-samples were obtained during events, when discharge rates were changing rapidly. The majority of the manual samples were taken during periods where discharge was constant or varying slowly.

The meteorological station at St. Esprit, located near the centre of the watershed, was equipped with sensors for air and soil temperature, wind speed and direction, solar radiation, rain fall and snow accumulation. A Campbell CR 10 datalogger was used to record the data.

3.2.2 Sampling analysis

The water samples were analysed for two different classes of pollutants.

1. suspended sediment

2. nutrients nitrate (NO_3), phosphate (PO_4), potassium (K), ammonium (NH_4), total phosphorus (TP), total Kjeldahl nitrogen (TKN)

The nitrate concentration was detected using the cadmium reduction method (method 4500 - NO_3). This method is described by the American Public Health Association (1992). The phosphate concentration was determined using the Mehlich III method as outlined by CPVQ (Agdex 533).

All tests were performed in laboratories at McGill University. The amount of suspended sediment in stream discharge was measured using a pre-weighed water sample. This sample was then passed through a pre-weighed micro-fibre filter paper (0.5 μ) with the aid of vacuum filtration equipment. The next step was to dry the filter paper with the entrapped sediment for 24 hours and re-weigh it.

To confirm the accuracy of all water quality samples an external laboratory was used to verify the results of the internal laboratories.

With respect to the detection limits of the laboratories, the results for NO_3 –N and K were excellent. Almost all samples (>99%) had a measured concentration above the detection limit. Good correlation between the internal and external laboratories on paired samples was determined. The determined R^2-values were above 0.9. The results for PO_4-P and NH_4-N could be qualified as good, with 73 % of PO_4 concentrations above the detection limit and 42 % of the samples were greater than the detection limit for NH_4. Also there was a greater variation between the internal and external laboratories for paired samples. The results for TP could only be qualified as fair. Because the values for the detection limit were very high. Only 37 % of the measured TP values had concentrations greater than the calculated detection limit (Enright, 1998).

3.2.3 Water quality data sets

The data used in this project were collected between January1994 and December 1996 inclusive. They include the following parameters:

- Nitrates (NO_3-N)
- Ammonium (NH_4)
- ortho-Phosphate (o- PO_4)
- Potassium (K)
- Total Kjeldahl nitrogen (TKN)
- Total phosphorus (TP)
- Suspended sediment

For each watershed, two data sets were used to conduct the statistical analysis. The first data set includes all of the water samples ('all'), i.e. both auto-samples and manual samples. The second data set is a subset of the first, and it includes only those samples taken manually ('grab').

Manual samples collected on a fixed time interval, is the norm in most water sampling strategies. Because of the size of the watersheds, and the rapid hydrologic response, the use of an auto-sampler was deemed necessary, during runoff events. However, for evaluating water quality trends, it is not known if additional efforts required for conducting a flow weighted sampling program are necessary. One of the objectives of this study was to evaluate if the manually collected samples, on a fixed time interval gave the same results as a flow weighted sampling program.

Because, the sampling program on the watersheds was flow weighted, the number of samples collected each year varied. The total number of samples collected each year (including auto-samples and manual samples) on each watershed is shown in Tables 3.5 and 3.6.

In general, the greater the number of surface runoff events within a given year, the greater the number of samples. Given that 1995 was relatively a dry year, almost all samples were taken manually. Most of the samples collected in 1994 and 1996 were collected using the automated sampler.

Table 3.5 Water Sampling for the St. Esprit watershed

Year	Total sample number	# grab samples	Number of samples tested for						
			NO_3	NH_4	PO_4	K	TKN	TP	Sediment
1994	201	39	188	180	188	188	192	184	195
1995	93	52	93	93	93	93	92	82	92
1996	153	48	153	136	152	153	104	81	153

Table 3.6 Water Sampling summary for Desrochers watershed

Year	Total sample number	# grab samples	Number of samples tested for						
			NO_3	NH_4	PO_4	K	TKN	TP	Sediment
1994	176	39	171	158	170	171	174	167	168
1995	89	54	89	89	89	89	88	82	87
1996	129	47	128	115	128	129	86	72	128

3.3 Data Analysis Methods

This study was undertaken to determine the effects of best management practices (BMP's) applied to the St. Esprit watershed in Quebec. The most widely adopted practises were soil conservation practices and fertiliser management. The expected results of these techniques might be an improved water quality in the study area, particularly sediment, nitrogen and phosphorus. With respect to environmental impacts, such as climatic variation or application of the BMP's it was necessary to use a control watershed, Desrochers. This was necessary to determine if an explored trend is a result of the BMP's or of short-term climatic variations. To determine trends and uncover the statistical properties in the St. Esprit and Desrochers watersheds water quality time series, appropriate test must be employed. In order to have the highest probability of detecting expected statistical characteristics, which may be present in the time series, we must select a set of tests that possess the best capabilities to detect the statistical properties of the data sets. As described in section 2.1 one must distinguish between exploratory and confirmatory data analysis tools to detect the specific behaviours of the water quality time series. Hence, one applies the exploratory data analysis tools first and than applies the confirmatory tools. To perform the analysis of the existing data sets it was necessary to choose between parametric or distribution free methods. Because of the nature of water quality data, which tends to be highly skewed, non-normally distributed and affected by climatic variations, distribution free approaches were chosen.

Table 3.7 Statistical methods used in the St. Esprit and Desrochers watershed study

Type of analysis	General Purpose	Purpose in the study	Method
Exploratory	For each series and population want to know exact values, observation spacing, amount of samples taken	Same as under general purpose	Data listing
Exploratory	Determine the common behaviour	Determine the central tendency of every parameter	Descriptive statistics – mean – median – geometrical mean – 1 and 3 quantile – maximum and minimum – standard deviation
Exploratory	graphical display of important parameters for each season in a year	see a plot of five numbers for each month in a series	Box - Whisker - plot using the maximum, median, first and third quantile, minimum
Exploratory	detecting a trend by comparing to years with each other	see a plot for one year against another	Q - Q plot for 1994 and 1995, 1994 and 1996; using the parameters computed in the descriptive statistics
Confirmatory	test for monotone trends for each parameter	Same as under general purpose Taking seasonality in account	Seasonal Kendall test for 1994 to 1996
Confirmatory	test for monotone trends for each parameter	non seasonal test to detect trends for each measured parameter	Mann - Kendall test 1994 to 1996
Confirmatory	determine monotone trends for each parameter	Verify the results of the seasonal Kendall and the Mann Kendall test	Spearman's rho 1994 to 1996
Confirmatory	determine step trends for each year of the series	Testing for improvement of water quality after applying BMP	Wilcoxson-Mann-Whitney test for the years of 1994 to 1995, 1995 to 1996, and 1994 and 1996

The selected tests have the proof of relatively high power (see Table 2.2) and are widely used for trend detection in water quality time series.

All methods used in the study are listed in Table 3.7. A detailed description of the applied methods will be given below. The methods described are applied to all measured parameter.

3.3.1 Exploratory trend analysis methods

The first step in analysing the measured water quality data was to tabulate each parameter by value, time, site and types of sample. The differentiation between the sample type was made because one aim of this study was to analyse and compare the manually collected samples (hereafter referred to as 'Grab') and all of the collected data (hereafter referred to as 'All'). This sample type includes grab and auto samples. These data listings are also used to determine the value of missing data and data below the limit of detection. This is necessary, because if 20 to 30 % of a data set is constituted by missing or non-detectable, the results of the method for detecting trend are questionable.

The next step in the exploratory part of the study was a descriptive statistical analysis to measure the central tendencies of the data sets. This includes the maximum, minimum, arithmetic mean, geometric mean, median, the 25 and 75 percentile, and the standard deviation. This analysis was performed on the data sets of all samples. These parameters were used to develop the Box - Whisker plots for the first two years and Q - Q plots for 1994 to 1996. A description of both methods is given in section 2.2.

The Box - Whisker plots in this study include the median, the percentiles, the maximum and the minimum for each month. This method is used to describe how the water quality data are distributed each month.

For the Q - Q plots one use all the parameters computed as descriptive statistics. This method is applied to detect trends between the years on an annual basis.

3.3.2 Confirmatory trend analysis methods

The second tool to detect trends in water quality time series data sets is the confirmatory data analysis. In the St. Esprit and Desrochers watersheds, study non-parametric methods were chosen to perform this second part. The following tests were all computed using the WQHYDRO-Program (Aroner, 1997) and a spreadsheet software (EXCEL95, Microsoft 1996). All tests described below were performed to all measured parameters, described under section 3.2.3, for both watersheds.

To apply all methods to the data sets it was necessary to aggregate the multiple observations for one month to a single observation per period. To do so, a point nearest to the midpoint of the observation was chosen. It is also possible to use the mean of the observation. In addition, we assumed all observations were independent for each season and all statistical analyses do not rely on the distribution of the samples.

The first step in analysis of the data sets for trends was to define the non-parametric hypotheses that will be tested.

Non-parametric hypotheses are more generalised than parametric hypotheses and make no assumption about the type of F. Two types of hypotheses exists. The first one is the null hypothesis which can be generally be defined as H_0: $F=F_0$. This means that F_0 is the distribution function of the population. Sometimes it is necessary to test a population for another hypothesis as H_a: $F < F_0$. This type of hypothesis is called an alternative hypothesis.

In this study, a null hypothesis (H_0) is assumed, that no trend exists in the tested population and the sample trend is the result of random sampling variability.

$$H_0 : F = F_0$$

The alternate hypothesis (H_a) is that a trend, upward or downward, exists in the population.

$$H_a : F \neq F_0$$

The acceptance of the alternate hypothesis of trend (H_a) depends on the chance that we are willing to accept of falsely concluding that a population trend exists. A tool to estimate the likelihood that a trend in an observed data set exists is the two - sided P value (2*P), the probability of a type one error. For example, a 2*P result (Type I error estimate) of 0.031, indicates that there is a 3.1 % probability that the trend evident in the sample does not exist in the population. Namely, that the observed trend is a result of random sampling variability.

The determined 2*P value is then compared to a pre-determined error level which represents the chance that we are willing to accept an incorrect conclusion. This parameter is known as the significance level.

To determine the significance level in this study, we had to decide if the consequences of failing to detect a true trend are minimal and the consequence of a false conclusion is severe. Considering the length of the time series, the amount of data and the environmental condition at the time of measurement we are willing to conclude that a trend exists (H_a) at a 2*P value > 0.10. This means the hypothesis will be rejected at significance level (α) < 0.10 or a confidence level < 90 %.

The first test applied was the seasonal Kendall test without correction of correlation. The test is relatively powerful for time series of less than ten years. To perform the test one uses equations 2.1 and 2.2.

This test relies on monotone trend estimation; therefore, it was necessary to test the given populations for homogeneity of trend between the seasons. Because it is possible that the global seasonal Kendall test will be offset by different trends in two seasons and this will lead to a false conclusion of absence of a global trend. A commonly used method to determine the homogeneity is the

Chi - square test. If a non-homogenous trend is detected, an examination of each season will be performed.

The Chi - square test for an overall trend will be computed with equation 3.1 and the test for seasonal homogeneity with equation 3.2:

$$\aleph^2_{trend} = HM\overline{Z}^2 \qquad (3.1)$$

$$\aleph^2_{season} = M\sum_{h=1}^{H}\overline{Z}_h^2 - HM\overline{Z}^2 \qquad (3.2)$$

where
H = number of seasons
M = number of stations
$\overline{Z}^2$ = the grand mean over all H seasons and M stations

For equation 3.1 the degree of freedom is 1 and for equation 3.2 the degree of freedom is H-1.

In order to visualise a monotone trend slope we apply a nonparametric estimator for slope. This estimator developed by Sen (1968) will be computed for the seasonal slope using equation 3.3:

$$d_{ijk} = (x_{ij} - x_{ik}) / (j - k) \qquad (3.3)$$

for all paired observations X_{ij}, X_{ik} (j>k) within season i for i=1,2,...,h, for h seasons where j and k are years. To determine the seasonal slope we take the median of all the d_{ijk} 's from all seasons.

It should be mentioned that the slope is computationally related to the Mann-Kendall based test. Hence, the nonparametric hypothesis tests for trend are not a test of significance for the estimated slope magnitude.

As indicated before the next step in the confirmatory trend analysis is the Mann - Kendall test, which is, described in equations 2.4 and 2.5. To visualise the trend slope non-seasonal slope will be computed by determining the median of all n(n-1)/2 slopes.

To verify the result of both adaptations of the seasonal Kendall test and the Mann-Kendall test we also performed the Spearman's rho test, which can be computed from equation 2.6.

As a last step in the confirmatory trend analysis, we applied the distribution free seasonal Wilcoxsons - Mann - Whitney test to all data sets. The application of this test is made considering the fact that we know the point of intervention at the St. Esprit watershed. This means that best management practises such as soil conservation and fertiliser management were applied at the end of 1994. Hence, we can clearly distinguishing between a before and after period. To verify that the determined trends are not a result of variation of the climate, we applied the test also to the Desrochers watershed, to compare both results.

As shown for the monotone trend analysis there is also an estimator of trend magnitude for step trend analysis. The estimator was introduced by Hodges and Lehmann (Hirsch, 1988). This Hodges - Lehmann estimator is the difference between the n_1*n_2 differences, or the Median $\{X_i$- Y_i, for $i= 1$ to n_1 and $j = 1$ to n_2). In this study, we use the Seasonal Hodges-Lehmann estimator who is identical to his non-seasonal approach except that only differences between data from the same seasons are computed.

Finally a graphical visualisation for the applied methods will be developed and a comparison between the behaviour of the St. Esprit and Desrochers watershed will be made

4. Result and Discussions

4.1. Precipitation vs. sampling frequency

The long term average monthly precipitation for the study area was taken from the MEF weather station at St. Jacques de Montcalm, which is situated just outside of the studied basin. The monthly precipitation for the period 1994 – 1996 is shown in Table 4.1 and a graphical display of the precipitation for the same period is shown in Figure 4.1.

Table 4.1 Monthly and long term average Precipitation for 1994 - 1996

Month	monthly R (mm)[1]	Long term average R (mm)	Month	monthly R (mm)[1]	Long term average R (mm)	Month	monthly R (mm)[1]	Long term average R (mm)
	1994,0			1995			1996	
January	89.0	59.9	January	104.0	59.9	January	95.7	59.9
February	45.0	46.3	February	18.1	46.3	February	102.0	46.3
March	36.5	61.2	March	36.5	61.2	March	24.2	61.2
April	70.1	72.1	April	84.6	72.1	April	173.8	72.1
May	109.1	93	May	77.6	93	May	73.5	93
June	216.9	113.6	June	38.1	113.6	June	86.2	113.6
July	114.2	85.8	July	124.1	85.8	July	132.2	85.8
August	113.6	102	August	87 7	102	August	84.0	102
September	44.8	100.4	September	58.8	100.4	September	143.1	100.4
October	19.1	96.7	October	166.9	96.7	October	146.1	96.7
November	96.5	87.2	November	114.8	87.2	November	118.2	87.2
December	53.0	79.5	December	29.8	79.5	December	104.4	79.5
Total	1008			941			1283	

1- 'average' of for stations: St.-Esprit, St. Liguori, St. Alexis weather station and the St. Jacques weather station.

As shown in Table 4.1 there was an appreciable variation in the monthly precipitation over the study period. The year 1994 can be described as average, year if one looks at the annual precipitation. If we look more closely through the year, we can see that for most of the time the monthly precipitation was less than the long-term average precipitation. The exception was the period from May to August.

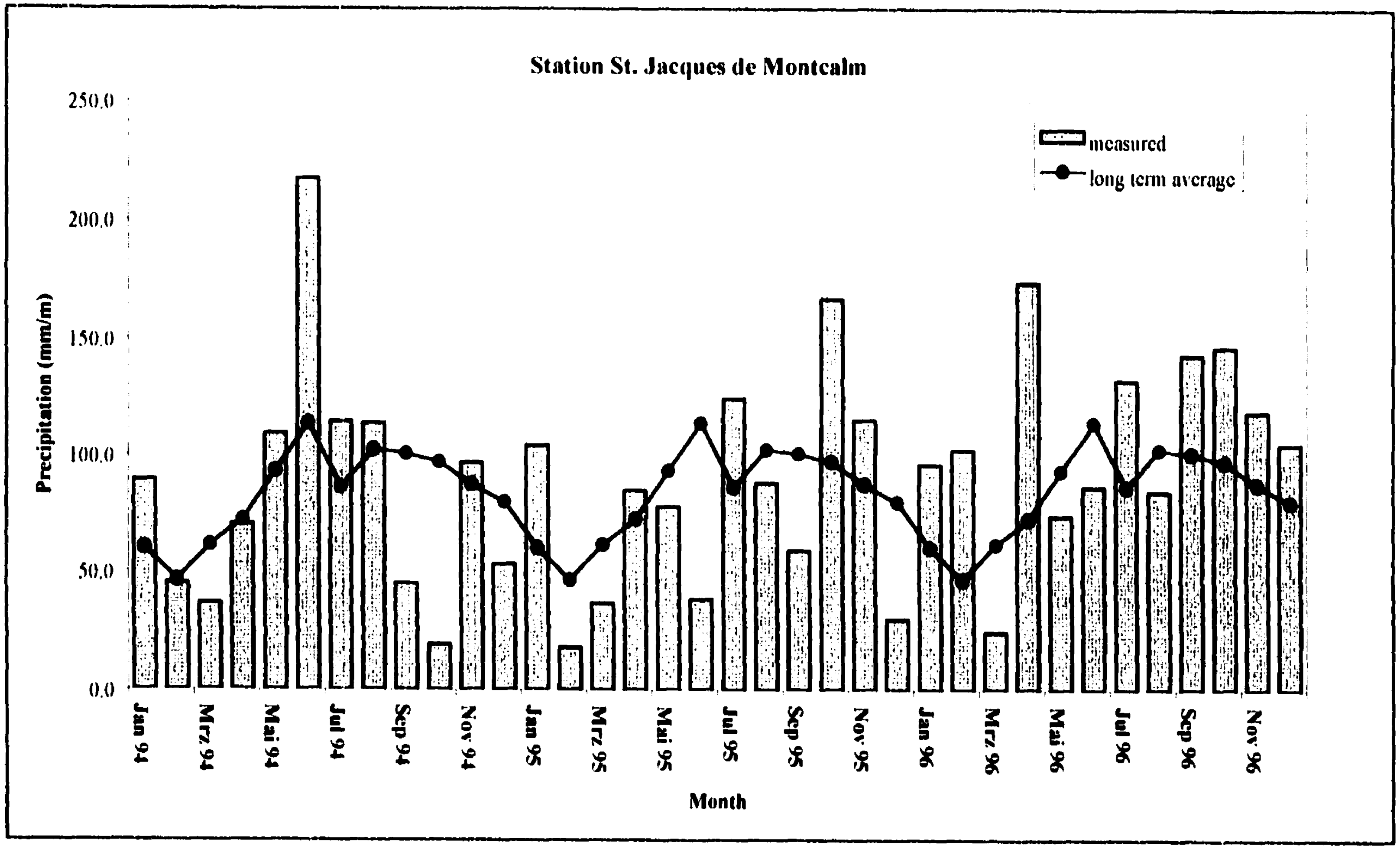


Figure 4.1 Monthly precipitation at the St. Jacques weather station for 1994 – 1996

These four months provided 54 % of the annual precipitation in 1994.

The year 1995 can be characterised as 'dry'. The annual precipitation was approximately 6 % lower than the annual average. Most of the precipitation occurred in January, July and from October to November. Almost all of the precipitation that fell in November and December 1995 occurred as snow. As such, it only appeared as surface runoff in 1996.

The year 1996 can be characterised as an exceptionally wet year, with an annual precipitation of 1283 mm that is approximately 28 % above the long-term average. In particular, precipitation was well above average in the month of April, and October to December. All of the observed precipitation in November 1996 occurred during one rainfall event.

Because of the variations in rainfall and runoff patterns, the amount of samples that were taken each year varied. In addition, the ratio between grab samples and total number of samples taken during each year differed, due to the climatic variations for the St. Esprit and Desrochers watershed.

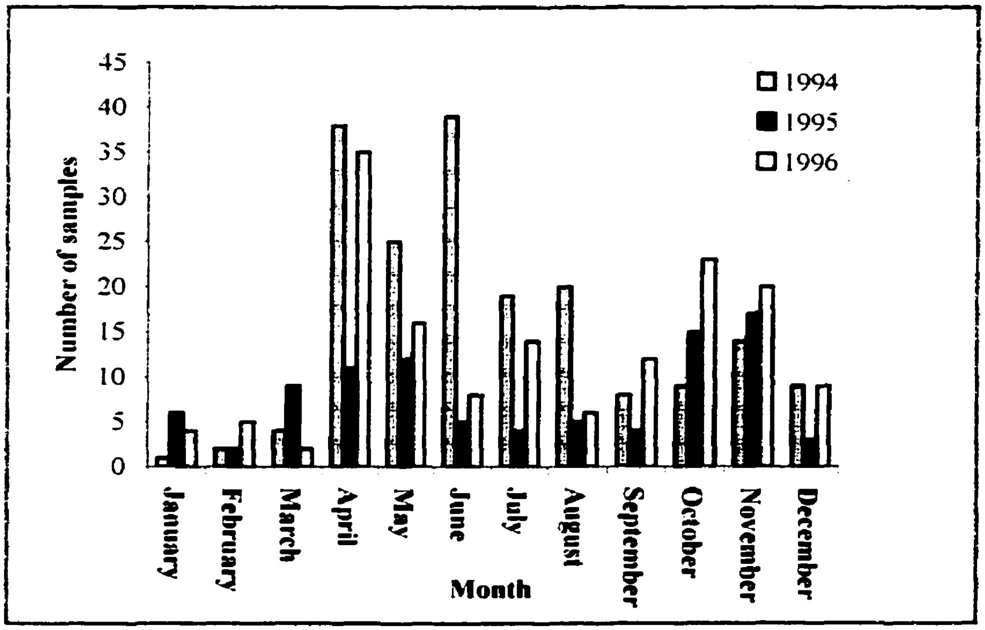


Figure 4. 1 Water sample frequency at the St. Esprit watershed

Because of the intensity of the water quality monitoring program on the two watersheds, there is an excellent database available for conducting the statistical analysis.

The frequency with which the samples were taken on the watersheds will provide the trend analysis with a good database. The number of samples collected for each month on the St. Esprit watershed is shown in Figure 4.2. The water sampling strategy and frequency at the Desrochers watershed was similar.

Figure 4.2 shows that the amount of samples collected from January to March is relatively low. This is a result of the climate. During January to March, the area is mostly covered by snow, which results in reduced sampling. The exception was January 1995 that was characterised by partial snowmelt events, which led to higher discharge activities at the watersheds. For further information on the relation between precipitation and discharge at the St. Esprit watershed, see Lapp (1996).

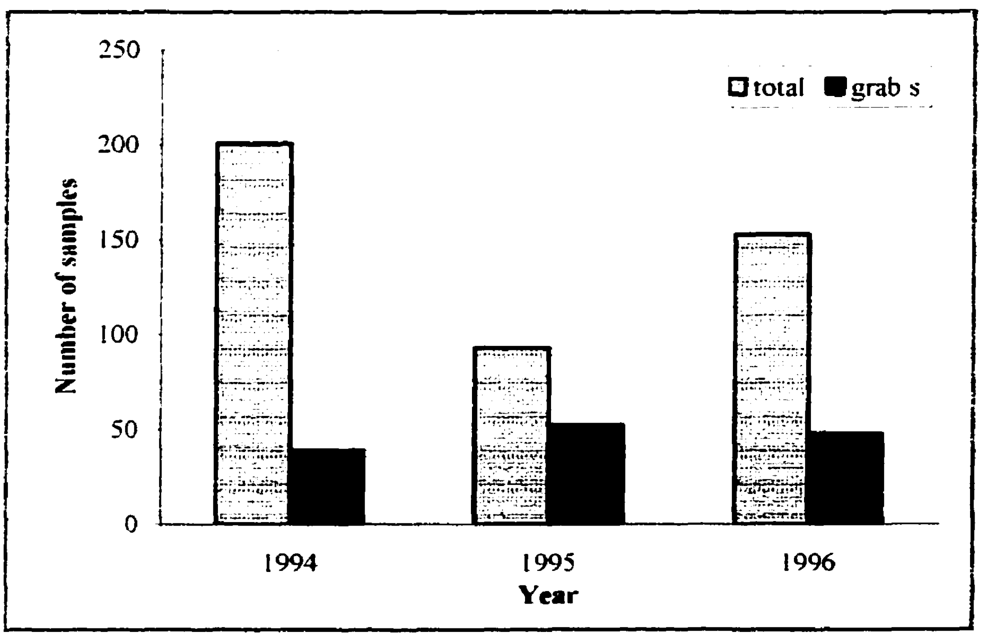


Figure 4.3a Number of samples at the St. Esprit watershed

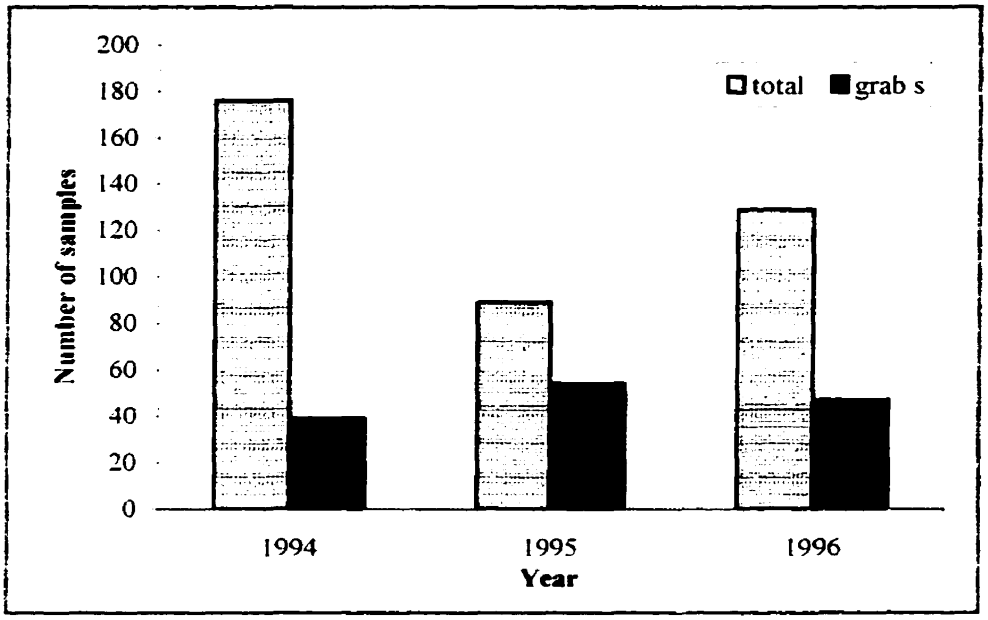


Figure 4.2b Number of samples at the Desrochers watershed

As shown in Figures 4.3a and 4.3b the amount of grab samples taken in 1995 represented more than 50 % of the total number of samples, whereas in 1994, one-third and 1996 one-fourth of all samples were grab samples. It should also be mentioned that the general reduction of samples over the years was a result of an adjusted sampling strategy.

4.2 Descriptive Statistics

As stated before, an important step to get a 'feeling' for the observed time series is to perform standard statistical analyses. The tests were performed with the complete 'All' data sets taken for each watershed (Tables 3.5 and 3.6).

This section presents the annual summaries on the water quality results for nitrate (NO_3), ammonium (NH_4), phosphate (PO_4) and suspended sediment. A detailed listing of monthly descriptive statistics performed at the St. Esprit and Desrochers watershed is given in Appendix A. An extended description of all parameters computed would go beyond the scope of this dissertation. All computed parameters listed in Appendix A are used to perform the graphical trend assessments in the following section.

The results of the annual numerical summaries for the St. Esprit watershed are given in Table 4.2 and for the Desrochers watershed in Table 4.3.

Table 4.2 Numerical summaries for the St. Esprit watershed

Year	Parameter	Nitrate	Ammonium	Phosphate	Sediment
1994	Minimum	0.40	0.01	0.01	0.00
	Aritmetic mean	2.82	0.26	0.05	0.05
	Maximum	8.60	1.67	0.28	0.70
	Coefficient of Skewness	1.07	2.33	2.09	4.26
1995	Minimum	0.34	0.01	0.02	0.00
	Aritmetic mean	2.33	0.33	0.05	0.04
	Maximum	4.47	1.00	0.14	0.48
	Coefficient of Skewness	-0.01	0.44	1.31	4.71
1996	Minimum	0.79	0.01	0.01	0.00
	Aritmetic mean	2.83	0.24	0.09	0.09
	Maximum	8.94	1.62	0.35	0.56
	Coefficient of Skewness	2.41	2.97	1.97	1.97

After examining the numerical annual summaries, one can determine that the observed climatic variation has an impact on the changes in concentration for selected parameters. The computed arithmetic mean for the parameters on both watersheds shows that the concentrations of the measured parameters in 1995 fell to half the values as in 1994 and 1996. This might be due to the climatic variation and should be considered by evaluating results of the confirmatory analysis. Most parameters on both watersheds are positively skewed. This means that the samples have a long tail to the right. This might be due to the sampling strategy, which is related to the discharge. This depends on the precipitation in the basin. The exception is the nitrate concentration at the St. Esprit watershed, which is negatively skewed.

Overall, the summaries in Tables 4.2 and 4.3 indicate that the two watersheds are quite similar.

Table 4.3 Numerical summaries for the Desrochers watershed

Year	Parameter	Nitrate	Ammonium	Phosphate	Sediment
1994	Minimum	0.09	0.01	0.01	0.00
	Aritmetic mean	2.92	0.25	0.07	0.03
	Maximum	11.29	1.52	0.20	0.44
	Coefficient of Skewness	1.38	2.18	0.65	4.08
1995	Minimum	0.23	0.04	0.02	0.00
	Aritmetic mean	2.50	0.31	0.06	0.02
	Maximum	5.86	1.01	0.24	0.27
	Coefficient of Skewness	0.26	0.58	2.13	5.23
1996	Minimum	0.30	0.01	0.02	0.00
	Aritmetic mean	3.33	0.20	0.10	0.06
	Maximum	10.37	1.81	0.62	0.49
	Coefficient of Skewness	0.99	4.03	3.32	2.52

The observed variability in concentrations over the years as shown in Tables 4.2 and 4.3 does not provide information for trends in the water quality. Therefore, the next exploratory step was undertaken, i.e. the box plot analysis.

4.3 Box and Whisker Plots

Box and whisker plots can be employed as an important exploratory tool for intervention studies. Since the time of intervention for this study can be determined at the end of 1994, we could expect that trends in the water quality occur at this point of time. The box and whisker technique was applied to all parameters on both watersheds. The intervention in this paired watershed study was the application of soil conservation practices and fertiliser management at the St. Esprit watershed. The graphical results of all the analyses can be found in Appendix B.

The numerical summaries from the monthly descriptive statistics for all samples in Appendix A were used to develop the box and whisker plots.

If one looks at the figures in Appendix B one will see the upper and lower ends of the rectangle for a given month will present the hinges and the line drawn horizontally within each rectangle is the value for the median. The maximum and minimum values in a chosen month are the end points of the lines, and are called "whiskers". The total number of observations for each month is listed above the plots in brackets.

As mentioned before an extended discussion of all parameters would go beyond the scope of this study. However, two parameters do provide some insight into how water quality parameters evolved on the watersheds. They are nitrate and phosphorus. Both parameters provide us with the general behaviour of all measured parameters. Nitrate and phosphate are chosen considering their different transport paths. Nitrate is lost through the subsurface drainage system whereas phosphate reaches the watercourse mostly via surface runoff. In addition, these nutrients are the parameters, which are likely influenced by the applied fertiliser management practises.

The box and whisker plots for the nitrate concentrations for the paired watershed are shown in Figures 4.4 to 4.9. When the two graphs Figures 4.4 and 4.5 are compared, it appears that there is a slight drop in the median after the intervention in the St. Esprit watershed. If we compare the graphs for the same periods at the control watershed (Figures 4.7 and 4.8) one can see that it follows the same pattern as the St. Esprit watershed. Hence, we can assume that the detected changes are due to the changing climatic condition for the observed periods.

To verify these observations we also compared the graphs in Figures 4.4 and 4.6 for the St. Esprit watershed and in Figures 4.7 and 4.9 of the control watershed.

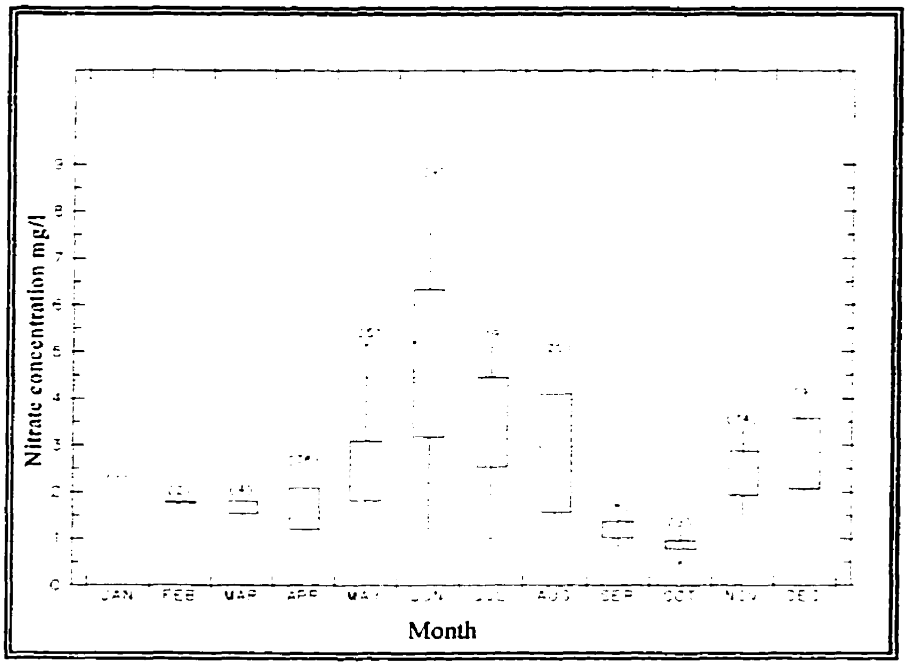


Figure 4.4 Box - Whisker plots for 1994 nitrate concentrations **at St. Esprit**

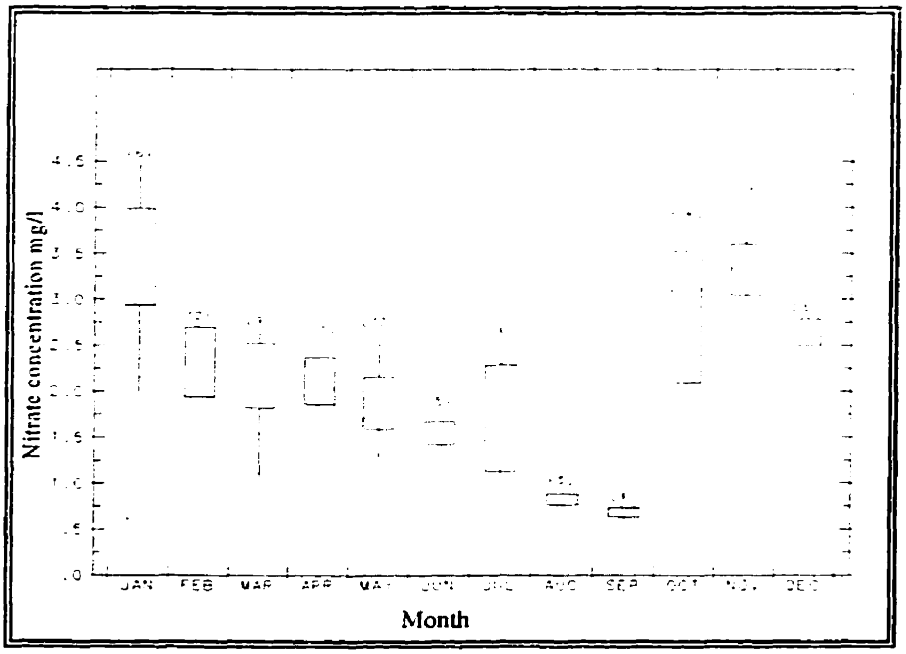


Figure 4.5 Box - Whisker plots 1995 nitrate concentrations at St. Esprit

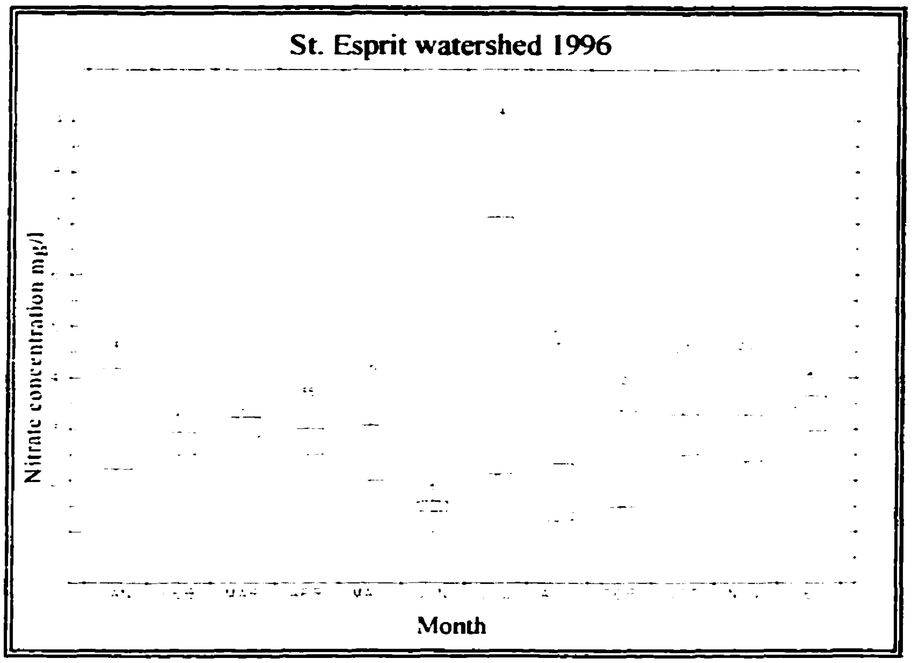


Figure 4.6 Box - Whisker plots for 1996 nitrate concentrations at St. Esprit

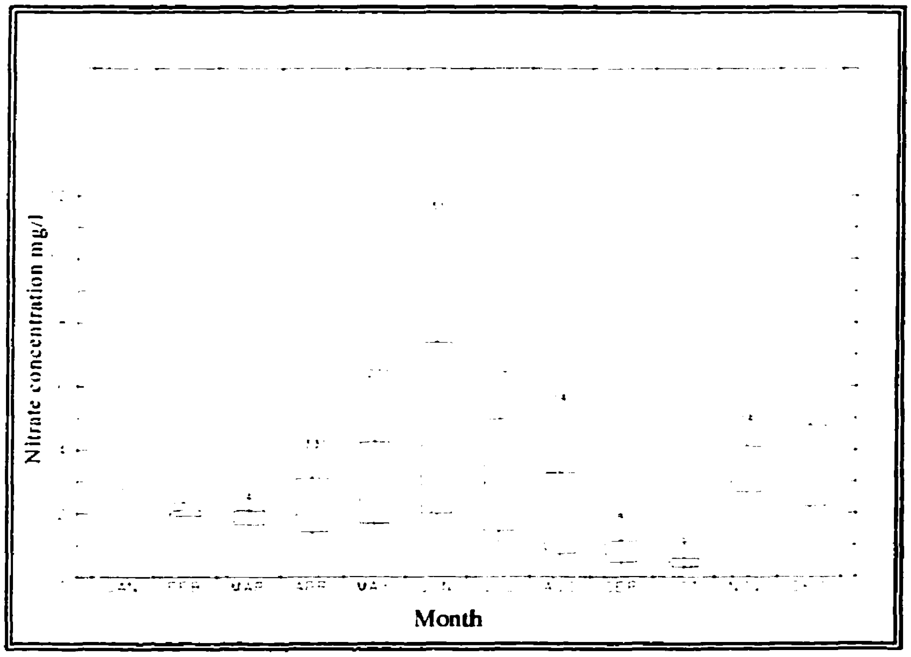


Figure 4.7 Box - Whisker plots for 1994 nitrate concentrations at Desrochers

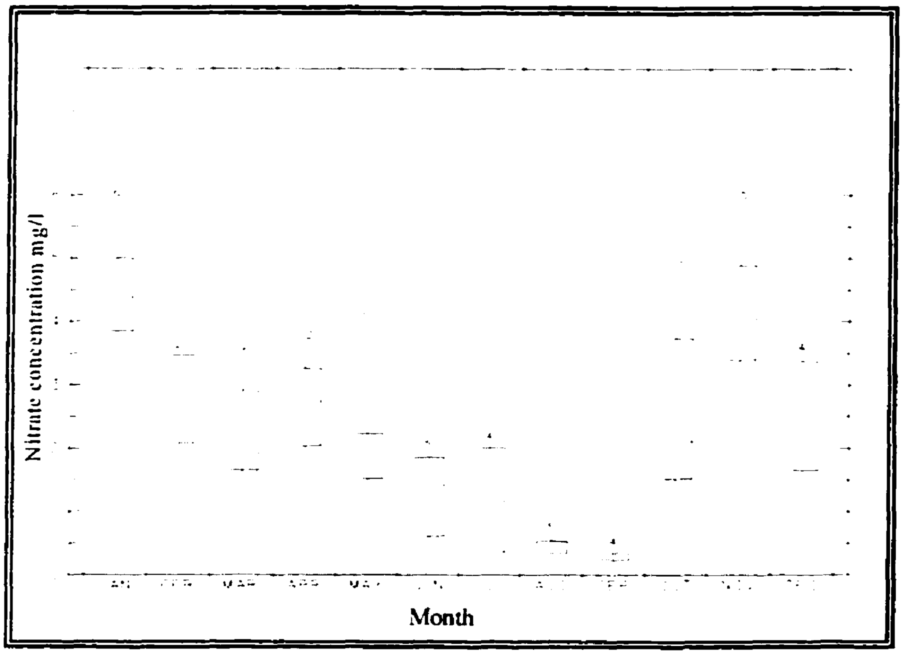


Figure 4.8 Box - Whisker plots for 1995 nitrate concentrations at Desrochers

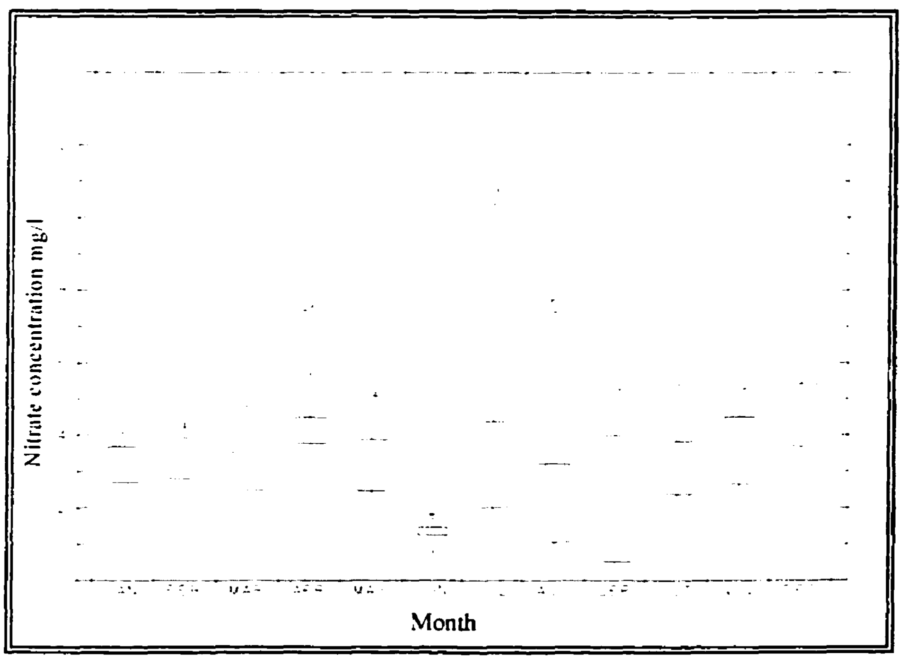


Figure 4.9 Box - Whisker plots for 1996 nitrate concentrations at Desrochers

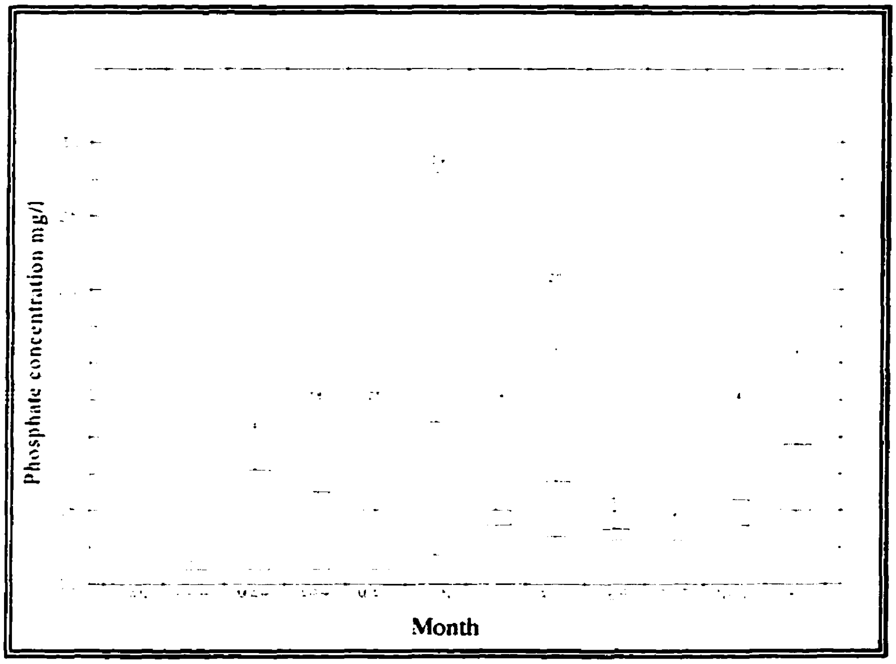


Figure 4.10 Box - Whisker plots for 1994 phosphate concentrations at St. Esprit

Figure 4.11 Box - Whisker plots for 1995 phosphate concentrations at St. Esprit

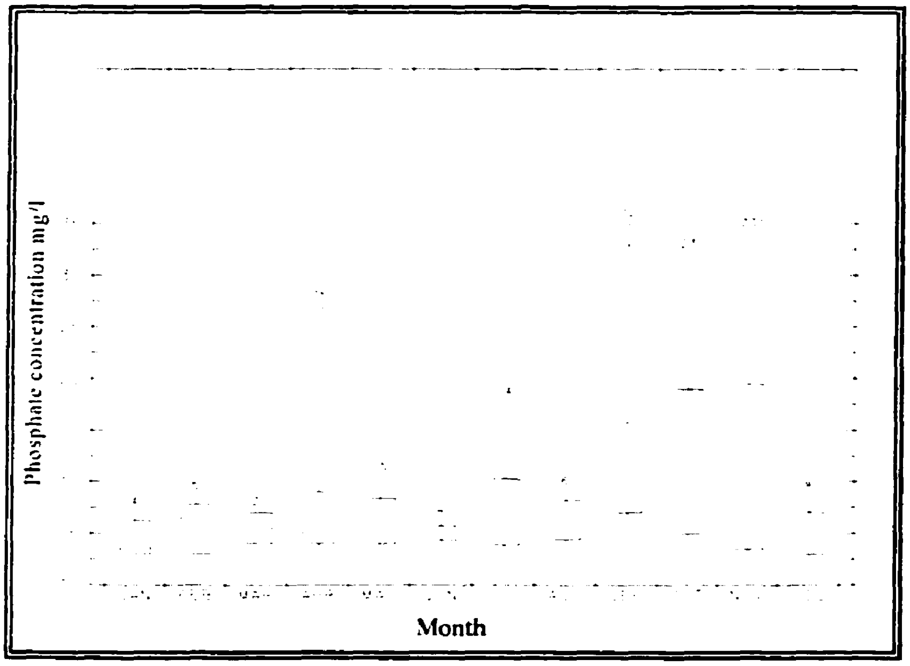


Figure 4.12 Box - Whisker plots for 1996 phosphate concentrations at St. Esprit

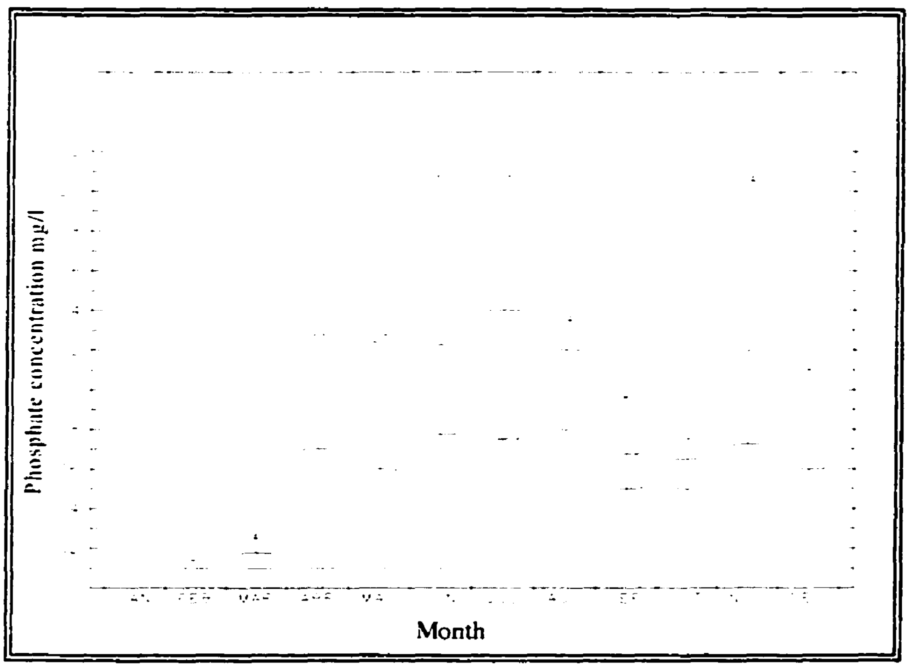


Figure 4.13 Box - Whisker plots for 1994 phosphate concentrations at the Desrochers

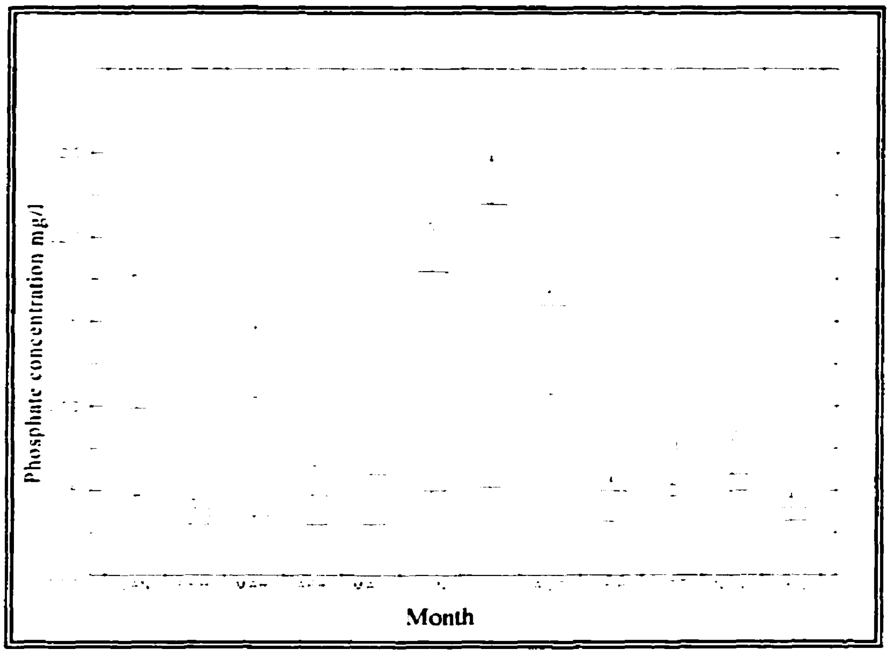


Figure 4.14 Box - Whisker plots for 1995 phosphate concentrations at the Desrochers

Figure 4.15 Box - Whisker plots for 1996 phosphate concentrations at Desrochers

When the comparison is made, it should prove our hypothesis from the first observation that the concentrations will increase again due to the wet climate in 1996.

As expected the medians increase slightly between 1994 and 1996 on the two watersheds. It shows also that the changes in nitrate concentrations were corresponding with the precipitation and the resulting runoff, i.e. the nitrate concentrations were high when rainfall and runoff were increasing.

After we examine the box and whisker plots for the phosphate concentrations on the paired watershed, one can see that the phosphate concentrations also vary with climate. The examination of the box and whisker plots for K, TKN, TP and suspended sediment produced the same results (Appendix B). These parameters also follow the precipitation pattern quite closely.

The box and whisker plots would seem to indicate there is no consistent upward or downward trend in the St. Esprit and Desrochers watershed. To verify this exploration we will use a last exploratory tool, the Q-Q plots.

4.4 Q-Q Plots

To develop the Q – Q plot it was necessary to compute the annual arithmetic mean, the maximum and minimum, the 25 and 75 percentile and the geometric mean for all measured parameters. These parameters were than plotted against each other for the years 1994 and 1995, and 1994 and 1996. If there are no changes in the water quality, the matched points should lie on a straight line with the general behaviour X=Y. The 'All' sample data set was used to perform the test.

The graphical results of the analyses are shown in Appendix C, and Table 4.4 shows a summary of the analyses using a sign system.

Table 4.4 Results of the Q-Q plots

St. Esprit watershed							
Parameter	**Nitrate**	**Ammonium**	**Phosphate**	**Potassium**	**TKN**	**TP**	**Sediment**
1994 and 1995	-	+	0	0	+	-	0
1994 and 1996	+	0	+	+	0	0	+
Desrochers watershed							
1994 and 1995	-	+	0	-	+	-	-
1994 and 1996	+	0	+	0	+	0	+

(0) – No changes
(+) – Increasing
(-) – Decreasing

As shown in Table 4.4 the pattern we detected using the box and whisker plots are not shown using the Q-Q technique. After analysing all parameters, we can observe that there are different changes when we use annual numerical summaries instead of monthly summaries.

One can see that for the St. Esprit and Desrochers watersheds the phosphate concentrations showed no trend for 1994 and 1995, whereas we concluded in the previous section that there is a slight drop in concentrations. However, when 1994 and 1996 are compared using the Q-Q plot technique. The observed upward trend assessed with the box and whisker plot technique can be confirmed.

If we look at the nitrate concentrations one can determine a downward trend between 1994 and 1995 and an upward trend between 1994 and 1996. This confirms the observation made in the previous section using the box and whisker plots.

After examining the Q-Q plots for K, TP and sediment, their behaviour confirms the observations made with the box and whisker plots. An exception has to be made for NH_4 and TKN, which show an upward trend for the years 1994 and 1995 on the paired watershed, that continues for TKN at the Desrochers watershed for 1996 whereas for NH_4 no changes could be observed.

Considering the results of the exploratory analyses, the next step in our trend analyses is to determine if the observed trends are statistically significant or only the result of graphical evaluation of the data sets.

After performing the exploratory analyses, it was necessary to confirm the explored trends. This part is also known as confirmatory analysis.

4.5 Nonparametric Trend Assessments

Two approaches are chosen to perform these analyses. The first approach will give an overview of an overall monotone trend over the 3 years for each parameter. The second approach, the detection of step trends, is more distinctive and will take the point of intervention into account, which allows us to differentiate between a distinctive before and after period. The nonparametric tests were performed on two different types of data sets. The first data set includes 'All' samples for each parameter at the paired watersheds. The second one includes only the manually taken samples. This differentiation was made because one scope of the study is to determine the impact of different sampling strategies the statistical analyses. The results of this comparison will be discussed later in section 4.6.

Since one has more than one sample per month, it was necessary to thin the data sets to one observation per month. With respect to former studies and recommendations by Aroner (1997) the point nearest to the midpoint for each month was chosen to determine the value used for the calculations. It also took some noise out of the all sample data sets, which was due to the sampling strategy.

This noise was due to the flow weighted sampling strategy for the 'All' sample data sets, which relies on changes in discharge that was significant during the storm events.

4.5.1 Monotone trend assessments

To perform the monotone trend assessments three different methods were used. These methods include one seasonal test, the seasonal Kendall test for trend without correction for correlation, and two non-seasonal tests, namely the Mann-Kendall test for trend and Spearman's rho. Application of the non-seasonal tests was necessary because some data sets were 'flunked'. This means in the observed data sets trends in different direction between the seasons were found. To determine if the data were 'flunked', the Chi^2-square test was performed with the seasonal Kendall test.

The results for the overall trend analyses for the paired watersheds are shown in Tables 4.5 to 4.16. The graphical display for the trends for each parameter can be found in Appendices D to J.

In this chapter, only the statistical significant trends will be discussed. The exception will be suspended sediment, because soil conservation practises were widely applied and as such, some influences on sediment concentrations might be expected. In general, one can say that the most changes detected with the exploratory trend detection tools could not be confirmed as statistically significant trends. This would indicate that the explored trends were due to "normal" short-term climatic variations, and not to the adoption of conservation practices. The significance level for this paired watershed study was selected as $\alpha < 0.10$. This means trends which are statistically significant have a 2*P level of less than 0.10. In Tables 4.5 to 4.20, values of 2*P that are less than 0.10 are shown in bold.

The examination of overall trends for the two watersheds shows that for some parameters, the trends on the two watersheds are not the same. With respect to the pre-determined significance level of $\alpha < 0.10$, a statistically significant trend using all tests could only be computed for phosphate concentration at the St. Esprit watershed.

Table 4.5 Results of the Seasonal Kendall test for trend for the St. Esprit watershed (all samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	***0.050***	0.760	***0.045***	0.880	0.451	1.000	0.328
(Z) statistic	1.960	0.305	2.006	-0.151	0.754	0.000	-0.978
tau	0.389	0.083	0.389	-0.055	0.167	-0.091	-0.194
Chi^2 sample stat	11.91	9.39	9.55	5.36	13.36	14.55	9.89
Chi^2 critical stat	13.70	13.70	13.70	13.70	13.70	13.70	13.70
Slope	0.283	0.033	0.010	-0.060	0.683	-0.003	-0.002

Table 4.6 Results of the Seasonal Kendall test for trend for the St. Esprit watershed (grab samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	***0.050***	0.760	***0.045***	0.880	0.451	1.000	0.328
(Z) statistic	1.960	0.305	2.006	-0.151	0.754	0.000	-0.978
tau	0.389	0.083	0.389	-0.055	0.167	-0.091	-0.194
Chi^2 sample stat	11.91	9.39	9.55	5.36	13.36	14.55	9.89
Chi^2 critical stat	13.70	13.70	13.70	13.70	13.70	13.70	13.70
Slope	0.283	0.033	0.010	-0.060	0.683	-0.003	-0.002

Table 4.7 Results of the Mann-Kendall test for trend for the St. Esprit watershed (all samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	0.438	0.913	***0.038***	0.643	0.334	0.721	0.218
(Z) statistic	0.776	-0.190	2.074	0.463	0.967	-0.357	-1.232
Slope	0.126	-0.002	0.009	0.093	0.289	-0.014	-0.004

Table 4.8 Results of the Mann-Kendall test for trend for the St. Esprit watershed (grab samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Cor. TP	Sediment
2*P level	0.614	0.653	***0.009***	0.817	0.558	0.693	0.477	0.413
(Z) statistic	0.504	-0.450	2.596	0.232	0.586	0.395	-0.712	-0.819
Slope	0.115	-0.016	0.011	0.051	0.272	0.018	-0.026	-0.002

Table 4.9 Results of the Spearman's Rho test for trend for the St. Esprit watershed (all samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	0.355	0.856	***0.038***	0.534	0.248	0.594	0.212
(Z) statistic	0.926	-0.181	2.078	0.622	1.154	-0.533	-1.248
Rho	0.156	-0.031	0.351	0.105	0.195	-0.094	-0.217
Slope	0.126	-0.002	0.009	0.093	0.289	-0.014	-0.004

Table 4.10 Results of the Spearman's Rho test for trend for the St. Esprit watershed (grab samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	0.479	0.719	**0.008**	0.671	0.381	0.454	0.348
(Z) statistic	0.710	-0.360	2.632	0.425	0.876	-0.749	-0.939
Rho	0.119	-0.061	0.448	0.072	0.148	-0.130	-0.159
Slope	0.115	-0.016	0.011	0.051	0.272	-0.026	-0.002

Table 4.11 Results of the Seasonal Kendall test for trend for the Desrochers watershed (all samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	***0.097***	0.345	1.000	0.651	0.880	0.876	0.440
(Z) statistic	1.658	-0.945	0.000	0.452	0.151	0.156	0.772
tau	0.333	-0.250	0.028	0.111	0.056	0.111	0.166
Chi^2 sample stat	10.91	4.49	7.34	13.82	11.91	12.53	13.82
Chi^2 critical stat	13.70	13.70	13.70	13.70	13.70	13.70	13.70
Slope	0.508	-0.031	0.004	0.188	0.295	0.001	0.003

Table 4.12 Results of the Seasonal Kendall test for trend for the Desrochers watershed (grab samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	***0.020***	0.421	0.747	1.000	0.876	0.872	1.000
(Z) statistic	2.333	-0.804	0.323	0.000	0.156	-0.161	0.000
tau	0.500	-0.278	0.139	0.055	0.000	0.056	-0.056
Chi^2 sample stat	10.59	7.70	10.06	10.53	10.52	13.45	0.93
Chi^2 critical stat	13.70	13.70	13.70	13.70	13.70	13.70	13.70
Slope	0.540	-0.025	0.005	-0.092	0.110	-0.032	0.000

Table 4.13 Results of the Mann-Kendall test for trend for the Desrochers watershed (all samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	0.241	***0.088***	0.419	0.633	0.693	0.854	0.935
(Z) statistic	0.172	-1.705	0.808	0.477	0.395	0.185	-0.082
Slope	0.345	-0.058	0.006	0.106	0.131	0.007	0.000

Table 4.14 Results of the Mann-Kendall test for trend for the Desrochers watershed (grab samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	0.156	***0.048***	0.398	0.966	0.887	0.976	0.875
(Z) statistic	1.420	-1.974	0.846	0.043	-0.142	-0.030	0.157
Slope	0.414	-0.067	0.006	0.007	-0.089	-0.003	0.000

Table 4.15 Results of the Spearman's Rho test for trend for the Desrochers watershed (all samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	0.191	0.123	0.358	0.563	0.587	0.827	0.858
(Z) statistic	1.307	-1.549	0.919	0.578	0.544	0.212	-0.183
Rho	0.221	-0.264	0.155	0.098	0.092	0.037	-0.031
Slope	0.346	-0.058	0.006	0.106	0.131	0.007	0.000

Table 4.16 Results of the Spearman's Rho test for trend for the Desrochers watershed (grab samples)

Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
2*P level	0.110	***0.091***	0.320	0.958	1.000	0.941	0.970
(Z) statistic	1.597	-1.689	0.994	0.052	0.000	0.075	0.038
Rho	0.274	-0.294	0.170	0.009	0.000	0.013	0.065
Slope	0.414	-0.067	0.006	0.007	-0.089	-0.003	0.000

The 2*P levels for phosphate vary between 0.008 and 0.045. The detected trend shows that there is an increase in phosphate concentration over the three years. As the trend was observed in both the 'All' and the 'Grab' data set, one can assume that it is not due to the concentration measured at storm events which might increase the phosphate concentrations in the channel. After computing the tests for the control watershed, it could be seen that the detected trend does not evolve in the same way as it does at the St. Esprit watershed. The 2*P level at the

Desrochers watershed for phosphate varies from 0.32 to 1 which lies above the pre-determined significance level and lead to a rejection of the hypotheses.

This indicates that the phosphate concentrations on the St. Esprit watershed are trending upward in a fashion which is statistically significant. However, on the control watershed, an upward trend could be observed, but the trend was not statistically significant.

It is known that sediment and phosphate correspond in the same manner. Hence, one should examine the results for the suspended sediment to see if sediment changes in the same pattern as the phosphate concentration.

After performing the test for trend detection in the suspended sediment data, it was determined that no significant changes on either watershed had occurred. This might lead to the conclusion that certain undetectable antrophogenus factors influenced the phosphorus concentrations at the St. Esprit watershed.

An alternate explanation is that the two watersheds did not respond equally to the variable precipitation pattern over the three years.

Another parameter that showed a trend on both watersheds was nitrate. The trend could be only detected only using the seasonal Kendall test. After using the Mann-Kendall test and Spearman's rho the trend could not be confirmed at the pre-determined significance level.

One might assume that the detected trend using the seasonal Kendall test was due to the fluctuations in the climate. This means that taking the transport path of nitrate into account and knowing that in January 1995 a snow melt period occurred, it is possible that the impact from this event effects the seasonal test results. Hence, the results of the seasonal Kendall test may have been influenced by the winter snowmelt events.

The last parameter that illustrated a statistically significant trend was the ammonium concentration at the control watershed, which showed a downward trend. This trend could not be detected at the St. Esprit watershed. This might due to the fact those different crops were cultivated at the St. Esprit watershed. For the other observed parameters on the paired watershed, no significant trend could be determined.

4.5.2 Step trend assessments

The last tool that is applied to the existing data sets is the Wilcoxson-Mann-Whitney test, also known as U–Test. This test was applied to the data set because distinctive before and after period existed. One can define 1994 as a before period.

The years 1995 and 1996 are defined as after periods. Because at the end of 1994, the application of soil conservation practices and fertiliser management were undertaken by a large number of farmers on the St. Esprit watershed and continued in the following year. The results of the step trend analyses are shown in Tables 4.17 to 4.20. The graphical displays of these results are shown in Appendices D to J.

Table 4.17 Results of the Wilcoxson-Mann-Whitney test for trend for the St. Esprit watershed (all samples)

Years	Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
1994-1995	2*P level	0.728	0.149	***0.043***	0.773	0.149	1.000	1.000
	(Z) statistic	0.289	1.444	2.021	-0.289	1.443	0.000	0.000
	Seasonal Hodges-Lehmann	0.125	0.165	0.020	-0.325	2.918	-0.033	0.006
1995-1996	2*P level	0.149	0.386	0.752	1.000	0.386	1.000	0.114
	(Z) statistic	1.443	-0.866	-0.316	0.000	-0.866	0.000	-1.581
	Seasonal Hodges-Lehmann	0.430	-0.103	-0.002	0.054	-0.876	0.017	-0.007
1994 and 1996	2*P level	0.148	1.000	***0.043***	1.000	0.386	1.000	1.000
	(Z) statistic	1.489	0.000	2.021	0.000	0.866	0.000	0.000
	Seasonal Hodges-Lehmann	0.643	0.022	0.020	-0.030	1.114	-0.007	-0.003

Table 4. 18 Results of the Wilcoxson-Mann-Whitney test for trend for the St. Esprit watershed (grab samples)

Years	Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
1994-1995	2*P level	0.773	0.228	0.149	0.773	0.386	0.546	0.546
	(Z) statistic	-0.289	1.206	1.440	-0.289	0.866	-0.603	-0.603
	Seasonal Hodges-Lehmann	-0.530	0.190	0.010	-0.470	2.944	-0.021	-0.003
1995-1996	2*P level	0.937	0.773	1.000	0.773	0.149	1.000	1.000
	(Z) statistic	2.598	-0.289	0.000	-0.289	1.443	0.000	0.000
	Seasonal Hodges-Lehmann	0.505	-0.130	0.055	-0.314	0.092	-0.008	-0.001
1994 and 1996	2*P level	0.149	0.773	0.149	1.000	0.773	1.000	1.000
	(Z) statistic	1.440	0.289	1.443	0.000	0.288	0.000	0.000
	Seasonal Hodges-Lehmann	0.643	0.031	0.020	-0.125	1.758	-0.007	-0.002

Table 4.19 Results of the Wilcoxson-Mann-Whitney test for trend for the Desrochers watershed (all samples)

Years	Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
1994-1995	2*P level	0.773	***0.070***	0.386	1.000	0.149	0.386	1.000
	(Z) statistic	0.288	1.809	0.866	0.000	1.440	-0.866	0.000
	Seasonal Hodges-Lehmann	0.458	0.090	0.025	-0.055	2.702	-0.053	0.001
1995-1996	2*P level	0.386	***0.009***	0.386	0.772	0.149	0.227	0.752
	(Z) statistic	0.866	-2.598	-0.866	0.289	-1.440	1.206	0.316
	Seasonal Hodges-Lehmann	0.573	-0.231	-0.020	0.218	-0.390	0.096	0.002
1994 and 1996	2*P level	0.149	0.343	1.000	0.773	0.773	1.000	0.386
	(Z) statistic	1.443	-0.949	0.000	0.288	0.289	0.000	0.866
	Seasonal Hodges-Lehmann	0.958	-0.020	0.010	0.375	1.013	0.070	0.009

Table 4.20 Results of the Wilcoxson-Mann-Whitney test for trend for the Desrochers watershed (grab samples)

Years	Parameter	NO_3	NH_4	PO_4	K	TKN	TP	Sediment
1994-1995	2*P level	0.546	0.114	***0.070***	0.546	0.227	0.228	1.000
	(Z) statistic	0.603	1.581	1.809	-0.603	1.206	-1.206	0.000
	Seasonal Hodges-Lehmann	0.160	0.110	0.030	-0.810	2.214	-0.070	0.004
1995-1996	2*P level	0.149	0.043	0.343	0.773	0.386	0.546	0.546
	(Z) statistic	1.443	-2.020	-0.949	0.289	-0.866	0.603	-0.603
	Seasonal Hodges-Lehmann	0.640	-0.356	-0.013	0.405	-0.393	0.134	-0.003
1994 and 1996	2*P level	0.070	0.343	1.000	1.000	1.000	1.000	0.752
	(Z) statistic	1.809	-0.949	0.000	0.000	0.000	0.000	0.316
	Seasonal Hodges-Lehmann	1.030	-0.040	0.000	0.330	0.514	-0.043	0.003

These analyses show that only two of the seven analysed parameters resulted in a statistically significant result at a 90 % confidence level for some seasons on the paired watersheds.

For phosphate concentrations at the St. Esprit watershed, significant increasing step trends could be determined for the seasons 1994 – 1995 and 1994 and 1996. These results support the investigated overall monotone trend detected in the previous section. Unlike the monotone trend analysis, this step trend could only be detected for the all sample data sets. The grab sample data showed no significant trend at all. Since one can consider that the impact of storm events in the 'All' sample data sets is quite high, due to the sample strategy, it illustrates the fact that the phosphate transport is related to the surface runoff.

The phosphate concentrations at the control watershed did not show any trend for the 'All' sample data set, which confirms the results from the monotone trend analyses.

The second parameter that shows a significant trend is ammonium at the control watershed. The ammonium concentration evolves a significant upward trend for the seasons 1994 – 1995 with a 2*P level of 0.070 and a significant downward trend for the seasons 1995 – 1996. Another downward movement is detected between 1994 and 1996 but the 2*P level is 0.343, hence it is not considered as a trend.

The other parameter for both watersheds does not show any significant trend. Hence, the result of the Q-Q plot analyses for an increase over the years could not be confirmed.

4.6 Auto sampling vs. manual sampling

Another objective in this study was to investigate how different sampling strategies influenced the statistical results.

The main conclusion that could be drawn is that the manually taken samples provide us with the same information with respect to nonparametric trend analysis methods, as the more complex flow weighted sampling program.

After investigating, the results for the monotone trend assessment (Figures 4.5 to 4.16) one can observe that the computed results do not differ for the different types of data sets. For instance, the results of the seasonal Kendall test for the St. Esprit (Figures 4.5 and 4.6) for the 'All' sample and grab sample data sets are identical. Whereas the same test at the control watershed produced different results at the 2*P level, but the overall direction and the significance of the trend is the same.

As we take a closer look at the results of the analyses of the 'Grab' sample data sets, one can see that the 2*P level is always smaller than the 2*P level for 'All' samples. This might be because the grab sample data set is not influenced by noise produced through the samples taken during storm events for the all sample strategy.

A manual sampling strategy is easier to conduct. It does not require automated sampling equipment, which results in a smaller number of samples per year. This reduces the cost of the analyses. However, since the analyses for trend with 'Grab' sample data set leads to the same conclusions as with an 'All' sample data set, we can conclude that for trend analyses on small watersheds the manual sampling strategy is the preferred.

4.7 Observation periods vs. overall trends

Monitoring of the two watersheds was continued in 1997. However not all parameters analysed in 1994 – 1996 were measured in 1997. The collected data set for 1997 is almost entirely 'Grab' samples. In addition, the data were not available until very recently. As such the analyses conducted in section 4.1 to 4.6, were only based upon the 1994 – 1996 data sets.

Because of the fact that during the three years of this study, the climate seems to have an important impact on the monotone trend results, it was interesting to investigate. If the results for trend detection for a four-year period confirm the results for the monotone trend assessments.

Since only nitrate and phosphate in the St. Esprit watershed showed significant trends in the years 1994 – 1996, the monotone trend analysis for nitrate and phosphate were computed.

The results of the analyses of the nitrate concentrations for the St. Esprit watershed evolved a slight downward trend over the four-year period, instead of an upward trend for the three-year period. Unfortunately, the trend was not significant at a 90 % confidence level. However, it showed a downward trend that might due to the imposition of good fertiliser management practices.

A drastic change in the behaviour of phosphate concentrations could be observed in the control watershed. In the trend assessment for the period of 1994 – 1996, phosphate does not show any significant trend at all. After running the analyses for 1994–1997, a quite different picture can be drawn.

The phosphate concentration of this period showed a significant upward trend with 2*P level from 0.010 to 0.015. Hence, it shows the same behaviour as the phosphate concentrations in the St. Esprit watershed and one can assume that phosphate concentrations are a product of the climatic variations in the basin.

The results of this investigation supported the conclusions that the results on the monotone trend assessments on small watersheds are highly influenced by the climatic variations and more years of observations are needed to get better conclusions.

After computing the test for the other parameters, no significant changes could be conducted.

5. Summary and Conclusions

5.1 Summary

A research project to evaluate water quality measurements on two small agricultural watersheds in Quebec was undertaken from January 1994 to December 1996. Water samples were taken at the outlet of each watershed. The water samples were taken using two different strategies. One strategy was based on an intensive event-based sampling program using an auto-sampler at the outlets of the watersheds. The second was based on manually taken samples on a weekly basis. The two data sets were available for statistical analyses. The complete data sets consisted of both auto-samples and 'Grab' samples. A data set that consisted only of 'Grab' samples was also analysed.

The measured parameters for each data set were nitrate, ammonium, phosphate, potassium, TKN, total phosphorus and suspended sediment.

The water quality data were analysed to assess trends in the pollutant concentrations over a three-year period and between each year. Considering the properties of water quality data sets, non-parametric (distribution free) methods were used to detect trends, namely the seasonal Kendall test for trend without correction for correlation, the Mann-Kendall test, Spearman's Rho and the seasonal Wilcoxson-Mann-Whitney test.

The observed trends in water quality were then related to climatic parameters for the basins and to applied BMP's.

5.2 Conclusions

Exploratory trend analysis methods were applied to the complete data sets to detect trends for each parameter. These exploratory analyses led to the conclusion that the measured parameters were highly influenced by the climatic variation during the study period. The St. Esprit watershed and the control watershed responded in the same way. The exploratory analyses indicated that both watersheds exhibited similar trends.

Hence, it was necessary to employ confirmatory trend analysis methods to confirm the detected trends, because the graphically detected trends in the exploratory analyses did not provided a statistical significance. To determine the significance of the detected trends, four different methods were used to confirm the results of the exploratory analyses.

The four trends used were the seasonal Kendall test, the Mann-Kendall test, Spearman's rho and the seasonal Wilcoxson-Mann-Whitney test. These tests indicated a significant upward trend for phosphate at the St. Esprit watershed for the 1994 – 1996 period, which confirmed the results of the exploratory analysis. Comparing the results with the control watershed, the trend could be not confirmed. Hence, it might be due to undetectable anthropogenus impacts. After applying the tests for monotone trend on the data set from 1994 – 1997 the results at the control watershed changed significantly. They showed the same behaviour as the phosphate concentrations on the intervention watershed.

Analysing the other measured parameter, only the nitrate concentrations at the St. Esprit watershed showed an upward trend using the seasonal Kendall test, but the result could not be confirmed by the non-seasonal tests. Hence, one can conclude that it is due to the climatic variations over the years, specifically differences between the precipitation pattern in the winter months.

The other investigated parameters did not show any statistically significant trends. Hence, the behaviour of the parameters detected using graphical methods was not confirmed.

Therefore, one can conclude that graphical trend assessment methods do not provide a good understanding of significant changes in water quality. Hence, one should always confirm these results, using statistical hypothesis testing methods. The usage of confirmatory methods is essential.

For the two different sampling strategies which were used to detect the changes in water quality we can say that manually taken samples on a weekly basis produce the same results as the more complex sampling strategy which utilised both 'Grab' and automated samples.

In addition, taking the cost for an automatic sampling station into account (maintenance, changing sample equipment after a storm event) the manual sampling strategy should be the preferred for developing data sets for trend analysis on small watersheds.

The results for this study show that on small watersheds the effects of climatic variations over a short period (< 5 years) have a great impact on results of nonparametric trend assessment on small watersheds.

6. Recommendations for Future Research

It would be unreasonable to expect improvements in water quality within 3 years. The effects of more than 20 years of intensive agriculture on water quality cannot be easily reversed. Therefore, the main objective for the future studies should be to continue the application of conservation practices and to monitor the changes in water quality, on the paired watersheds. The questions which should be answered with those studies are: does the water quality improve and for how long? In addition, it might be useful to install monitoring stations on different watersheds to investigate the impact of different agricultural practices, soil and land use patterns on water quality.

Furthermore, approaches other than statistical methods should be found to detect trends in water quality data on a short-term base. Such as, combination of GIS and neural networks, which would allow us to adjust the initial conservation practices.

One should improve the existing statistical methods for trend detection and test new statistical methods for their application on water quality data, such as the van der Waerden normal score test.

7. List of References

Agriculture Canada. 1976. Glossary of Terms in Soil Science, Research Brand, Canada Department of Agriculture, Pub. 1459

Aroner, P. 1997. WQHYDRO –Manual, Portland OR

Asselin, R., P. Fournier, C. Desamaris, P. Lachance and T.L. Simard. 1992. Projet d'amenagement integre du bassin de la riviere Duncan. 16ieme Colloque de Genie Rural, University Laval, P. 169-183

UNESCO – WHO. 1978. Water quality surveys, a guide for the collection and interpretation of water quality data

Berryman, D., B. Bobee, D. Cluis and Haemmerli. 1988. Nonparametric test for trend detection in water quality time series, Water Resources Bulletin, AWRA, Vol. 24, No. 3

Boukchina, R., R. Lagace, F. Salehi, A. Pesant, J. Gallichand and D. Cluis. 1992. Mesures de debits et de la qualite de l'eau d'un petit bassin versant agricole. 16ieme Colloque de Genie Rural, University Laval, P. 29-54

Bradley, J.V. 1968. Distribution-Free statistical tests, Prentice-Hall, Inc., Englewood Cliffs, New Jersey

Chester, G. and L.J. Schierow. 1985. A primer on non-point pollution, Journal of Soil and Water Conservation, 40(1), P. 9-13

Chow, V.T., D.R. Maidment and L.W. Mays. 1988. Applied Hydrology, McGraw-Hill Book Company, New York

Crawford, C. G., R.M. Hirsch and J.R. Slack. 1983. Nonparametric tests for trends in water quality data using the Statistical Analysis System (SAS), U.S. Geological Survey Open-File Report 83-550

Enright, P., F. Papineau and C.A Madramootoo and E. Leger. 1995. The Impacts of Agricultural Production on Water Quality in Two Small Watersheds, CSAE paper # 95-101

Enright, P., F. Papineau and C.A Madramootoo. 1997. Water Quality and pollutant concentrations on paired agricultural watersheds in Quebec, CSAE paper # 97-129

Enright, P., F. Papineau and C.A Madramootoo. 1998. Gestion de l'eau dans le bassin versant de la partie superieure du ruisseau St. Esprit, Projet 61-13008, Rapport Final, Macdonald Campus at McGill University

EPA. 1993. Paired watershed study design, United States Environmental Protection Agency, Office of Water, Washington D.C.

Gadbois, L.E. and B. Neilson. 1988. Natural variability of water quality in a temperate Estuary, Virginia Institute of Marine Science

Hipel, K.W., A.I. McLeod. and P.K. Fosu. 1985. Empirical power comparison of some trends for trend, Statistical Aspects of Water Quality Monitoring, Proceedings of the Workshop at the Canada Centre for Inland Waters, P. 347 - 361, Oct. 7 - 10

Hipel, K.W., A.I. McLeod. and R.R. Weiler. 1988. Data Analysis of water Quality time Series in Lake Erie, Water Resources Bulletin AWRS, Vol. 24 No. 3, P. 533 - 544

Hipel, K.W. 1988. Nonparametric Approaches to Environmental Impact Assessment, Water Resources Bulletin, AWRA, Vol. 24 No. 3

Hirsch, R. M., J.R. Slack and R.A. Smith. 1982. Techniques of trend analysis for monthly water quality data, Water Resources Research Vol. 18, P. 107 - 121

Hirsch, R.M. and J.R. Slack. 1984. A nonparametric trend test for seasonal data with serial Dependence, Water Resources Research, Vol. 20 No. 6, P. 727 - 732

Hirsch, R. M. 1988. Statistical methods and sampling design for estimating step trends in surface water quality, Water Resources Bulletin, AWRA, Vol. 24 No. 3, P. 493 - 503

Kendall, M. and J. D. Gibbons. 1990. Rank Correlation Methods, Edward Arnold, a division of Hodder and Stoughton, London

Lapp, P. 1996. The Hydrology and Water Quality of an Intensive Agricultural Watershed in Quebec, McGill University

Lettenmaier, D.P. 1977. Detection of trends in stream quality: Monitoring network design and data analysis, Tech. Rep. 51, Harris Hydraul. Lab., Dept. Of Civil Engineering, University of Washington, Seattle

Lettenmaier, D.P. 1988. Multivariate nonparametric tests for trend in water quality, Water Resources Bulletin, AWRA, Vol. 24 No. 3, P. 505 - 512

MEF 1995 Statistiques Annuelles et Mensuelles - Station 70173380 (St. Jacques), Direction reseaux atmospheriques, Ministre de l'environment et faune, Quebec

Marascuilo, L. A. and McSweeney. 1977. Nonparametric and Distribution free methods for social sciences, Brooks/Cole Company, Belmont, CA

McGill, R., J.W. Tukey and A.W. Larsen. 1978. Variations of Box Plots, American Statistician 32(1), P. 12-16

Mousavizadeh, Mohammed H. 1996: Table of land use of the St. Esprit Watershed

Papineau, F. and P. Enright. 1997. Gestion de l'eau dans le bassin versant de la partie superieure du ruisseau St. Esprit, Projet 61-13008 Caracterisation de la problematique environmentale, Macdonald Campus at McGill University, 1997

Sachs, L. 1996. Angewandte Statistik – Anwendung statistischer Methoden, Springer Verlag, 8. Auflage

Storm, R. 1995. Wahrscheinlichkeitsrechnung, mathematische Statistik und statistische Qualitaetskontrolle, Fachbuchverlag Leipzig – Koeln, 10. Auflage,

Tukey, J.W. 1977. Exploratory data analysis, Addison-Wesley Publishing Co., Reading, MA

Tyagi A., M. Sharma and E. McBean. 1996. Best subset modelling of phosphorus in the Grand River using correlated variables, Canadian Journal of Civil Engineering, Vol. 23, P. 893 - 903

Appendix A

Descriptive statistics for all samples at

St. Esprit and Desrochers

List of Tables for Appendix A

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1994	January	# Samples	1	1	1	1	1	1	1
		High	2.02	0.25	0.01	3.33	2.31	0.32	0.06
	February	# Samples	2	2	2	2	2	2	1
		Low	1.77	0.11	0.01	3.99	1.16	0.16	n.d.
		25 % Percentile	1.78	0.13	0.01	4.16	1.27	0.21	n.d.
		Median	1.78	0.14	0.01	4.32	1.37	0.27	n.d.
		75 % Percentile	1.79	0.16	0.01	4.49	1.48	0.32	n.d.
		Mean	1.78	0.14	0.01	4.32	1.37	0.27	n.d.
		High	1.79	0.17	0.01	4.65	1.59	0.38	0.02
		SD	0.01	0.04	0.00	0.47	0.30	0.15	n.d.
		Geometric mean	1.78	0.14	0.01	4.31	1.36	0.25	n.d.
	March	# Samples	4	4	4	4	4	4	4
		Low	1.50	0.34	0.01	4.10	1.20	0.07	0.02
		25 % Percentile	1.64	0.42	0.01	4.40	1.23	0.15	0.02
		Median	1.74	0.60	0.01	5.32	1.58	0.19	0.04
		75 % Percentile	1.80	0.87	0.03	6.51	2.13	0.24	0.07
		Mean	1.70	0.69	0.03	5.59	1.78	0.20	0.05
		High	1.81	1.24	0.10	7.63	2.77	0.34	0.09
		SD	0.14	0.40	0.05	1.62	0.74	0.11	0.03
		Geometric mean	1.69	0.61	0.02	5.42	1.68	0.17	0.04
	April	# Samples	38	37	38	38	38	38	37
		Low	0.40	0.03	0.01	0.53	0.36	0.03	0.01
		25 % Percentile	1.21	0.09	0.01	2.62	0.91	0.16	0.02
		Median	1.45	0.13	0.02	2.73	1.30	0.24	0.06
		75 % Percentile	2.07	0.18	0.06	2.99	1.84	0.33	0.09
		Mean	1.57	0.15	0.04	2.84	1.56	0.25	0.07
		High	2.45	0.46	0.12	4.37	5.18	0.53	0.22
		SD	0.52	0.09	0.03	0.62	1.05	0.12	0.06
		Geometric mean	1.48	0.13	0.03	2.74	1.31	0.22	0.05

Table A 1

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1994	May	# Samples	25	22	25	25	32	26	32
		Low	1.32	0.01	0.01	2.62	0.59	0.08	0.00
		25 % Percentile	1.82	0.10	0.01	3.08	0.97	0.17	0.00
		Median	2.58	0.17	0.01	3.33	1.19	0.23	0.01
		75 % Percentile	3.02	0.24	0.04	3.74	1.71	0.34	0.01
		Mean	2.66	0.21	0.03	3.77	1.62	0.28	0.02
		High	5.16	0.80	0.12	7.44	5.54	0.69	0.16
		SD	0.98	0.21	0.03	1.15	1.25	0.16	0.03
		Geometric mean	2.50	0.12	0.02	3.64	1.35	0.25	0.01
	June	# Samples	39	35	39	39	36	34	43
		Low	1.19	0.01	0.01	1.84	0.24	0.00	0.00
		25 % Percentile	3.30	0.13	0.02	3.45	0.51	0.29	0.02
		Median	5.21	0.55	0.04	3.86	0.94	0.40	0.03
		75 % Percentile	6.31	1.03	0.11	5.39	1.92	0.56	0.14
		Mean	4.88	0.59	0.08	4.55	1.80	0.45	0.11
		High	8.60	1.67	0.28	9.91	13.68	0.98	0.70
		SD	1.91	0.53	0.07	1.75	2.59	0.23	0.17
		Geometric mean	4.41	0.27	0.05	4.28	1.05	0.37	0.05
	July	# Samples	19	19	19	19	19	19	18
		Low	1.92	0.05	0.03	2.62	0.22	0.05	0.00
		25 % Percentile	2.59	0.06	0.04	2.92	0.94	0.28	0.01
		Median	3.32	0.10	0.05	3.18	1.13	0.38	0.01
		75 % Percentile	4.40	0.19	0.05	3.50	1.99	0.47	0.03
		Mean	3.43	0.16	0.05	3.26	1.59	0.38	0.03
		High	5.13	0.55	0.12	4.84	6.49	0.62	0.15
		SD	1.00	0.14	0.02	0.56	1.34	0.14	0.04
		Geometric mean	3.28	0.12	0.05	3.22	1.27	0.34	0.01

Table A 2

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1994	August	# Samples	20	20	20	20	20	20	13
		Low	1.07	0.02	0.03	3.03	0.98	0.09	0.00
		25 % Percentile	2.00	0.06	0.04	3.22	1.33	0.16	0.00
		Median	2.97	0.15	0.06	3.45	1.65	0.20	0.00
		75 % Percentile	4.03	0.25	0.07	4.50	3.42	0.25	0.01
		Mean	2.93	0.17	0.07	4.24	2.82	0.23	0.01
		High	4.84	0.59	0.20	9.19	10.99	0.72	0.02
		SD	1.22	0.14	0.05	1.65	2.55	0.13	0.01
		Geometric mean	2.64	0.12	0.06	4.02	2.16	0.21	0.00
	September	# Samples	8	8	8	8	8	8	8
		Low	0.78	0.04	0.03	4.14	0.50	0.13	0.00
		25 % Percentile	1.06	0.05	0.03	4.72	0.70	0.22	0.01
		Median	1.25	0.05	0.03	4.64	0.67	0.22	0.01
		75 % Percentile	1.31	0.14	0.03	6.08	0.80	0.23	0.01
		Mean	1.19	0.15	0.03	5.30	0.76	0.22	0.01
		High	1.46	0.58	0.05	7.53	1.49	0.34	0.01
		SD	0.22	0.19	0.01	1.34	0.32	0.06	0.00
		Geometric mean	1.17	0.09	0.03	5.17	0.71	0.21	0.01
	October	# Samples	9	9	9	9	9	9	9
		Low	0.51	0.04	0.03	4.30	2.14	0.13	0.00
		25 % Percentile	0.79	0.05	0.03	4.65	4.50	0.16	0.01
		Median	0.83	0.05	0.03	4.75	5.01	0.27	0.02
		75 % Percentile	0.92	0.05	0.03	4.89	6.55	0.43	0.03
		Mean	0.86	0.05	0.03	5.32	5.96	0.29	0.03
		High	1.13	0.06	0.04	10.21	11.47	0.47	0.13
		SD	0.17	0.01	0.00	1.85	2.84	0.14	0.04
		Geometric mean	0.84	0.05	0.03	5.12	5.38	0.26	0.02

Table A 3

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1994	November	# Samples	14	14	14	14	14	14	13
		Low	1.45	0.01	0.04	3.37	0.84	0.04	0.00
		25 % Percentile	1.95	0.05	0.04	3.71	1.16	0.20	0.01
		Median	2.52	0.10	0.05	4.08	2.17	0.24	0.02
		75 % Percentile	2.87	0.16	0.05	5.54	11.31	0.27	0.05
		Mean	2.45	0.10	0.06	4.90	10.37	0.24	0.04
		High	3.34	0.24	0.12	10.25	46.98	0.42	0.19
		SD	0.56	0.07	0.02	1.87	14.99	0.09	0.05
		Geometric mean	2.39	0.08	0.05	4.65	3.75	0.21	0.02
	December	# Samples	9	9	9	9	9	9	0
		Low	1.66	0.16	0.03	2.21	2.55	0.17	n.d.
		25 % Percentile	2.23	0.20	0.05	3.11	3.05	0.19	n.d.
		Median	2.86	0.25	0.06	4.20	3.94	0.25	n.d.
		75 % Percentile	3.31	0.32	0.09	4.86	5.51	0.29	n.d.
		Mean	2.85	0.28	0.07	4.25	4.83	0.26	n.d.
		High	3.89	0.50	0.15	7.60	10.26	0.46	n.d.
		SD	0.80	0.11	0.04	1.56	2.39	0.09	n.d.
		Geometric mean	2.75	0.27	0.07	4.01	4.41	0.25	n.d.

Table A 4

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1995	January	# Samples	6	6	6	6	5	5	5
		Low	2.74	0.20	0.04	3.50	1.96	0.19	0.01
		25 % Percentile	4.24	0.27	0.05	3.53	4.98	0.20	0.02
		Median	4.38	0.50	0.07	3.59	4.98	0.27	0.02
		75 % Percentile	4.66	0.62	0.07	3.88	5.62	0.30	0.03
		Mean	4.39	0.45	0.08	3.80	5.13	0.28	0.03
		High	5.86	0.62	0.17	4.62	8.11	0.44	0.06
		SD	1.00	0.20	0.05	0.44	2.19	0.10	0.02
		Geometric mean	4.28	0.40	0.07	3.78	4.67	0.27	0.02
	February	# Samples	2	2	2	2	2	2	2
		Low	2.08	0.53	0.03	3.37	4.61	0.38	0.00
		25 % Percentile	2.43	0.57	0.03	3.38	4.65	0.38	0.00
		Median	2.78	0.61	0.04	3.39	4.70	0.38	0.00
		75 % Percentile	3.12	0.65	0.04	3.39	4.75	0.38	0.01
		Mean	2.78	0.61	0.04	3.39	4.70	0.38	0.00
		High	3.47	0.69	0.04	3.40	4.80	0.38	0.01
		SD	0.98	0.11	0.01	0.02	0.14	0.00	0.00
		Geometric mean	2.69	0.60	0.03	3.38	4.70	0.38	0.00
	March	# Samples	9	9	9	9	9	9	9
		Low	1.27	0.44	0.02	0.68	3.30	0.15	0.01
		25 % Percentile	1.66	0.47	0.04	2.01	3.53	0.20	0.01
		Median	1.91	0.51	0.06	2.44	4.56	0.24	0.01
		75 % Percentile	2.55	0.55	0.09	3.19	7.28	0.45	0.03
		Mean	2.19	0.57	0.07	2.48	5.53	0.39	0.02
		High	3.39	1.01	0.14	4.59	9.97	0.89	0.06
		SD	0.75	0.19	0.04	1.13	2.41	0.27	0.02
		Geometric mean	2.09	0.55	0.06	2.21	5.10	0.32	0.02

Table A 5

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1995	April	# Samples	11	11	11	11	11	9	11
		Low	1.79	0.42	0.02	1.29	3.48	0.03	0.01
		25 % Percentile	1.91	0.47	0.02	1.68	5.09	0.08	0.01
		Median	2.04	0.49	0.03	1.84	6.04	0.35	0.02
		75 % Percentile	2.34	0.55	0.03	2.18	6.80	0.59	0.02
		Mean	2.13	0.51	0.03	1.97	5.94	0.33	0.02
		High	2.55	0.62	0.05	3.14	8.64	0.72	0.08
		SD	0.28	0.06	0.01	0.48	1.52	0.28	0.02
		Geometric mean	2.11	0.51	0.03	1.92	5.76	0.20	0.02
	May	# Samples	12	12	12	12	12	12	12
		Low	1.29	0.19	0.02	1.97	4.11	0.12	0.00
		25 % Percentile	1.62	0.47	0.02	2.09	5.66	0.22	0.01
		Median	1.71	0.49	0.03	2.29	7.45	0.28	0.01
		75 % Percentile	2.15	0.56	0.04	3.00	12.64	0.39	0.02
		Mean	1.83	0.53	0.04	3.26	10.91	0.42	0.02
		High	2.64	1.00	0.14	12.70	27.31	1.30	0.06
		SD	0.41	0.18	0.03	3.00	7.84	0.38	0.02
		Geometric mean	1.79	0.50	0.03	2.72	8.93	0.32	0.01
	June	# Samples	5	5	5	5	5	5	5
		Low	1.40	0.02	0.05	2.43	3.06	0.07	0.01
		25 % Percentile	1.45	0.10	0.05	2.85	3.77	0.12	0.01
		Median	1.46	0.13	0.05	3.11	5.74	0.28	0.02
		75 % Percentile	1.58	0.31	0.06	3.19	18.42	0.28	0.03
		Mean	1.53	0.18	0.06	3.08	11.65	0.21	0.02
		High	1.77	0.35	0.07	3.83	27.26	0.32	0.04
		SD	0.15	0.14	0.01	0.51	10.72	0.11	0.01
		Geometric mean	1.53	0.12	0.06	3.05	8.02	0.18	0.02

Table A 6

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1995	July	# Samples	4	4	4	4	4	4	4
		Low	1.10	0.01	0.03	2.23	3.98	0.05	0.01
		25 % Percentile	1.21	0.08	0.05	3.07	4.38	0.10	0.01
		Median	1.40	0.17	0.07	3.81	4.57	0.13	0.02
		75 % Percentile	1.80	0.24	0.08	4.83	4.91	0.16	0.03
		Mean	1.61	0.15	0.07	4.09	4.73	0.14	0.02
		High	2.53	0.27	0.09	6.50	5.79	0.23	0.05
		SD	0.64	0.12	0.03	1.81	0.76	0.07	0.02
		Geometric mean	1.52	0.09	0.06	3.79	4.68	0.12	0.02
	August	# Samples	5	5	5	5	5	5	5
		Low	0.74	0.02	0.04	3.48	4.15	0.11	0.01
		25 % Percentile	0.80	0.14	0.06	3.83	4.70	0.16	0.01
		Median	0.82	0.15	0.07	4.10	5.01	0.23	0.02
		75 % Percentile	0.85	0.16	0.07	4.66	5.24	0.28	0.02
		Mean	0.83	0.14	0.06	4.27	5.15	0.25	0.02
		High	0.92	0.23	0.08	5.28	6.65	0.47	0.03
		SD	0.07	0.08	0.02	0.71	0.93	0.14	0.01
		Geometric mean	0.82	0.11	0.06	4.22	5.08	0.22	0.01
	September	# Samples	4	4	4	4	4	4	4
		Low	0.61	0.20	0.05	4.13	2.64	0.24	0.02
		25 % Percentile	0.69	0.25	0.05	5.29	4.59	0.24	0.03
		Median	0.73	0.30	0.05	5.74	5.31	0.26	0.03
		75 % Percentile	0.74	0.34	0.05	5.91	5.92	0.31	0.04
		Mean	0.70	0.29	0.05	5.46	5.20	0.30	0.03
		High	0.74	0.37	0.05	6.24	7.55	0.42	0.04
		SD	0.06	0.08	0.00	0.92	2.01	0.08	0.01
		Geometric mean	0.70	0.28	0.05	5.40	4.87	0.29	0.03

Table A 7

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1995	October	# Samples	15	15	15	15	15	15	15
		Low	0.34	0.08	0.04	4.18	2.33	0.05	0.00
		25 % Percentile	2.35	0.13	0.05	4.79	2.80	0.10	0.02
		Median	3.09	0.18	0.05	5.93	3.25	0.13	0.03
		75 % Percentile	3.38	0.24	0.06	8.08	4.68	0.17	0.11
		Mean	2.76	0.21	0.06	6.82	3.96	0.14	0.08
		High	3.79	0.48	0.13	11.91	9.81	0.28	0.48
		SD	0.95	0.11	0.02	2.69	1.93	0.07	0.12
		Geometric mean	2.47	0.18	0.06	6.40	3.65	0.13	0.04
	November	# Samples	17	17	17	17	17	12	17
		Low	2.61	0.05	0.02	2.82	0.60	0.04	0.01
		25 % Percentile	3.06	0.10	0.05	3.21	0.84	0.08	0.02
		Median	3.34	0.14	0.05	3.43	1.28	0.11	0.05
		75 % Percentile	3.51	0.21	0.07	4.44	3.62	0.16	0.09
		Mean	3.36	0.18	0.06	3.98	2.23	0.13	0.06
		High	4.05	0.41	0.14	7.29	4.70	0.30	0.21
		SD	0.40	0.11	0.03	1.26	1.57	0.08	0.06
		Geometric mean	3.34	0.15	0.05	3.83	1.71	0.11	0.04
	December	# Samples	3	3	3	3	3	n.d.	3
		Low	2.50	0.09	0.03	3.10	0.61	n.d.	0.01
		25 % Percentile	2.51	0.18	0.03	3.25	1.00	n.d.	0.01
		Median	2.52	0.26	0.03	3.40	1.39	n.d.	0.01
		75 % Percentile	2.66	0.28	0.04	3.44	1.45	n.d.	0.01
		Mean	2.60	0.22	0.03	3.33	1.17	n.d.	0.01
		High	2.79	0.30	0.04	3.48	1.50	n.d.	0.02
		SD	0.16	0.11	0.01	0.20	0.49	n.d.	0.00
		Geometric mean	2.60	0.19	0.03	3.32	1.08	n.d.	0.01

Table A 8

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1996	January	# Samples	3	3	3	3	3	n.d.	3
		Low	2.70	0.06	0.04	2.60	1.06	n.d.	0.01
		25 % Percentile	2.92	0.11	0.05	2.71	1.10	n.d.	0.02
		Median	3.15	0.15	0.05	2.82	1.13	n.d.	0.03
		75 % Percentile	3.41	0.17	0.05	3.75	17.97	n.d.	0.06
		Mean	3.18	0.13	0.05	3.36	12.33	n.d.	0.04
		High	3.68	0.19	0.05	4.67	34.80	n.d.	0.08
		SD	0.49	0.07	0.01	1.14	19.46	n.d.	0.04
		Geometric mean	3.15	0.12	0.05	3.25	3.47	n.d.	0.02
	February	# Samples	4	4	4	4	4	4	4
		Low	2.79	0.04	0.03	1.70	1.79	0.00	0.01
		25 % Percentile	2.80	0.12	0.04	2.00	1.95	0.01	0.01
		Median	3.36	0.18	0.06	2.43	3.04	0.03	0.01
		75 % Percentile	3.92	0.21	0.07	2.79	4.55	0.06	0.02
		Mean	3.36	0.16	0.06	2.36	3.46	0.04	0.02
		High	3.95	0.24	0.08	2.88	5.96	0.10	0.03
		SD	0.65	0.09	0.02	0.56	1.96	0.04	0.01
		Geometric mean	3.32	0.13	0.05	2.31	3.06	0.02	0.01
	April	# Samples	21	21	21	21	13	13	21
		Low	3.13	0.02	0.03	2.21	1.63	0.17	0.01
		25 % Percentile	3.88	0.07	0.05	2.96	1.93	0.34	0.02
		Median	3.98	0.10	0.07	3.47	3.43	0.40	0.05
		75 % Percentile	4.53	0.15	0.09	3.91	4.88	0.69	0.28
		Mean	4.26	0.11	0.07	3.54	3.73	0.52	0.15
		High	7.22	0.34	0.12	5.72	6.68	1.12	0.49
		SD	0.97	0.08	0.03	0.91	1.69	0.27	0.16
		Geometric mean	4.17	0.09	0.07	3.43	3.36	0.46	0.06

Table A 9

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1996	April	# Samples	35	35	35	35	18	18	35
		Low	2.00	0.02	0.03	1.99	1.51	0.14	0.01
		25 % Percentile	2.50	0.11	0.04	2.35	1.94	0.42	0.03
		Median	2.74	0.14	0.05	2.63	3.16	0.55	0.07
		75 % Percentile	2.99	0.19	0.08	3.29	4.15	0.59	0.11
		Mean	2.78	0.16	0.07	2.82	3.36	0.50	0.10
		High	3.49	0.44	0.27	4.38	7.00	0.76	0.45
		SD	0.37	0.08	0.05	0.63	1.60	0.16	0.11
		Geometric mean	2.75	0.14	0.06	2.76	3.04	0.46	0.06
	May	# Samples	16	16	15	16	11	7	16
		Low	1.80	0.02	0.04	2.12	1.90	0.06	0.00
		25 % Percentile	2.02	0.15	0.04	2.55	2.27	0.16	0.01
		Median	2.26	0.21	0.05	2.71	2.52	0.43	0.01
		75 % Percentile	2.73	0.25	0.07	3.25	2.67	0.57	0.04
		Mean	2.48	0.25	0.06	3.00	2.51	0.36	0.04
		High	3.99	0.88	0.10	5.70	3.30	0.57	0.25
		SD	0.65	0.22	0.02	0.91	0.37	0.22	0.06
		Geometric mean	2.41	0.17	0.06	2.90	2.49	0.27	0.02
	June	# Samples	8	8	8	8	7	6	8
		Low	1.01	0.12	0.04	1.93	0.59	0.02	0.00
		25 % Percentile	1.45	0.16	0.05	2.51	0.80	0.08	0.01
		Median	1.57	0.20	0.05	2.82	2.51	0.17	0.01
		75 % Percentile	1.60	0.24	0.06	2.98	2.81	0.23	0.02
		Mean	1.48	0.22	0.05	2.86	1.91	0.17	0.02
		High	1.66	0.46	0.06	4.27	3.07	0.34	0.04
		SD	0.21	0.11	0.01	0.68	1.12	0.12	0.01
		Geometric mean	1.47	0.20	0.05	2.79	1.57	0.12	0.01

Table A 10

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1996	July	# Samples	14	14	14	14	14	14	14
		Low	1.07	0.01	0.01	2.76	0.42	0.17	0.01
		25 % Percentile	2.27	0.07	0.04	3.23	1.58	0.32	0.01
		Median	3.77	0.11	0.06	3.89	5.04	0.40	0.03
		75 % Percentile	6.97	0.33	0.09	5.39	6.71	0.48	0.05
		Mean	4.55	0.21	0.07	4.88	4.31	0.52	0.06
		High	8.94	0.64	0.18	10.59	8.59	1.60	0.23
		SD	2.77	0.21	0.05	2.50	2.86	0.39	0.07
		Geometric mean	3.73	0.10	0.06	4.43	3.11	0.44	0.03
	August	# Samples	6	5	6	6	5	5	6
		Low	1.00	0.04	0.03	3.49	2.55	0.02	0.00
		25 % Percentile	1.31	0.11	0.05	3.85	3.34	0.26	0.00
		Median	1.37	0.12	0.06	4.04	3.69	0.36	0.01
		75 % Percentile	1.51	0.12	0.08	4.59	4.03	0.41	0.01
		Mean	1.88	0.10	0.06	4.34	3.70	0.31	0.01
		High	4.68	0.13	0.09	5.90	4.90	0.49	0.04
		SD	1.38	0.04	0.02	0.87	0.87	0.18	0.02
		Geometric mean	1.61	0.10	0.06	4.27	3.62	0.20	0.01
	September	# Samples	12	7	12	12	6	3	12
		Low	0.79	0.01	0.04	4.76	2.63	0.06	0.00
		25 % Percentile	1.89	0.03	0.07	5.42	3.00	0.13	0.01
		Median	3.16	0.08	0.09	5.62	3.07	0.20	0.02
		75 % Percentile	3.32	0.15	0.13	8.06	3.12	0.28	0.07
		Mean	2.55	0.10	0.13	8.03	3.07	0.21	0.05
		High	3.73	0.30	0.35	20.00	3.55	0.37	0.20
		SD	1.07	0.11	0.10	4.84	0.29	0.15	0.06
		Geometric mean	2.26	0.06	0.11	7.13	3.06	0.17	0.03

Table A 11

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1996	October	# Samples	23	14	23	23	13	9	23
		Low	1.66	0.12	0.04	3.94	1.20	0.02	0.00
		25 % Percentile	2.53	0.14	0.06	4.49	1.58	0.04	0.01
		Median	2.84	0.24	0.14	5.82	1.85	0.14	0.08
		75 % Percentile	3.23	0.29	0.19	7.61	2.91	0.18	0.20
		Mean	2.85	0.23	0.13	6.59	2.40	0.14	0.14
		High	4.35	0.36	0.32	14.60	5.28	0.28	0.56
		SD	0.62	0.09	0.08	2.67	1.37	0.09	0.17
		Geometric mean	2.78	0.22	0.11	6.16	2.13	0.10	0.05
	November	# Samples	20	18	20	20	15	11	20
		Low	1.70	0.02	0.02	2.57	0.65	0.01	0.01
		25 % Percentile	2.43	0.18	0.04	3.55	1.47	0.04	0.02
		Median	2.57	0.32	0.11	6.26	1.65	0.11	0.14
		75 % Percentile	3.18	0.56	0.19	7.50	2.08	0.32	0.24
		Mean	2.78	0.44	0.13	5.67	1.79	0.18	0.15
		High	4.40	1.62	0.34	8.69	3.26	0.45	0.46
		SD	0.65	0.39	0.10	2.14	0.65	0.16	0.14
		Geometric mean	2.71	0.29	0.09	5.24	1.67	0.10	0.08
	December	# Samples	9	8	9	9	6	4	9
		Low	1.67	0.18	0.03	2.52	1.70	0.09	0.01
		25 % Percentile	3.10	0.21	0.03	3.38	1.91	0.14	0.02
		Median	3.40	0.31	0.04	4.06	2.17	0.30	0.09
		75 % Percentile	3.49	0.36	0.06	4.63	2.22	0.53	0.15
		Mean	3.19	0.30	0.05	3.85	2.13	0.37	0.13
		High	3.84	0.50	0.09	4.75	2.66	0.78	0.49
		SD	0.64	0.11	0.02	0.82	0.34	0.31	0.15
		Geometric mean	3.11	0.29	0.04	3.77	2.10	0.26	0.07

Table A 12

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1994	January	# Samples	1	0	1	1	1	1	1
		High	2.39	0.00	0.01	4.34	1.61	0.20	0.06
	February	# Samples	2	1	2	2	2	2	2
		Low	1.92	n.d.	n.d.	5.23	1.27	0.32	0.01
		25 % Percentile	1.97	n.d.	n.d.	5.40	1.31	0.34	0.02
		Median	2.01	n.d.	n.d.	5.58	1.35	0.37	0.04
		75 % Percentile	1.97	n.d.	n.d.	5.40	1.31	0.34	0.02
		Mean	2.01	n.d.	n.d.	5.58	1.35	0.37	0.04
		High	2.10	0.44	0.01	5.92	1.42	0.42	0.06
		SD	0.13	n.d.	n.d.	0.49	0.10	0.07	0.03
		Geometric mean	2.01	n.d.	n.d.	5.56	1.35	0.37	0.03
	March	# Samples	4	3	4	4	4	4	4
		Low	1.63	0.06	0.01	4.10	1.27	0.18	0.01
		25 % Percentile	1.70	0.19	0.01	4.54	1.32	0.25	0.01
		Median	1.76	0.31	0.01	4.70	1.42	0.27	0.02
		75 % Percentile	1.89	0.32	0.01	4.92	2.18	0.29	0.04
		Mean	1.83	0.23	0.01	4.76	2.07	0.27	0.03
		High	2.18	0.33	0.02	5.55	4.18	0.34	0.05
		SD	0.24	0.15	0.01	0.60	1.41	0.06	0.02
		Geometric mean	1.82	0.18	0.01	4.73	1.81	0.26	0.02
	April	# Samples	33	31	33	33	34	34	34
		Low	0.60	0.02	0.01	1.43	0.42	0.03	0.01
		25 % Percentile	1.48	0.07	0.01	2.69	0.81	0.19	0.02
		Median	1.96	0.08	0.03	3.24	1.09	0.27	0.05
		75 % Percentile	3.09	0.12	0.07	3.53	1.88	0.37	0.07
		Mean	2.20	0.10	0.04	3.11	1.74	0.27	0.05
		High	3.83	0.29	0.12	4.53	9.58	0.50	0.15
		SD	0.94	0.06	0.03	0.62	1.79	0.11	0.04
		Geometric mean	1.99	0.09	0.03	3.04	1.30	0.24	0.04

Table A 13

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1994	May	# Samples	27	21	27	27	29	23	26
		Low	1.07	0.01	0.01	2.28	0.59	0.05	0.00
		25 % Percentile	1.73	0.07	0.01	3.55	0.87	0.23	0.01
		Median	2.44	0.12	0.03	3.68	1.79	0.29	0.01
		75 % Percentile	4.17	0.15	0.06	4.49	2.34	0.34	0.01
		Mean	2.98	0.11	0.04	3.98	2.42	0.30	0.02
		High	6.04	0.24	0.12	6.13	19.12	0.55	0.10
		SD	1.48	0.06	0.03	0.89	3.37	0.13	0.02
		Geometric mean	2.65	0.09	0.03	3.89	1.69	0.27	0.01
	June	# Samples	31	31	30	31	31	30	32
		Low	0.78	0.01	0.01	1.84	0.26	0.03	0.00
		25 % Percentile	2.23	0.33	0.08	4.48	1.03	0.25	0.01
		Median	4.17	0.80	0.10	4.96	1.77	0.44	0.02
		75 % Percentile	7.34	1.11	0.12	5.15	3.07	0.61	0.08
		Mean	5.01	0.75	0.10	4.74	2.45	0.47	0.06
		High	11.29	1.52	0.20	6.18	9.07	1.59	0.44
		SD	3.21	0.45	0.05	0.93	2.26	0.30	0.10
		Geometric mean	3.87	0.50	0.08	4.62	1.66	0.38	0.02
	July	# Samples	17	17	17	17	17	17	17
		Low	0.94	0.04	0.06	2.82	0.61	0.09	0.00
		25 % Percentile	1.47	0.08	0.08	3.75	0.88	0.28	0.01
		Median	2.96	0.12	0.10	4.16	1.16	0.40	0.02
		75 % Percentile	4.86	0.18	0.14	4.32	2.00	0.50	0.03
		Mean	3.31	0.20	0.11	4.13	1.51	0.41	0.04
		High	5.99	1.32	0.20	5.57	3.74	0.75	0.21
		SD	1.79	0.30	0.04	0.64	0.92	0.17	0.05
		Geometric mean	2.79	0.13	0.11	4.08	1.30	0.37	0.02

Table A 14

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1994	August	# Samples	14	14	14	14	14	14	14
		Low	0.53	0.02	0.06	3.10	0.82	0.17	0.00
		25 % Percentile	0.76	0.04	0.08	4.27	0.92	0.23	0.00
		Median	0.86	0.14	0.09	4.81	1.25	0.26	0.01
		75 % Percentile	2.75	0.19	0.12	6.38	1.52	0.29	0.01
		Mean	1.81	0.13	0.10	5.26	1.38	0.29	0.01
		High	5.28	0.28	0.13	8.01	2.87	0.68	0.08
		SD	1.60	0.09	0.02	1.46	0.59	0.12	0.02
		Geometric mean	1.32	0.09	0.09	5.08	1.29	0.27	0.01
	September	# Samples	8	8	8	8	8	8	6
		Low	0.32	0.04	0.03	3.85	0.55	0.11	0.00
		25 % Percentile	0.52	0.06	0.05	7.06	0.59	0.23	0.00
		Median	0.73	0.12	0.05	7.27	0.63	0.27	0.00
		75 % Percentile	1.13	0.17	0.06	9.95	0.91	0.29	0.00
		Mean	0.82	0.12	0.06	8.03	0.84	0.26	0.00
		High	1.52	0.21	0.09	11.84	1.56	0.38	0.00
		SD	0.41	0.07	0.02	2.47	0.42	0.08	0.00
		Geometric mean	0.73	0.10	0.05	7.66	0.77	0.25	0.00
	October	# Samples	9	9	9	9	9	9	9
		Low	0.09	0.04	0.04	9.14	1.87	0.05	0.00
		25 % Percentile	0.35	0.05	0.05	10.26	4.55	0.18	0.00
		Median	0.48	0.05	0.05	11.75	8.42	0.34	0.00
		75 % Percentile	0.56	0.11	0.06	13.18	24.82	0.52	0.00
		Mean	0.45	0.07	0.06	11.95	12.91	0.32	0.00
		High	0.76	0.11	0.07	15.08	29.56	0.53	0.02
		SD	0.20	0.03	0.01	1.92	11.38	0.20	0.01
		Geometric mean	0.39	0.06	0.05	11.81	8.46	0.24	0.00

Table A 15

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1994	November	# Samples	14	12	14	14	14	14	12
		Low	2.15	0.05	0.05	4.87	0.87	0.22	0.00
		25 % Percentile	2.77	0.05	0.05	5.34	1.01	0.26	0.01
		Median	3.39	0.08	0.07	5.75	1.59	0.28	0.01
		75 % Percentile	4.09	0.10	0.07	6.97	5.07	0.34	0.02
		Mean	3.41	0.08	0.08	6.87	4.99	0.30	0.01
		High	4.63	0.17	0.20	14.40	24.71	0.41	0.03
		SD	0.80	0.04	0.04	2.69	7.40	0.06	0.01
		Geometric mean	3.32	0.08	0.07	6.51	2.39	0.29	0.01
	December	# Samples	11	11	11	11	11	11	11
		Low	0.92	0.12	0.05	1.08	1.94	0.04	0.00
		25 % Percentile	2.30	0.14	0.06	3.29	2.62	0.18	0.00
		Median	0.28	0.25	0.27	0.34	0.27	0.04	0.02
		75 % Percentile	4.45	0.27	0.11	4.78	5.68	0.27	0.03
		Mean	3.41	0.21	0.09	4.00	4.60	0.23	0.02
		High	5.34	0.39	0.17	6.51	10.43	0.47	0.05
		SD	1.45	0.10	0.04	1.54	2.96	0.12	0.02
		Geometric mean	3.06	0.19	0.08	3.62	3.91	0.19	0.01

Table A 16

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1995	January	# Samples	6	6	6	6	5	5	5
		Low	2.74	0.20	0.04	3.50	1.96	0.19	0.01
		25 % Percentile	4.24	0.27	0.05	3.53	4.98	0.20	0.02
		Median	4.38	0.50	0.07	3.59	4.98	0.27	0.02
		75 % Percentile	4.66	0.62	0.07	3.88	5.62	0.30	0.03
		Mean	4.39	0.45	0.08	3.80	5.13	0.28	0.03
		High	5.86	0.62	0.17	4.62	8.11	0.44	0.06
		SD	1.00	0.20	0.05	0.44	2.19	0.10	0.02
		Geometric mean	4.28	0.40	0.07	3.78	4.67	0.27	0.02
	February	# Samples	2	2	2	2	2	2	2
		Low	2.08	0.53	0.03	3.37	4.61	0.38	0.00
		25 % Percentile	2.43	0.57	0.03	3.38	4.65	0.38	0.00
		Median	2.78	0.61	0.04	3.39	4.70	0.38	0.00
		75 % Percentile	3.12	0.65	0.04	3.39	4.75	0.38	0.01
		Mean	2.78	0.61	0.04	3.39	4.70	0.38	0.00
		High	3.47	0.69	0.04	3.40	4.80	0.38	0.01
		SD	0.98	0.11	0.01	0.02	0.14	0.00	0.00
		Geometric mean	2.69	0.60	0.03	3.38	4.70	0.38	0.00
	March	# Samples	9	9	9	9	9	9	9
		Low	1.27	0.44	0.02	0.68	3.30	0.15	0.01
		25 % Percentile	1.66	0.47	0.04	2.01	3.53	0.20	0.01
		Median	1.91	0.51	0.06	2.44	4.56	0.24	0.01
		75 % Percentile	2.55	0.55	0.09	3.19	7.28	0.45	0.03
		Mean	2.19	0.57	0.07	2.48	5.53	0.39	0.02
		High	3.39	1.01	0.14	4.59	9.97	0.89	0.06
		SD	0.75	0.19	0.04	1.13	2.41	0.27	0.02
		Geometric mean	2.09	0.55	0.06	2.21	5.10	0.32	0.02

Table A 17

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1995	April	# Samples	12	12	12	12	12	12	12
		Low	0.97	0.41	0.02	0.12	3.18	0.02	0.01
		25 % Percentile	2.33	0.47	0.03	1.08	4.52	0.06	0.01
		Median	2.75	0.50	0.03	2.61	4.89	0.16	0.01
		75 % Percentile	3.16	0.51	0.04	2.79	6.63	0.29	0.01
		Mean	2.58	0.50	0.04	2.15	5.37	0.24	0.02
		High	3.61	0.67	0.06	4.20	8.41	0.88	0.06
		SD	0.84	0.06	0.01	1.29	1.50	0.26	0.02
		Geometric mean	2.41	0.50	0.03	1.47	5.19	0.14	0.01
	May	# Samples	4	4	4	4	4	4	4
		Low	1.87	0.24	0.03	2.68	12.96	0.20	0.00
		25 % Percentile	2.13	0.39	0.03	3.02	19.65	0.23	0.00
		Median	2.22	0.45	0.05	3.17	22.26	0.24	0.01
		75 % Percentile	2.36	0.47	0.06	3.55	23.20	0.26	0.01
		Mean	2.27	0.41	0.05	3.40	20.59	0.25	0.01
		High	2.76	0.48	0.07	4.58	24.87	0.32	0.02
		SD	0.37	0.11	0.02	0.82	5.24	0.05	0.01
		Geometric mean	2.25	0.39	0.04	3.33	19.99	0.25	0.01
	June	# Samples	4	4	4	4	4	4	4
		Low	0.40	0.07	0.03	2.70	4.09	0.13	0.01
		25 % Percentile	0.72	0.09	0.08	3.77	4.36	0.13	0.01
		Median	1.12	0.14	0.13	4.89	5.64	0.18	0.02
		75 % Percentile	1.52	0.25	0.17	5.76	8.15	0.25	0.02
		Mean	1.12	0.20	0.12	4.65	6.86	0.20	0.02
		High	1.83	0.44	0.20	6.11	12.08	0.31	0.04
		SD	0.63	0.17	0.08	1.55	3.69	0.09	0.02
		Geometric mean	0.96	0.15	0.10	4.43	6.22	0.18	0.02

Table A 18

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1995	July	# Samples	4	4	4	4	4	4	4
		Low	0.36	0.04	0.05	3.29	4.26	0.14	0.01
		25 % Percentile	0.37	0.06	0.06	4.88	4.44	0.15	0.03
		Median	1.17	0.09	0.11	5.60	4.60	0.18	0.05
		75 % Percentile	1.98	0.19	0.18	6.16	4.87	0.20	0.06
		Mean	1.18	0.17	0.13	5.44	4.70	0.18	0.04
		High	2.02	0.46	0.24	7.27	5.35	0.21	0.07
		SD	0.94	0.20	0.09	1.64	0.47	0.03	0.02
		Geometric mean	0.85	0.11	0.10	5.23	4.69	0.17	0.04
	August	# Samples	5	5	5	5	5	5	5
		Low	0.34	0.05	0.07	7.09	3.19	0.14	0.01
		25 % Percentile	0.35	0.15	0.15	7.10	4.40	0.27	0.01
		Median	0.39	0.18	0.15	7.30	4.45	0.28	0.01
		75 % Percentile	0.49	0.19	0.16	7.49	5.28	0.29	0.01
		Mean	0.43	0.16	0.12	7.30	4.81	0.29	0.01
		High	0.58	0.26	0.16	7.90	6.44	0.30	0.01
		SD	0.10	0.08	0.04	0.34	1.20	0.07	0.00
		Geometric mean	0.42	0.15	0.13	7.37	4.63	0.24	0.01
	September	# Samples	4	4	4	4	4	4	4
		Low	0.23	0.20	0.03	5.92	3.67	0.22	0.00
		25 % Percentile	0.27	0.20	0.04	6.39	3.84	0.24	0.00
		Median	0.30	0.23	0.05	6.69	3.96	0.25	0.01
		75 % Percentile	0.32	0.27	0.05	7.21	4.50	0.28	0.01
		Mean	0.30	0.24	0.04	6.91	4.38	0.27	0.01
		High	0.36	0.31	0.05	8.35	5.94	0.37	0.01
		SD	0.05	0.05	0.01	1.03	1.05	0.07	0.00
		Geometric mean	0.29	0.24	0.04	6.86	4.30	0.27	0.01

Table A 19

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1995	October	# Samples	13	13	13	13	13	13	13
		Low	0.33	0.08	0.04	2.64	2.10	0.11	0.00
		25 % Percentile	1.59	0.12	0.05	5.71	2.79	0.14	0.01
		Median	2.12	0.15	0.05	9.56	3.68	0.16	0.01
		75 % Percentile	3.65	0.18	0.05	12.46	4.52	0.18	0.02
		Mean	2.54	0.16	0.05	9.16	3.93	0.16	0.04
		High	4.72	0.31	0.07	15.34	7.54	0.23	0.27
		SD	1.40	0.07	0.01	4.13	1.52	0.04	0.07
		Geometric mean	2.07	0.15	0.05	8.16	3.69	0.16	0.01
	November	# Samples	15	15	15	15	15	11	15
		Low	2.40	0.06	0.02	1.67	0.52	0.01	0.00
		25 % Percentile	3.59	0.10	0.05	3.61	0.75	0.03	0.01
		Median	4.04	0.12	0.05	4.03	0.97	0.07	0.02
		75 % Percentile	4.78	0.15	0.06	4.55	2.97	0.10	0.05
		Mean	4.14	0.13	0.05	4.05	1.83	0.07	0.03
		High	5.84	0.23	0.08	5.40	5.51	0.18	0.10
		SD	0.93	0.05	0.01	0.90	1.47	0.06	0.03
		Geometric mean	4.04	0.12	0.05	3.93	1.37	0.05	0.02
	December	# Samples	3	3	3	3	3	1	3
		Low	1.13	0.05	0.03	0.98	0.57	0.03	0.00
		25 % Percentile	2.18	0.05	0.04	1.85	0.96	0.03	0.00
		Median	3.23	0.05	0.04	2.71	1.35	0.03	0.00
		75 % Percentile	3.33	0.08	0.04	3.22	1.39	0.03	0.02
		Mean	2.59	0.07	0.04	2.47	1.12	0.03	0.01
		High	3.42	0.10	0.04	3.72	1.43	0.03	0.03
		SD	1.27	0.03	0.01	1.39	0.47	n.d.	0.02
		Geometric mean	2.32	0.06	0.04	2.15	1.03	0.03	0.01

Table A 20

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1996	January	# Samples	3	3	3	3	3	n.d.	3
		Low	2.70	0.06	0.04	2.60	1.06	n.d.	0.01
		25 % Percentile	2.92	0.11	0.05	2.71	1.10	n.d.	0.02
		Median	3.15	0.15	0.05	2.82	1.13	n.d.	0.03
		75 % Percentile	3.41	0.17	0.05	3.75	17.97	n.d.	0.06
		Mean	3.18	0.13	0.05	3.36	12.33	n.d.	0.04
		High	3.68	0.19	0.05	4.67	34.80	n.d.	0.08
		SD	0.49	0.07	0.01	1.14	19.46	n.d.	0.04
		Geometric mean	3.15	0.12	0.05	3.25	3.47	n.d.	0.02
	February	# Samples	4	4	4	4	4	4	4
		Low	2.79	0.04	0.03	1.70	1.79	0.00	0.01
		25 % Percentile	2.80	0.12	0.04	2.00	1.95	0.01	0.01
		Median	3.36	0.18	0.06	2.43	3.04	0.03	0.01
		75 % Percentile	3.92	0.21	0.07	2.79	4.55	0.06	0.02
		Mean	3.36	0.16	0.06	2.36	3.46	0.04	0.02
		High	3.95	0.24	0.08	2.88	5.96	0.10	0.03
		SD	0.65	0.09	0.02	0.56	1.96	0.04	0.01
		Geometric mean	3.32	0.13	0.05	2.31	3.06	0.02	0.01
	April	# Samples	21	21	21	21	13	13	21
		Low	3.13	0.02	0.03	2.21	1.63	0.17	0.01
		25 % Percentile	3.88	0.07	0.05	2.96	1.93	0.34	0.02
		Median	3.98	0.10	0.07	3.47	3.43	0.40	0.05
		75 % Percentile	4.53	0.15	0.09	3.91	4.88	0.69	0.28
		Mean	4.26	0.11	0.07	3.54	3.73	0.52	0.15
		High	7.22	0.34	0.12	5.72	6.68	1.12	0.49
		SD	0.97	0.08	0.03	0.91	1.69	0.27	0.16
		Geometric mean	4.17	0.09	0.07	3.43	3.36	0.46	0.06

Table A 21

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1996	May	# Samples	14	14	13	14	9	6	14
		Low	2.12	0.02	0.04	2.52	1.76	0.14	0.01
		25 % Percentile	2.54	0.12	0.05	3.21	1.91	0.28	0.01
		Median	3.26	0.16	0.05	3.28	1.98	0.38	0.01
		75 % Percentile	3 81	0.20	0.08	3.52	2.44	0.41	0.02
		Mean	3.30	0.16	0.06	3.34	2.92	0.34	0.02
		High	4.81	0.33	0.12	4.23	9.01	0.44	0.06
		SD	0.86	0.09	0.03	0.46	2.32	0.12	0.01
		Geometric mean	3.19	0.13	0.06	3.31	2.49	0.31	0.01
	June	# Samples	8	8	8	8	7	7	8
		Low	0.81	0.07	0.08	4.44	0.49	0.03	0.00
		25 % Percentile	1.25	0.15	0.09	4.62	0.65	0.15	0.01
		Median	1.30	0.20	0.10	5.01	1.52	0.28	0.01
		75 % Percentile	1.42	0.24	0.11	5.32	2.52	0.38	0.02
		Mean	1.28	0.19	0.10	5.10	1.61	0.26	0.02
		High	1.49	0.30	0.12	6.55	2.91	0.43	0.05
		SD	0.22	0.08	0.01	0.68	1.04	0.16	0.02
		Geometric mean	1.27	0.17	0.10	5.06	1.28	0.18	0.01
	July	# Samples	13	13	13	13	13	12	13
		Low	1.43	0.01	0.02	3.18	1.40	0.03	0.00
		25 % Percentile	2.06	0.05	0.07	4.80	1.96	0.27	0.01
		Median	2.52	0.08	0.09	5.05	5.33	0.36	0.03
		75 % Percentile	3.67	0.11	0.10	5.69	7.36	0.49	0.06
		Mean	3.68	0.10	0.08	5.04	4.87	0.45	0.04
		High	10.37	0.26	0.12	6.45	9.19	1.59	0.08
		SD	2.90	0.07	0.03	0.90	3.02	0.41	0.03
		Geometric mean	2.98	0.07	0.08	4.96	3.91	0.30	0.02

Table A 22

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1996	August	# Samples	6	6	6	6	5	5	6
		Low	0.76	0.01	0.07	5.33	2.76	0.10	0.00
		25 % Percentile	1.18	0.05	0.12	5.95	3.06	0.43	0.01
		Median	1.27	0.09	0.14	6.84	3.32	0.49	0.01
		75 % Percentile	1.68	0.13	0.16	8.89	3.50	0.52	0.03
		Mean	2.28	0.10	0.18	9.12	3.54	0.42	0.02
		High	7.41	0.24	0.47	20.48	5.05	0.54	0.06
		SD	2.54	0.08	0.15	5.75	0.89	0.18	0.02
		Geometric mean	1.63	0.06	0.15	8.08	3.46	0.36	0.01
	September	# Samples	13	6	13	13	7	6	13
		Low	0.30	0.04	0.08	6.38	2.77	0.10	0.00
		25 % Percentile	0.53	0.08	0.13	8.12	2.90	0.13	0.01
		Median	1.81	0.12	0.15	8.54	3.17	0.15	0.01
		75 % Percentile	3.74	0.17	0.17	9.75	3.26	0.16	0.03
		Mean	2.22	0.15	0.14	9.47	3.15	0.17	0.02
		High	4.88	0.35	0.19	17.20	3.78	0.32	0.08
		SD	1.70	0.11	0.03	2.79	0.35	0.08	0.02
		Geometric mean	1.52	0.12	0.14	9.17	3.13	0.16	0.01
	October	# Samples	13	7	13	13	8	6	12
		Low	1.59	0.04	0.04	3.80	1.15	0.02	0.01
		25 % Percentile	2.24	0.06	0.06	5.09	1.75	0.16	0.01
		Median	3.34	0.12	0.08	5.29	2.84	0.16	0.01
		75 % Percentile	3.67	0.23	0.10	6.30	4.10	0.26	0.02
		Mean	3.13	0.15	0.10	6.17	4.36	0.19	0.03
		High	5.18	0.30	0.38	14.35	16.32	0.32	0.17
		SD	1.14	0.11	0.09	2.70	4.99	0.11	0.05
		Geometric mean	2.93	0.11	0.09	5.80	2.98	0.15	0.02

Table A 23

Year	Month	Parameter	NO3	NH4	PO4	K	TKN	TP	Sediment
1996	November	# Samples	19	19	19	19	8	7	19
		Low	1.85	0.03	0.02	3.44	0.73	0.04	0.01
		25 % Percentile	2.81	0.15	0.07	4.44	0.84	0.20	0.02
		Median	3.41	0.37	0.15	6.68	1.11	0.31	0.13
		75 % Percentile	4.32	0.59	0.22	8.14	1.47	0.42	0.22
		Mean	3.49	0.41	0.14	6.34	1.27	0.29	0.14
		High	4.98	0.93	0.29	9.00	2.34	0.43	0.46
		SD	0.99	0.29	0.09	1.95	0.59	0.16	0.14
		Geometric mean	3.34	0.30	0.11	6.03	1.17	0.23	0.07
	December	# Samples	8	6	8	8	5	2	8
		Low	2.34	0.20	0.02	3.80	1.55	0.47	0.00
		25 % Percentile	3.83	0.22	0.03	4.19	1.61	0.47	0.01
		Median	4.74	0.24	0.07	4.33	1.75	0.48	0.03
		75 % Percentile	5.33	0.28	0.09	4.69	1.87	0.49	0.06
		Mean	4.53	0.25	0.06	4.43	1.90	0.48	0.04
		High	6.14	0.31	0.12	5.20	2.73	0.50	0.09
		SD	1.20	0.05	0.03	0.45	0.48	0.02	0.03
		Geometric mean	4.36	0.25	0.06	4.41	1.86	0.48	0.02

Table A 24

Appendix B

Box and whisker plots for all parameters at

St. Esprit and Desrochers

List of Figures in Appendix B

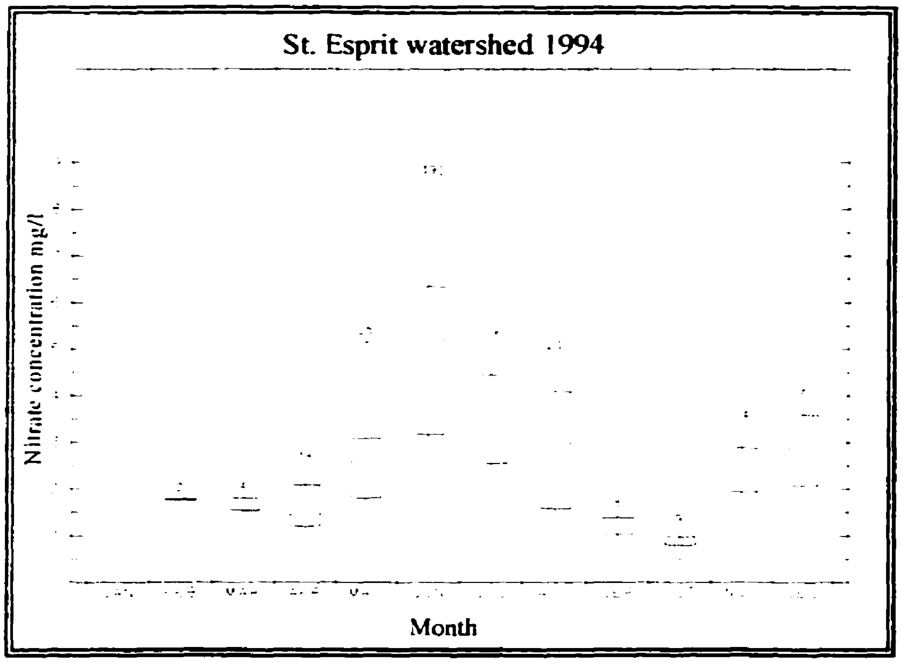


Figure B1

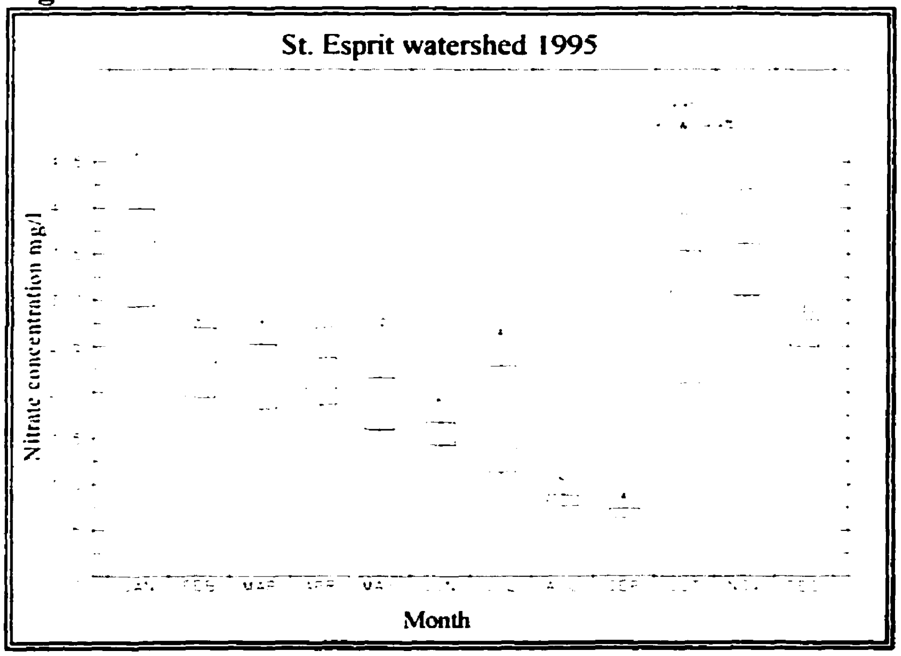


Figure B2

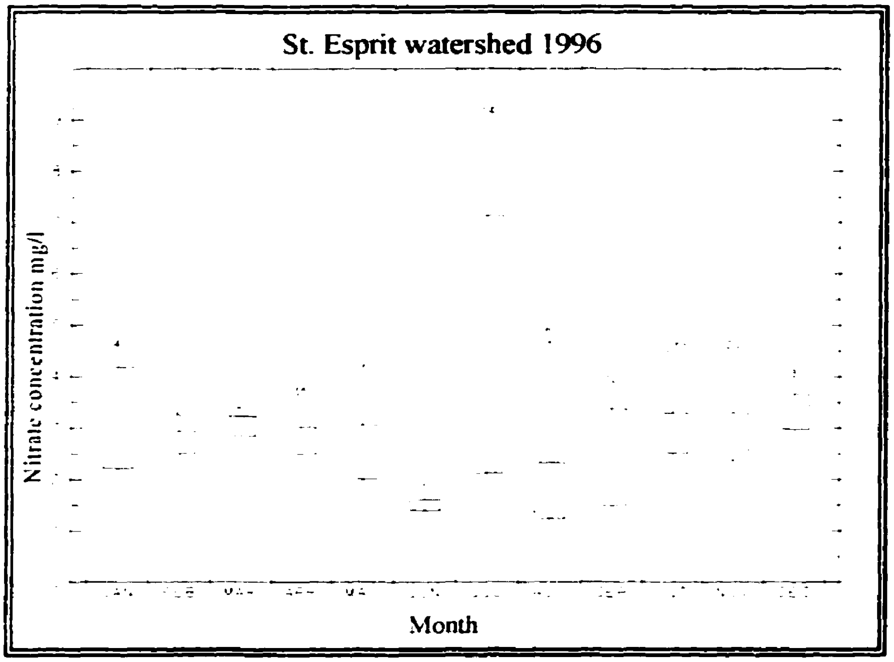


Figure B3

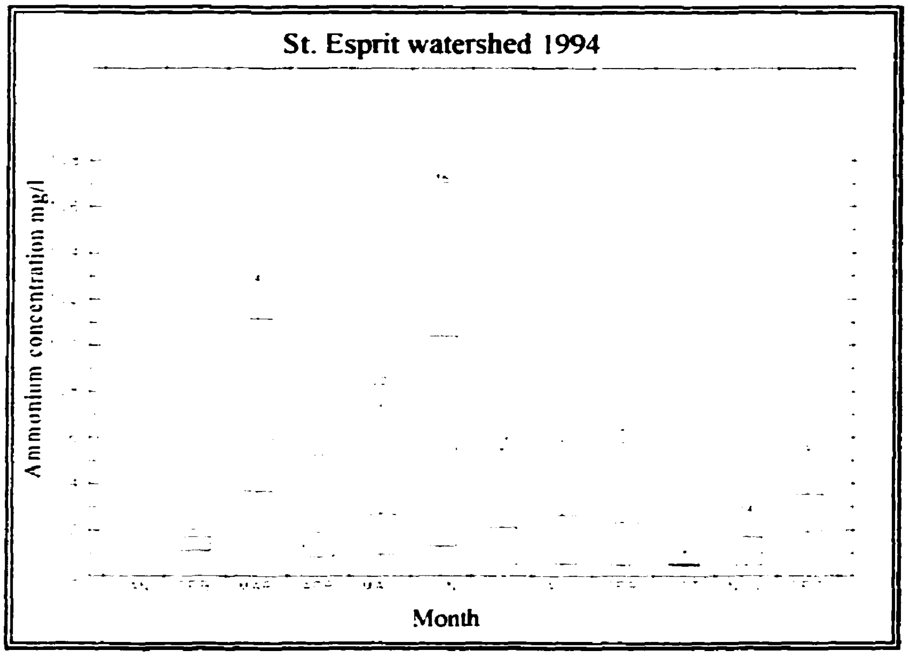


Figure B4

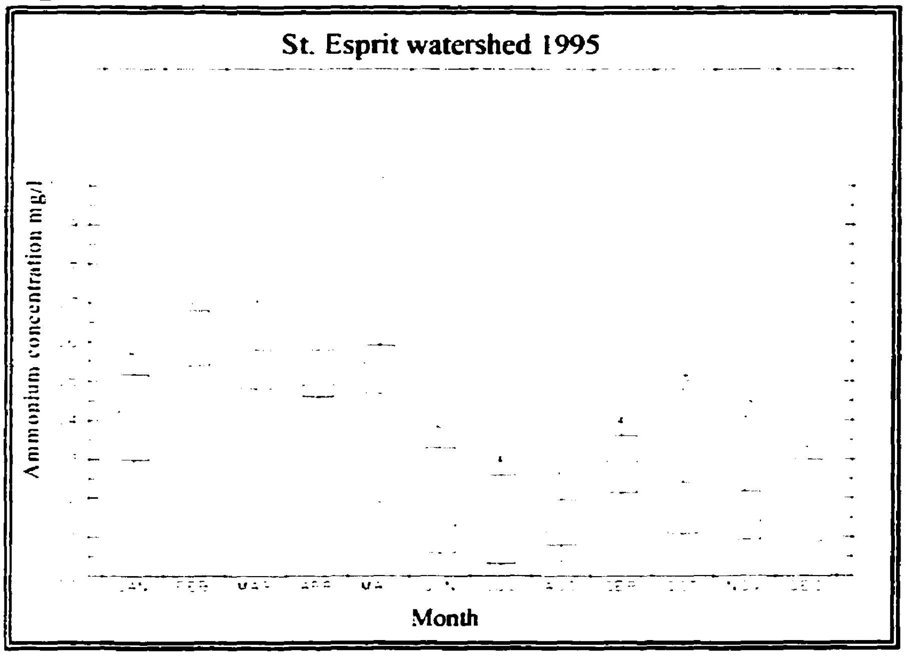


Figure B5

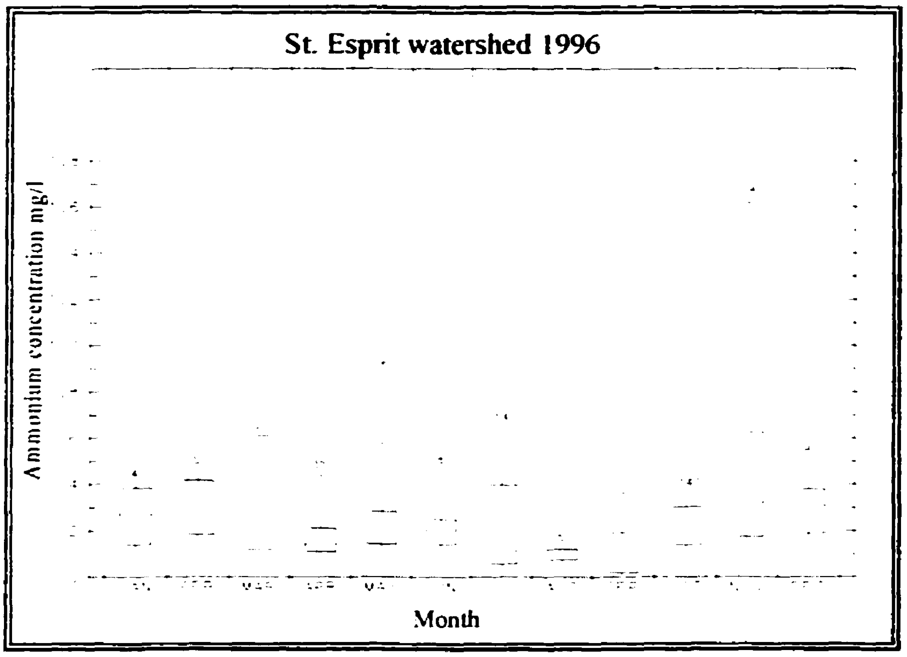

St. Esprit watershed 1996
Ammonium concentration mg/l
Month

Figure B6

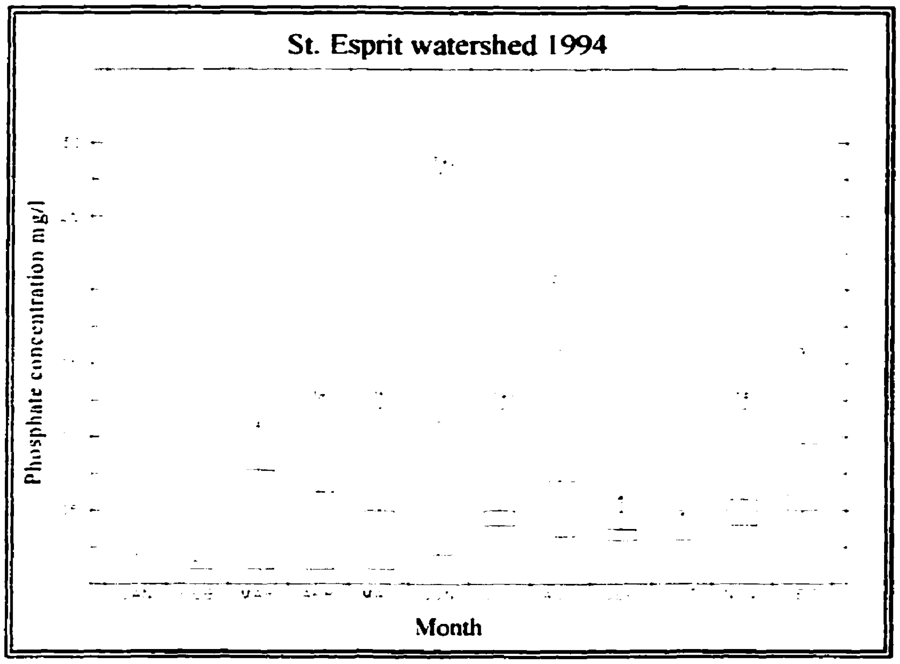


Figure B7

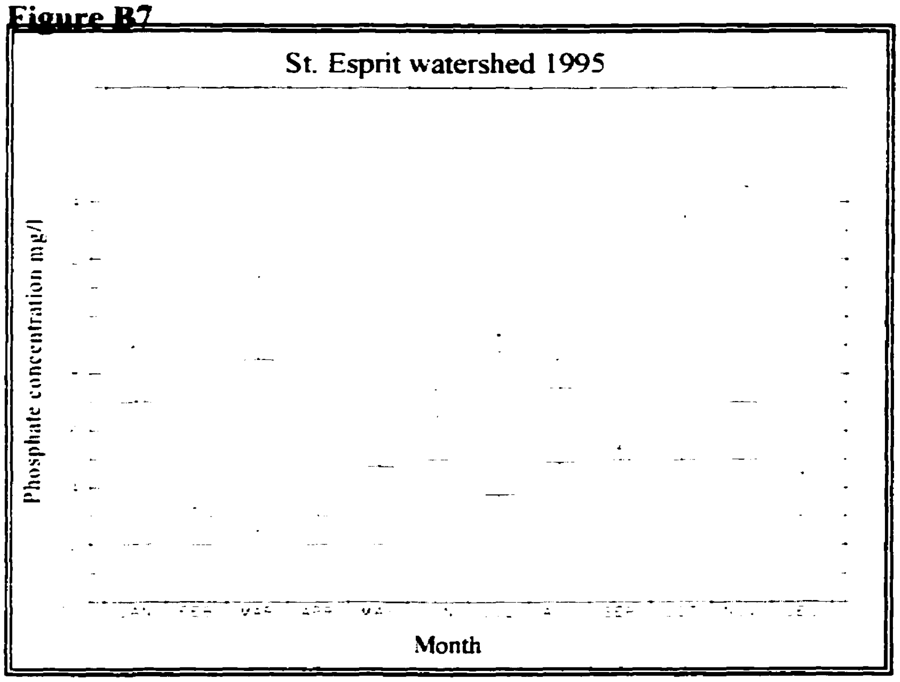


Figure B8

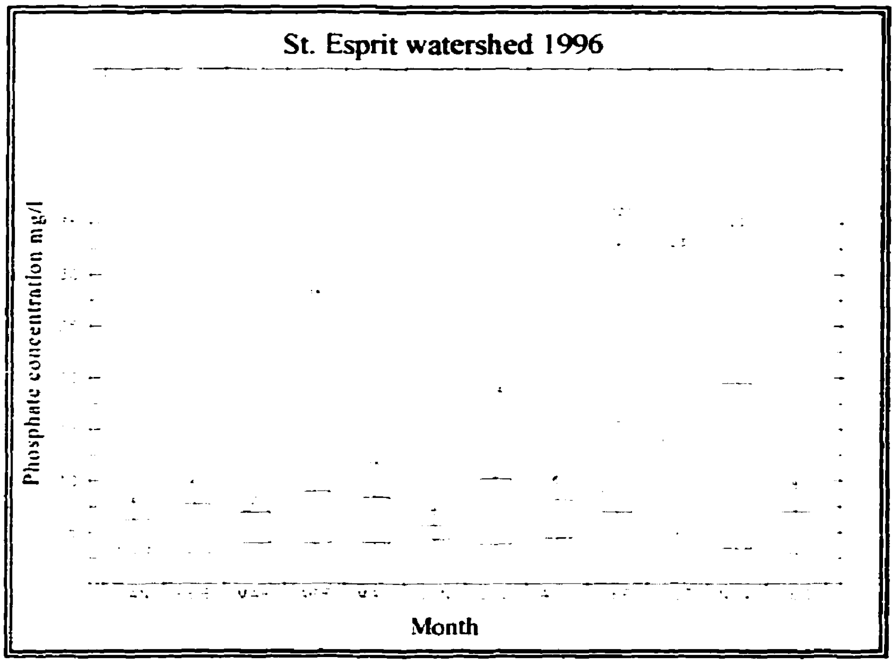

St. Esprit watershed 1996
Phosphate concentration mg/l
Month

Figure B9

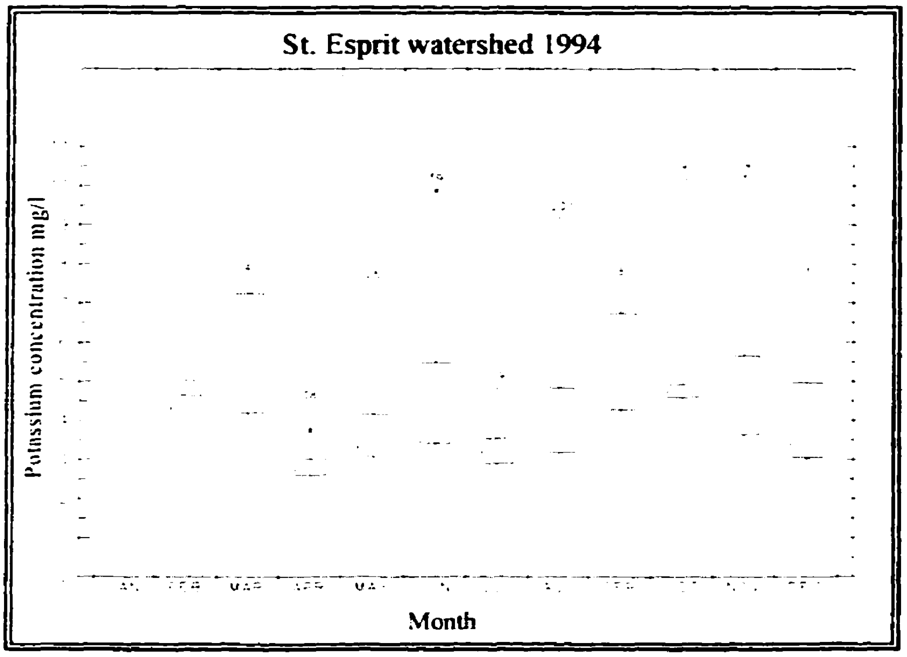


Figure B10

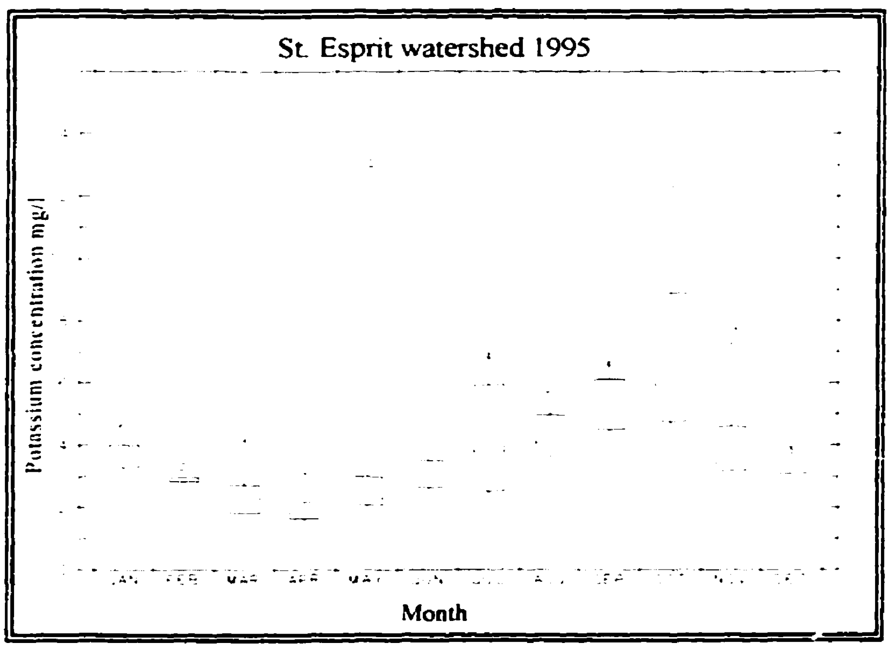


Figure B11

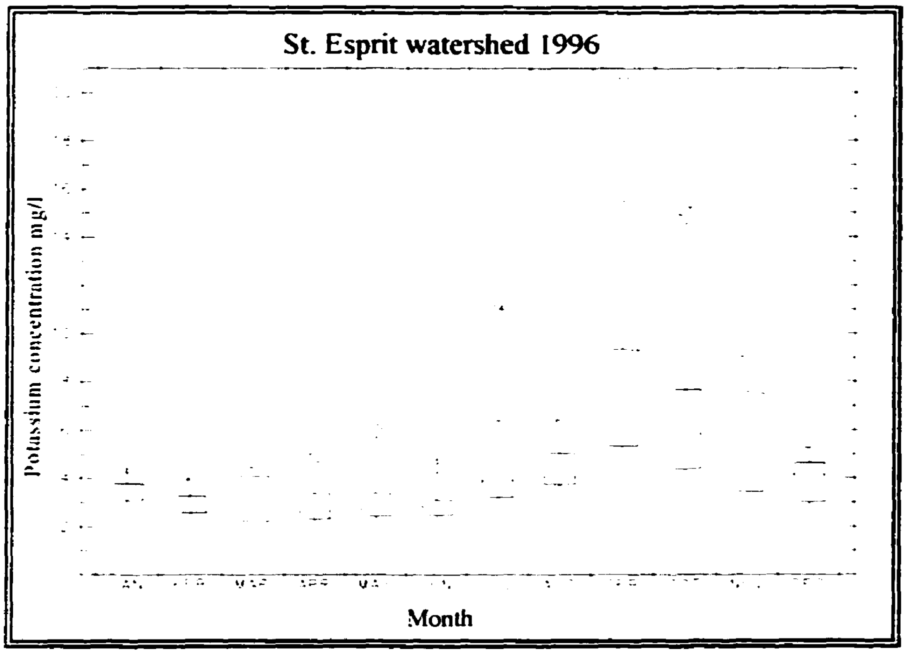

St. Esprit watershed 1996
Potassium concentration mg/l
Month

Figure B12

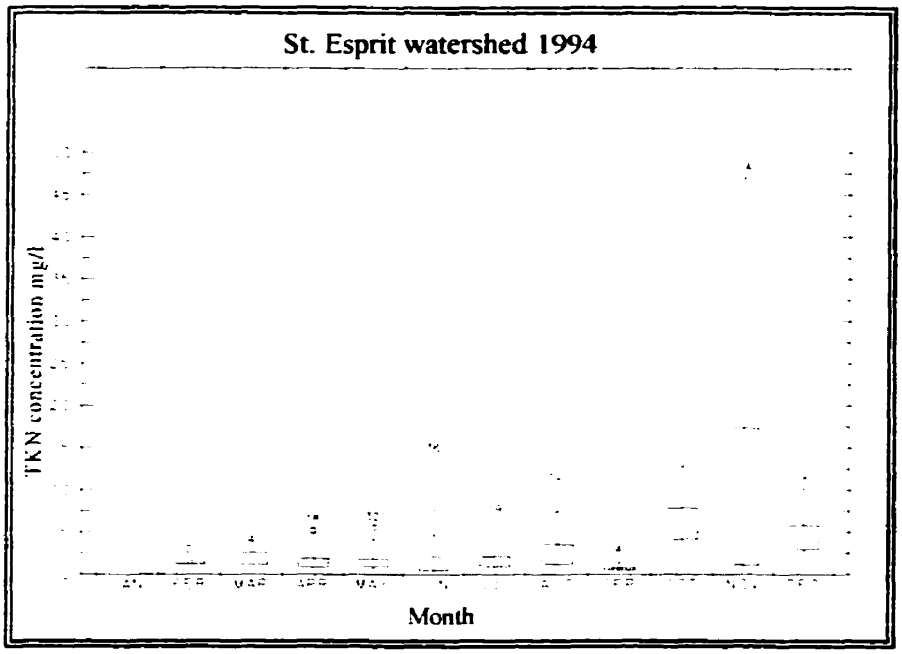


Figure B13

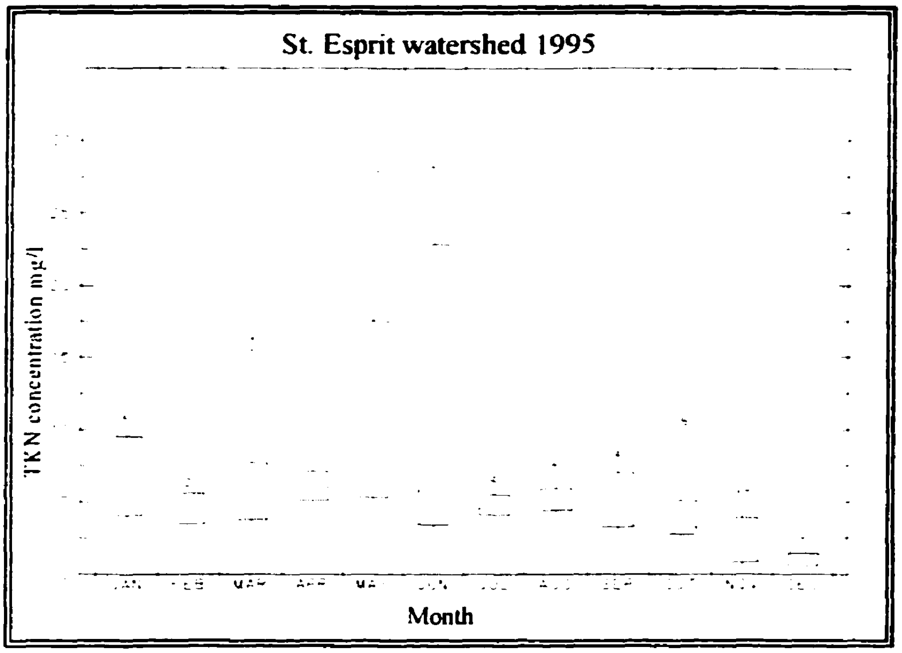


Figure B14

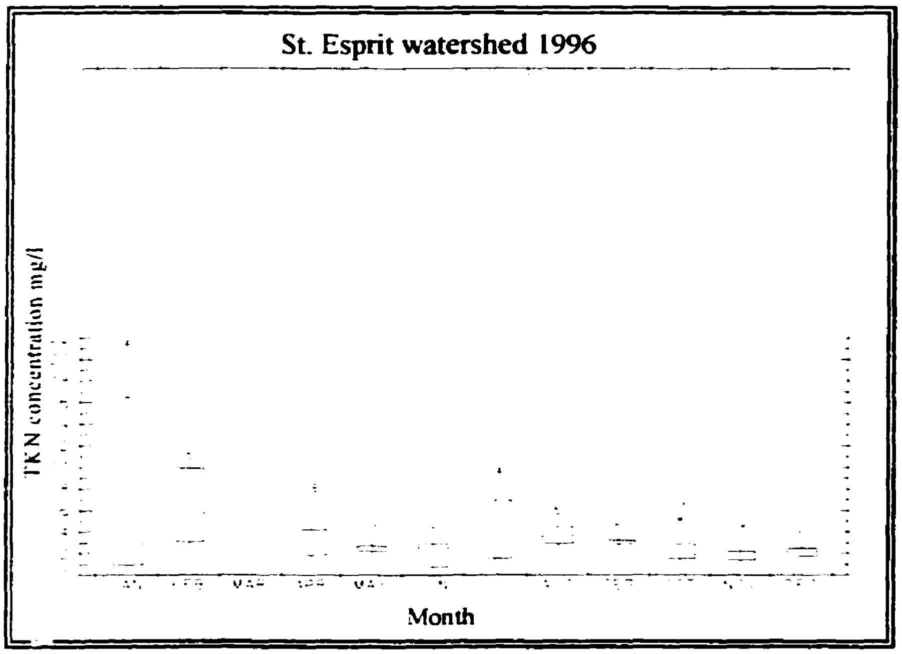


Figure B15

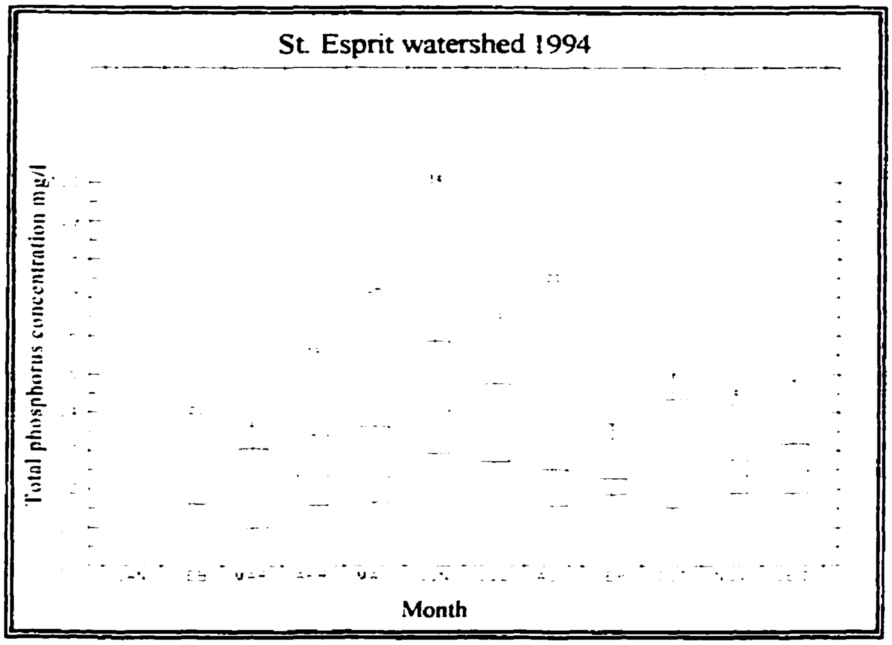


Figure B16

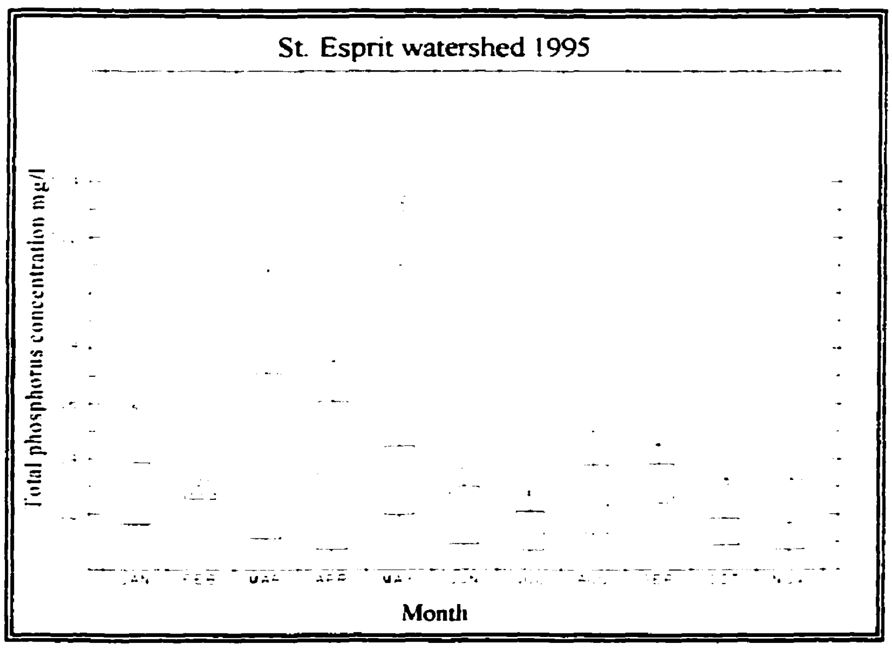
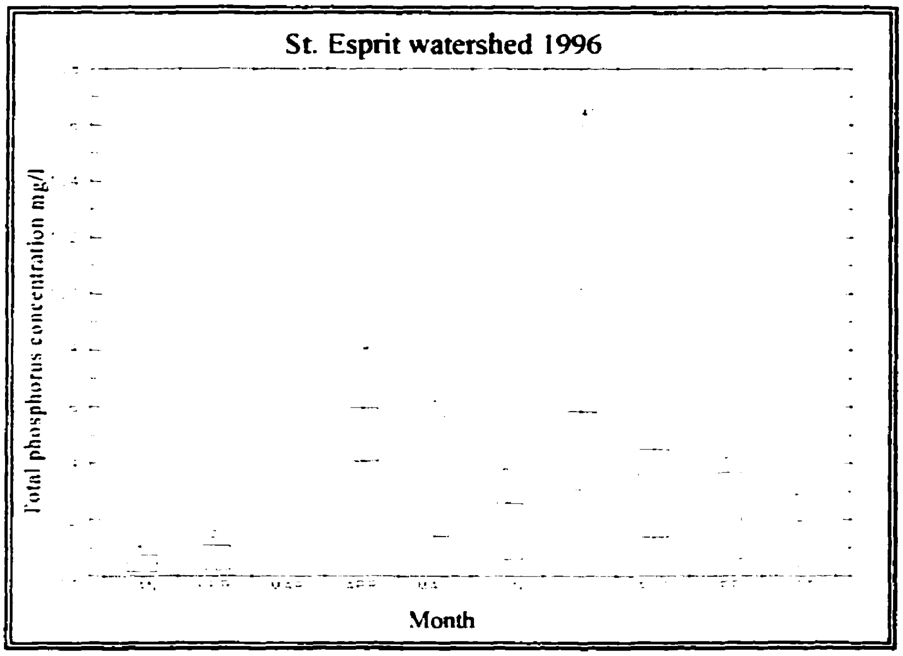


Figure B17


St. Esprit watershed 1996
Total phosphorus concentration mg/l
Month
Figure B18

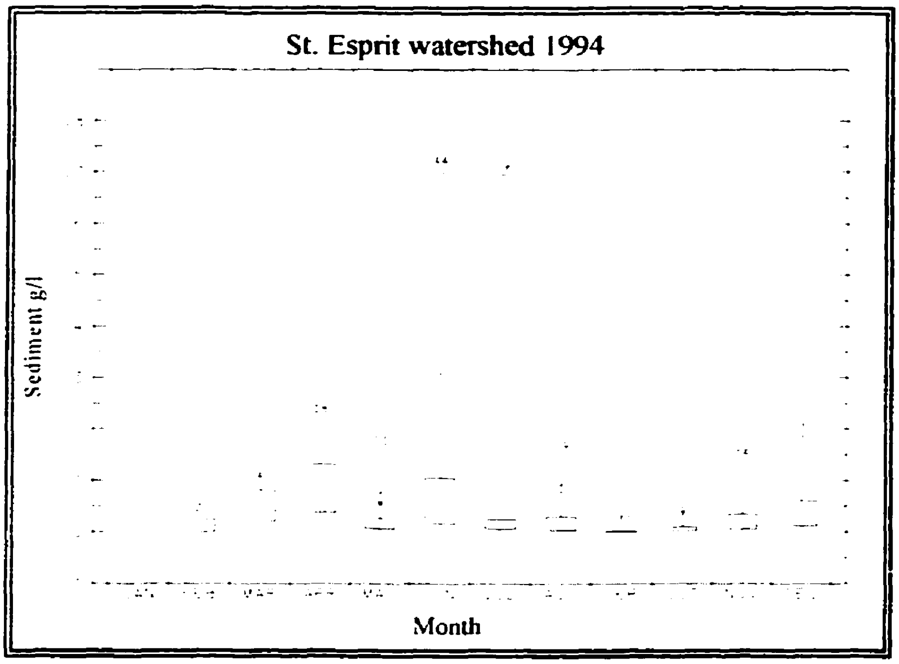


Figure B19

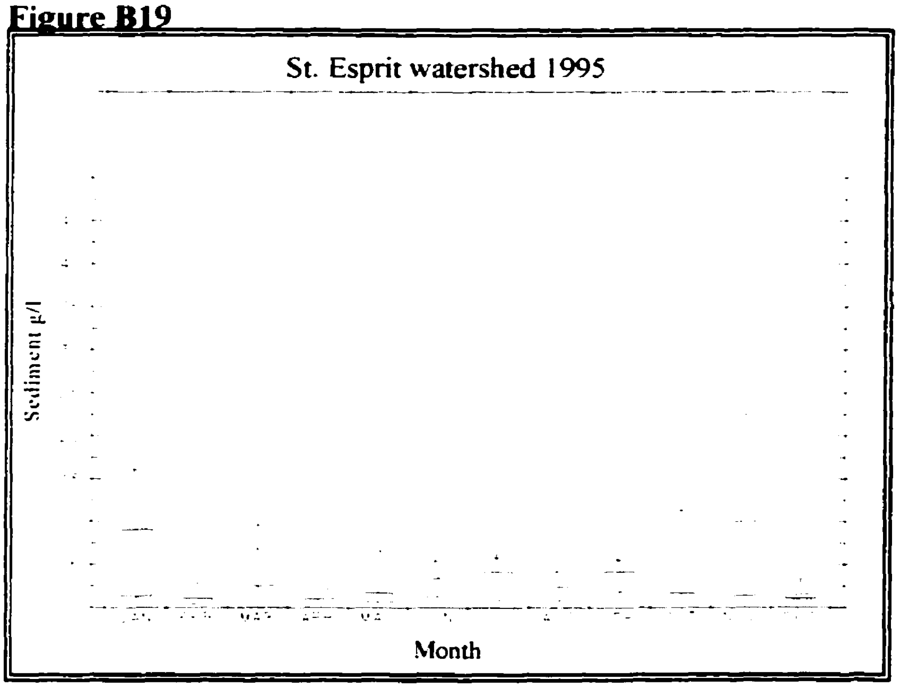


Figure B20

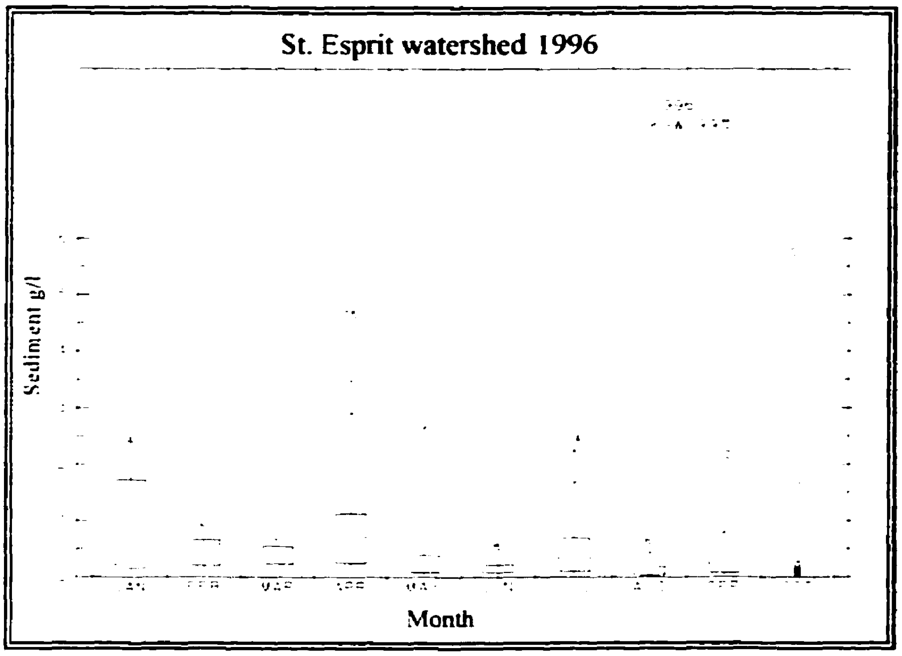


Figure B21

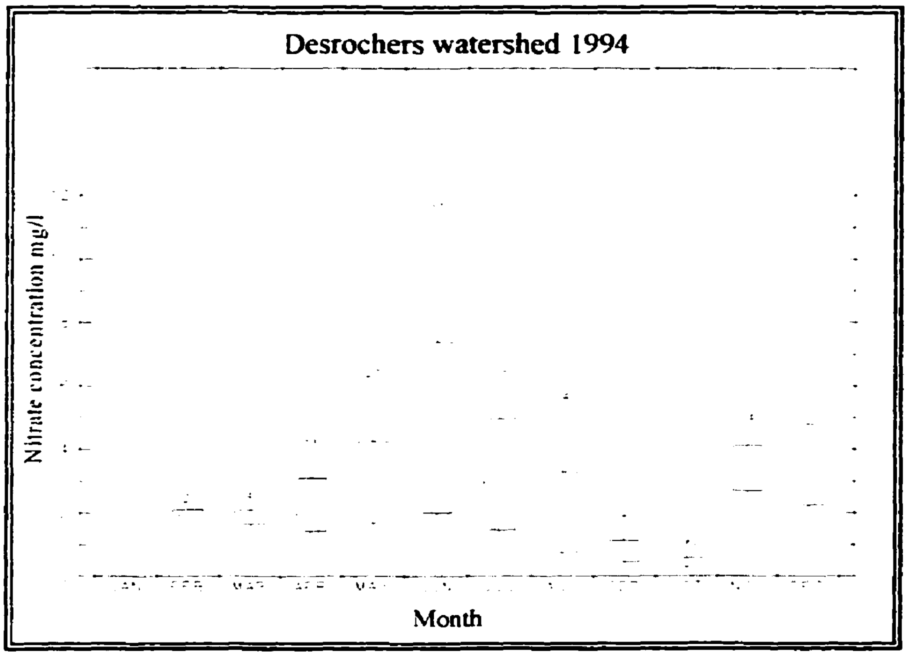


Figure B22

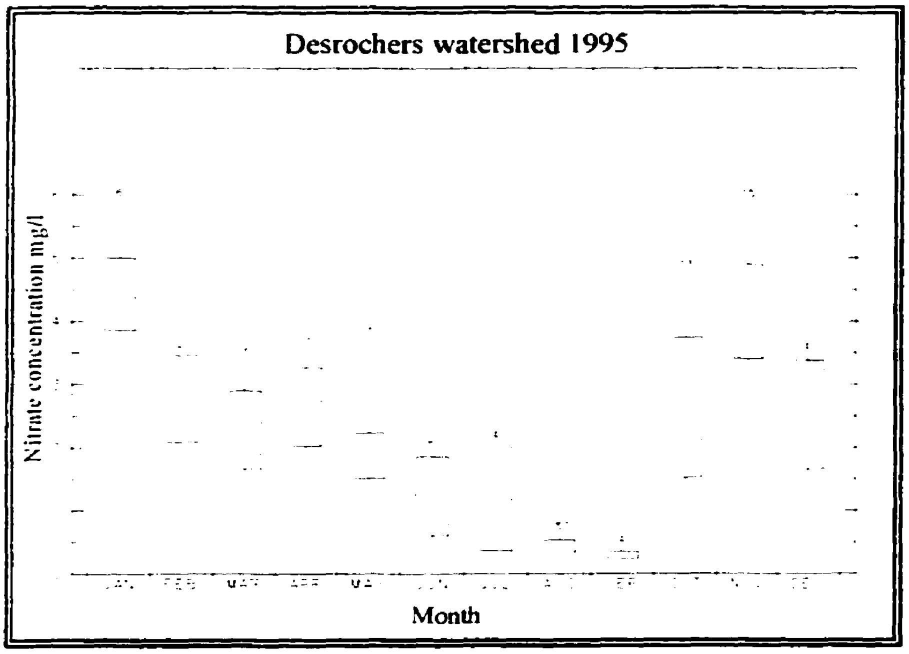
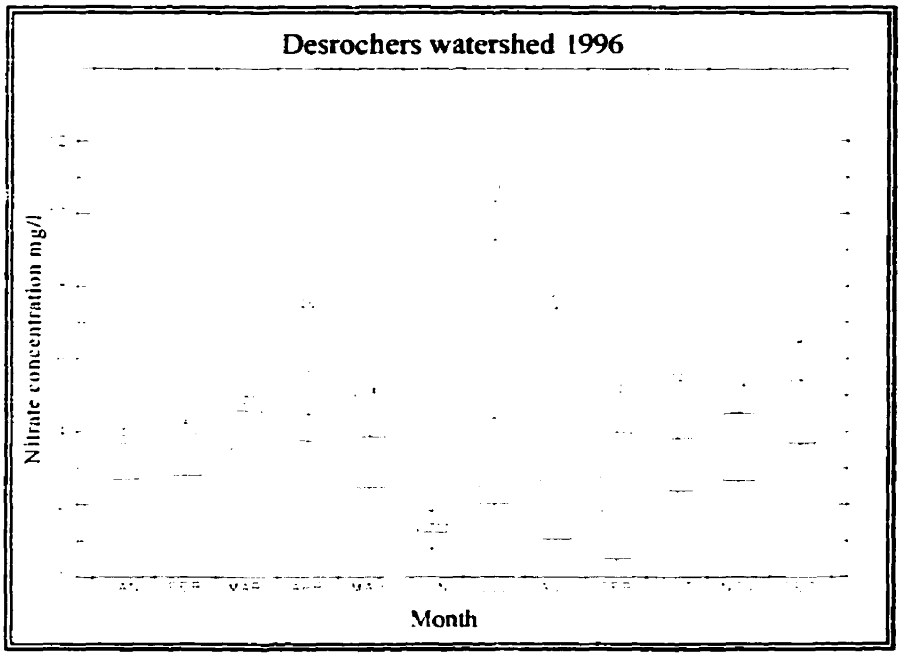


Figure B23



Desrochers watershed 1996
Nitrate concentration mg/l
Month

Figure B24

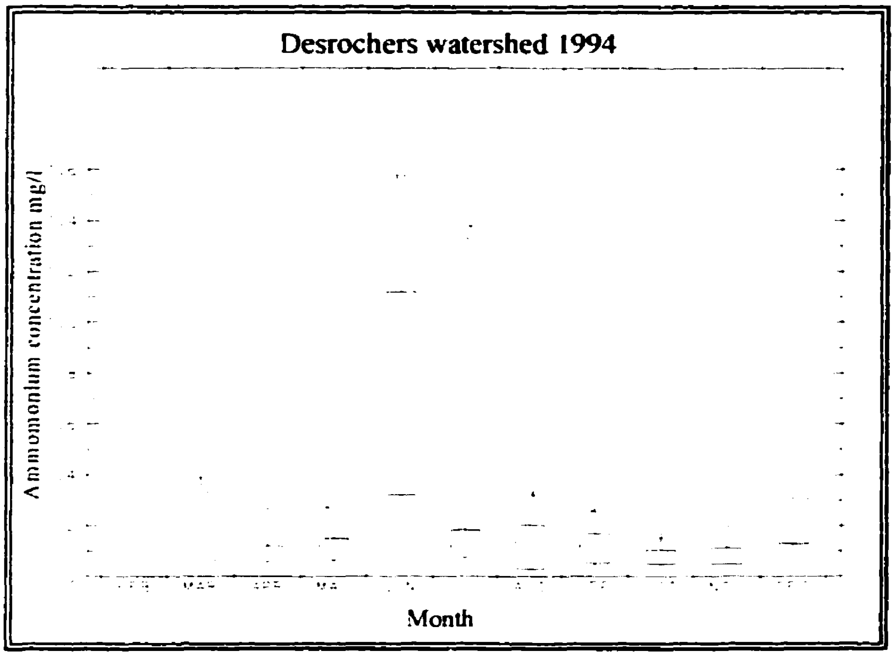


Figure B25

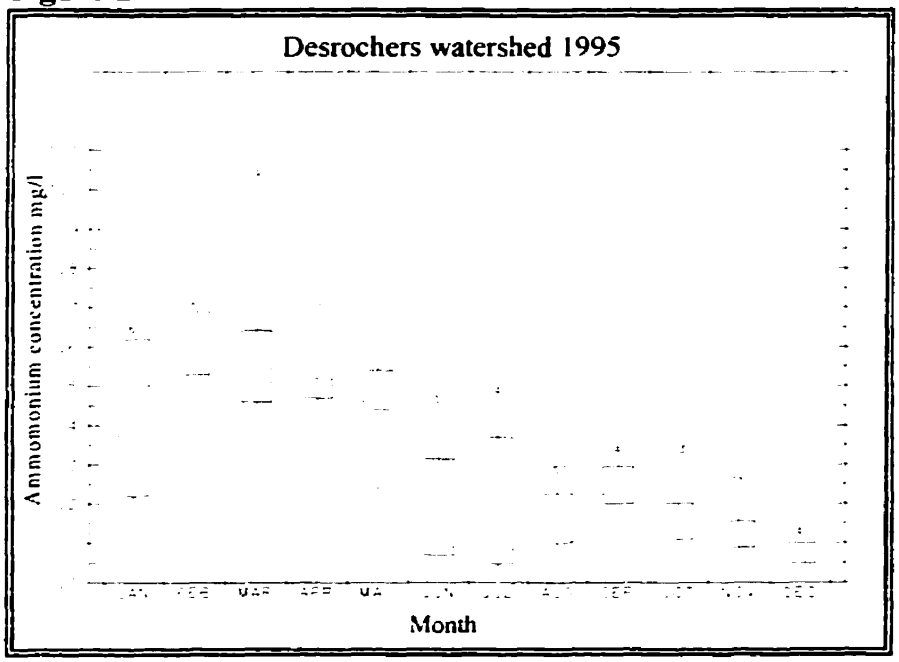
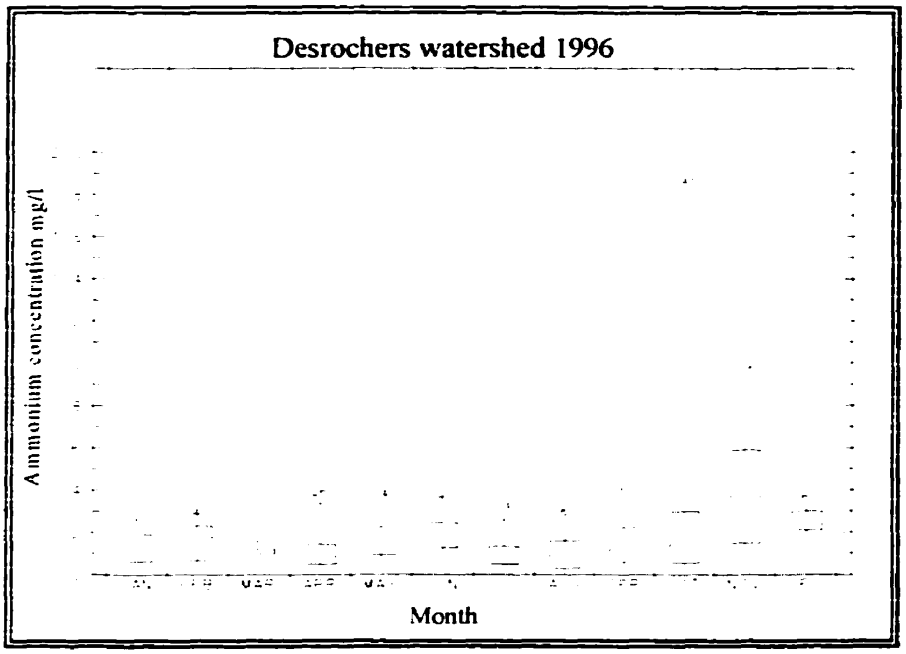


Figure B26


Desrochers watershed 1996
Ammonium concentration mg/l
Month

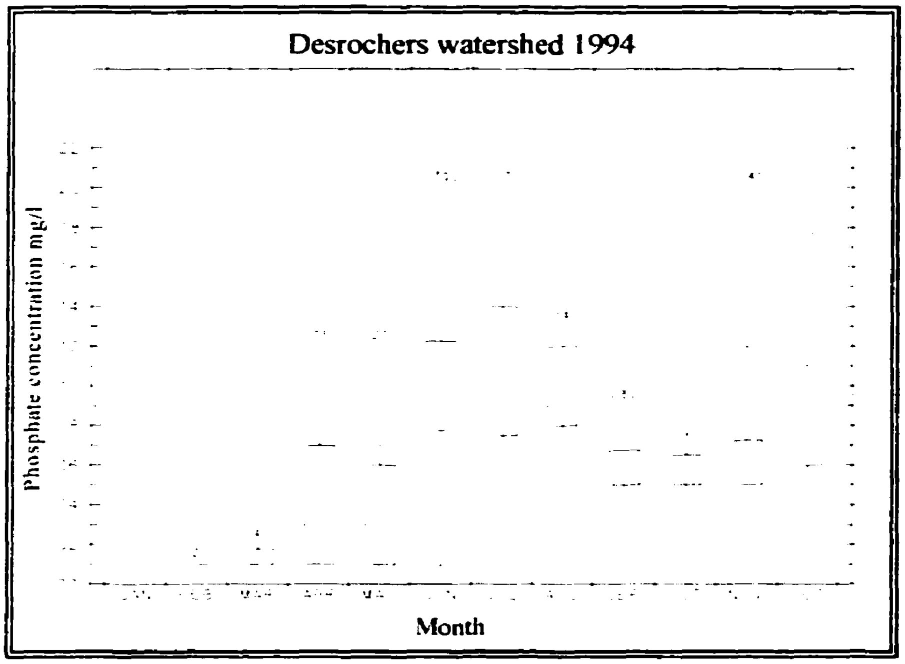


Figure B28

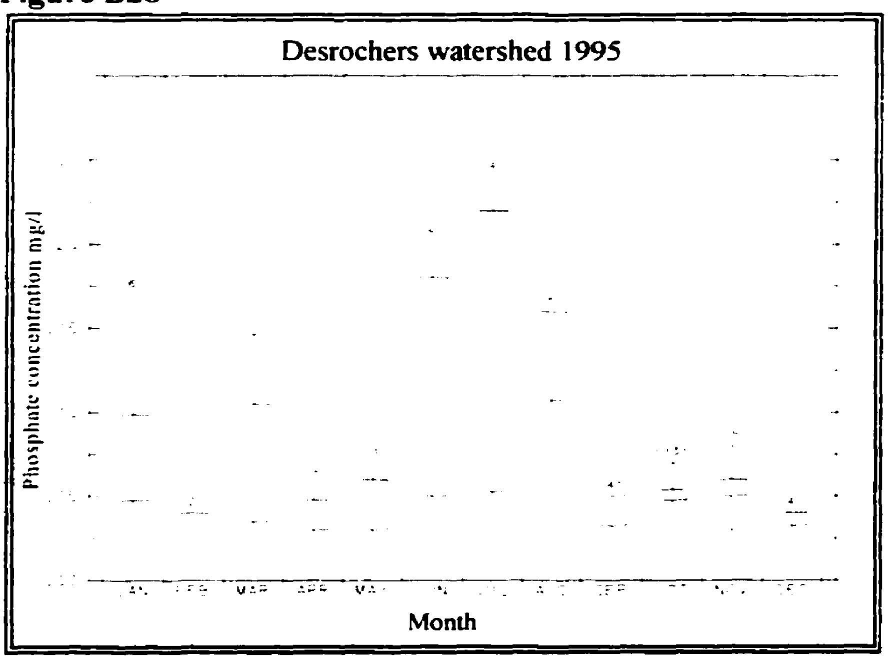


Figure B29

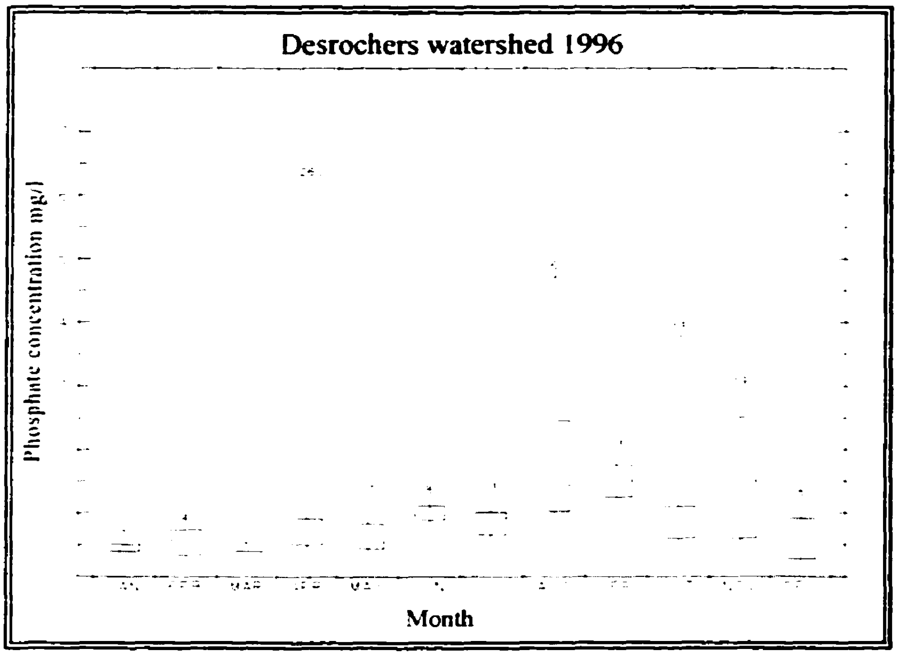

Desrochers watershed 1996
Phosphate concentration mg/l
Month

Figure B30

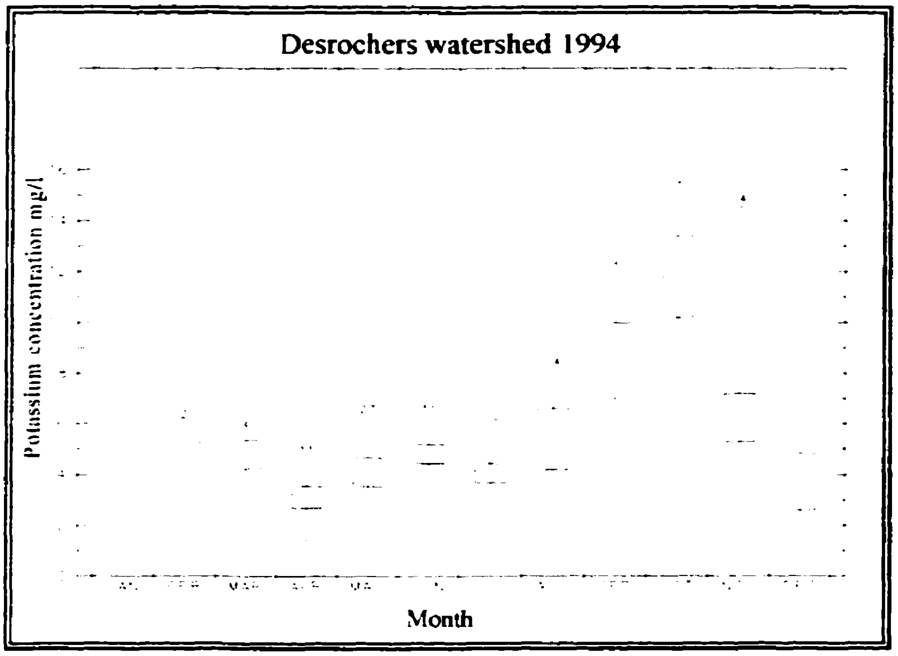


Figure B31

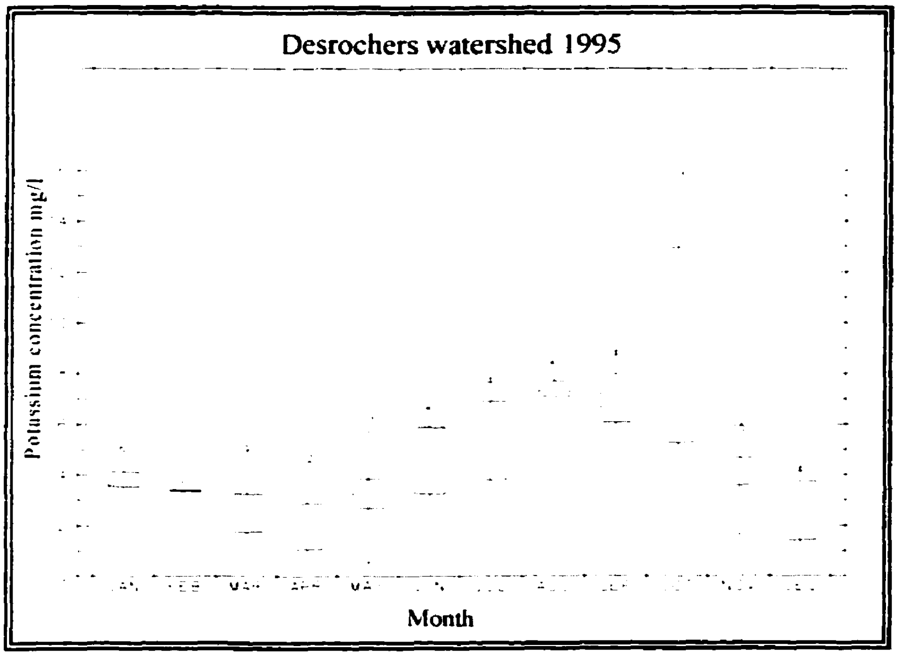


Figure B32

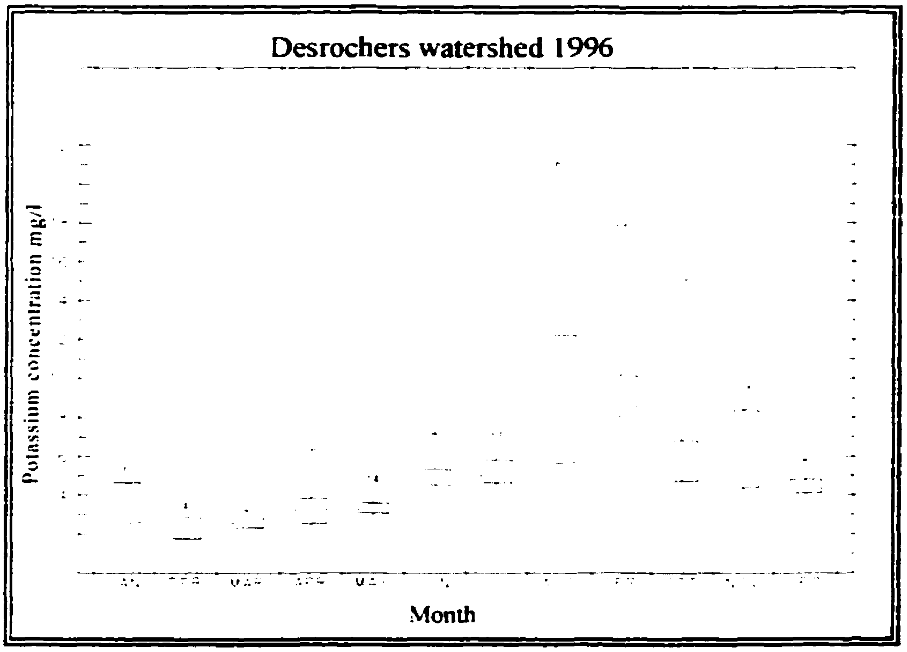

Desrochers watershed 1996
Potassium concentration mg/l
Month

Figure B33

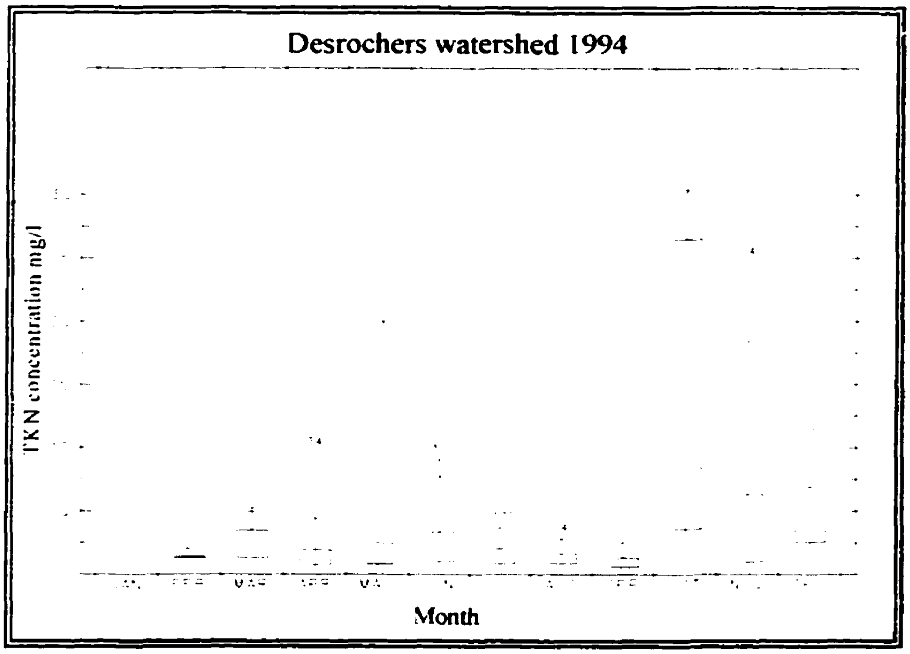


Figure B34

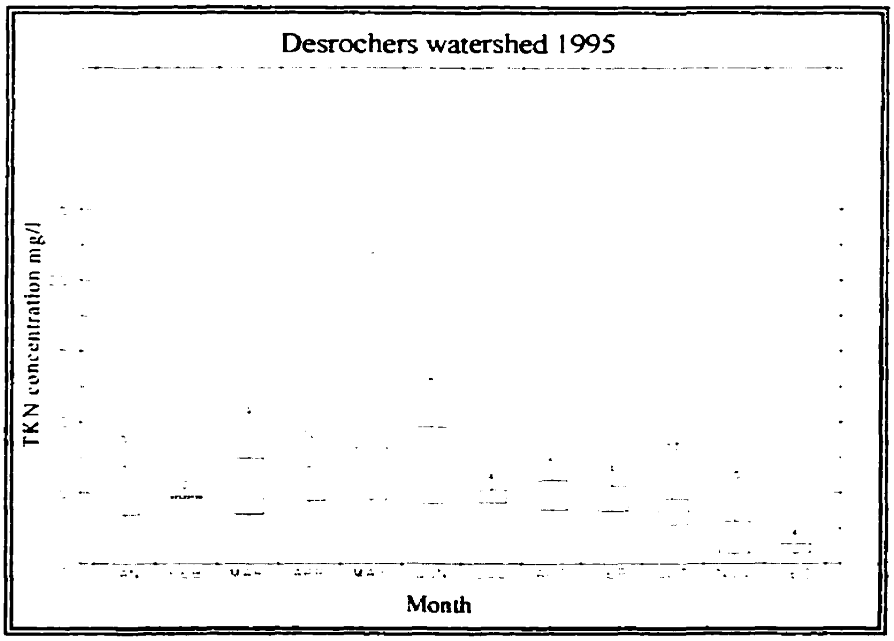


Figure B35

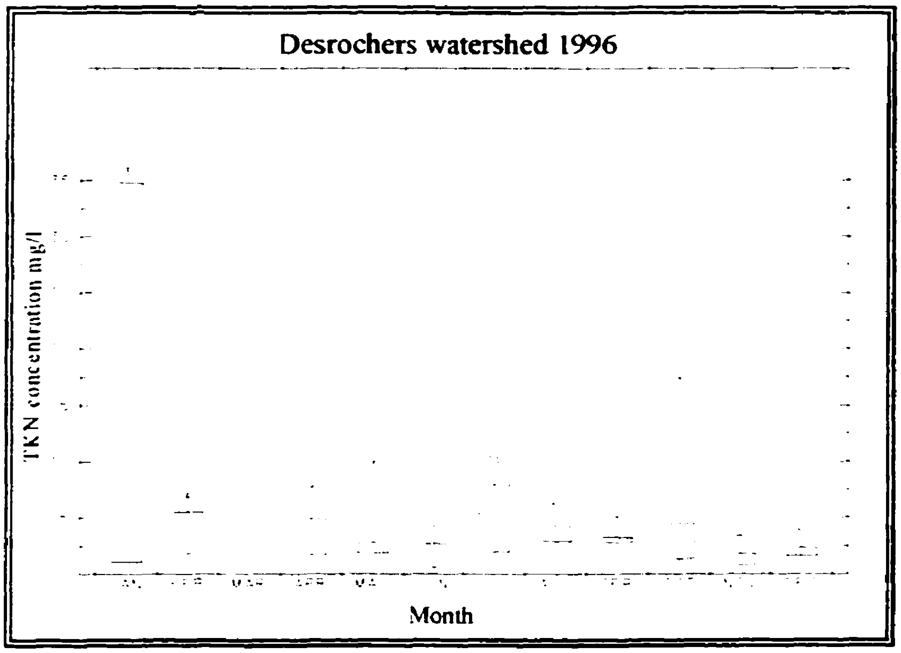


Figure B36

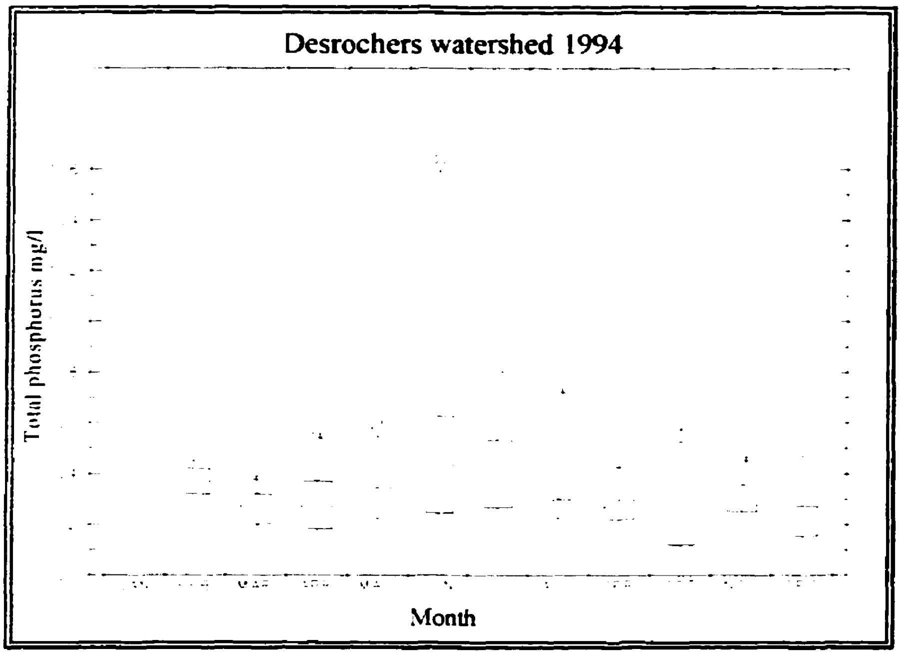


Figure B37

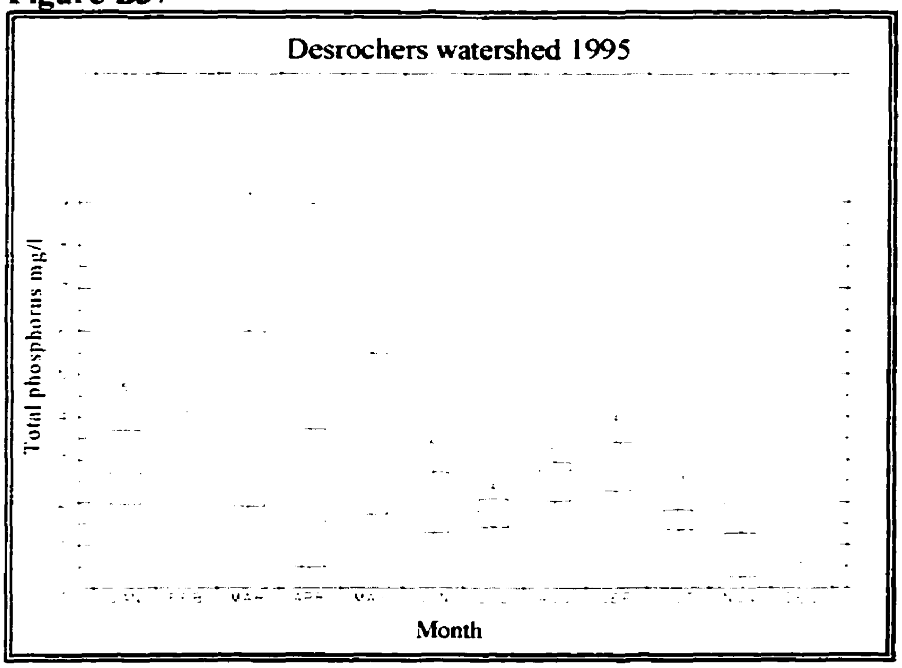


Figure B38

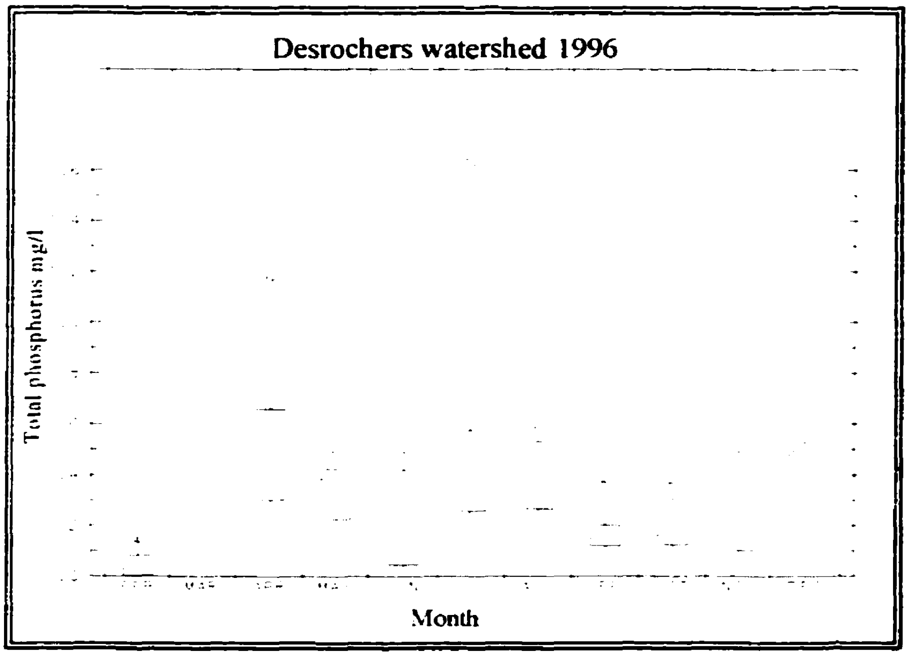


Figure B39

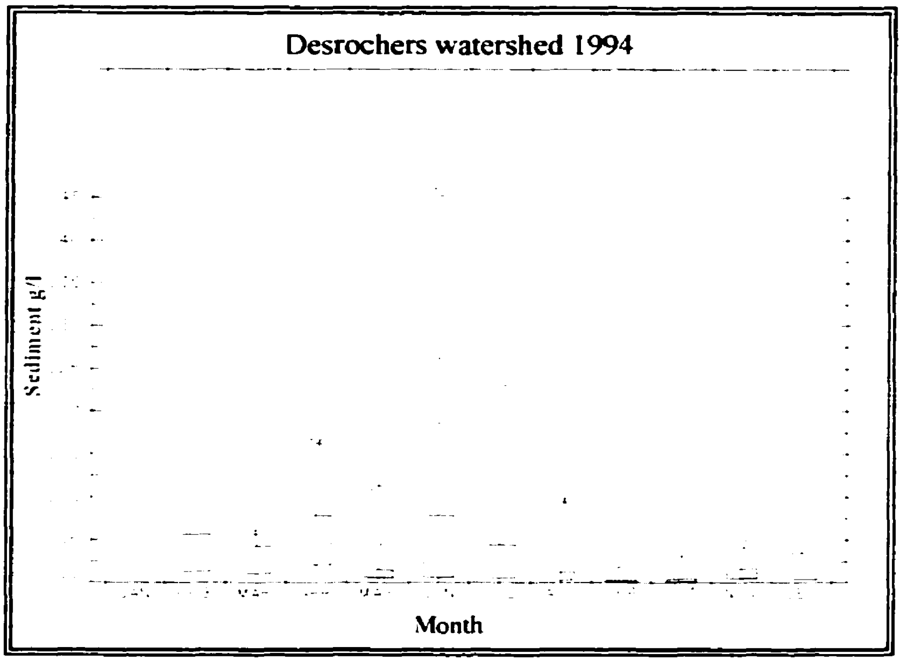


Figure B40

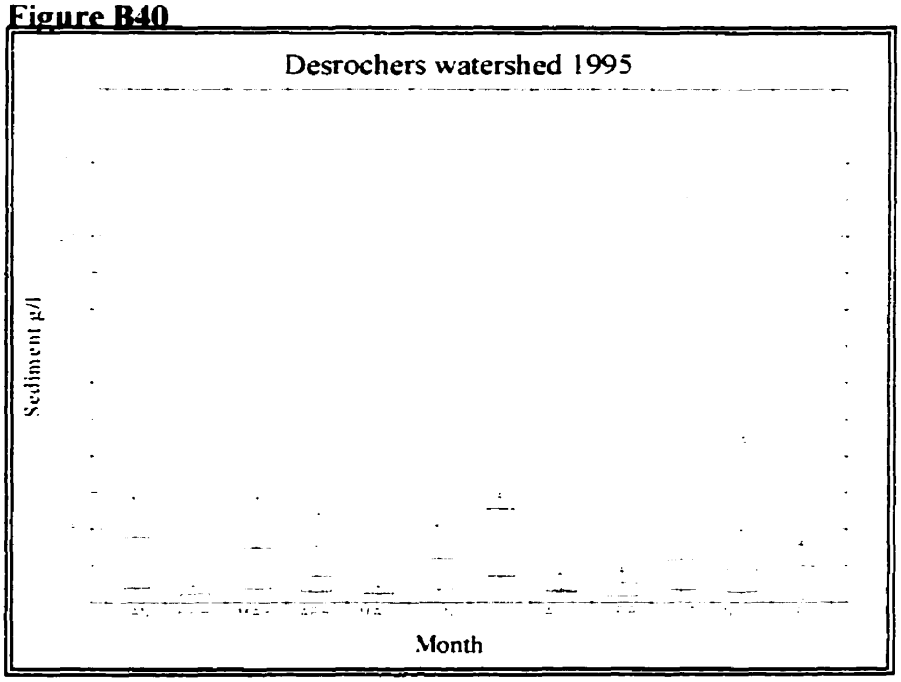


Figure B41

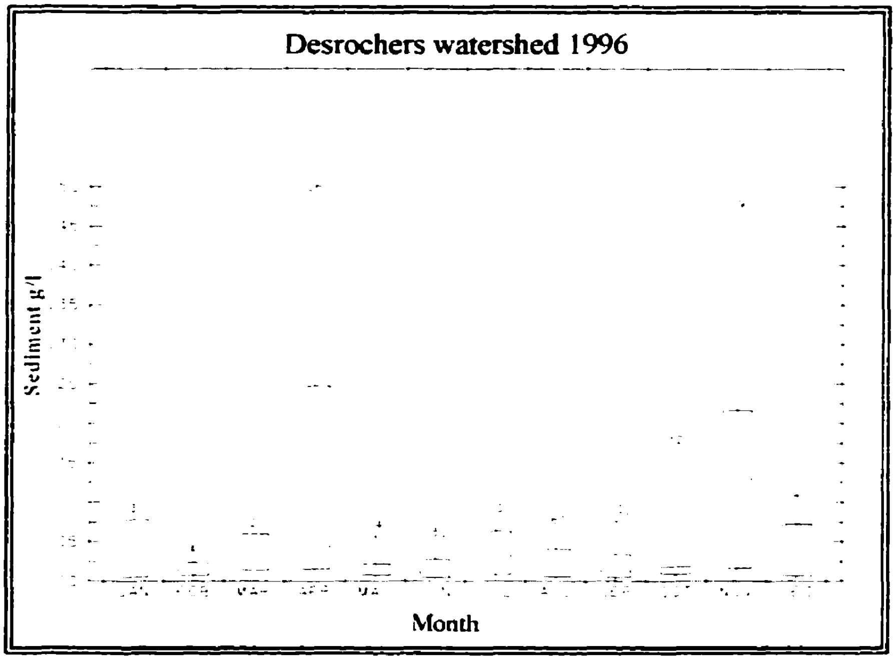


Figure B42

Appendix C
Q – Q plots for all samples at
St. Esprit and Desrochers

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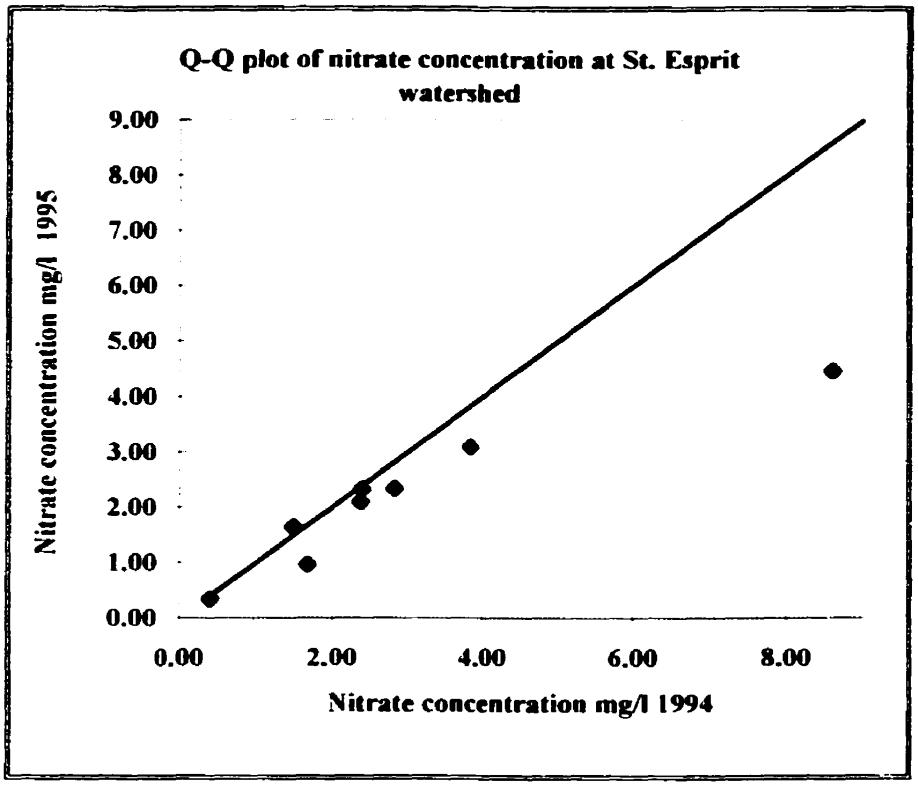


Figure C 1

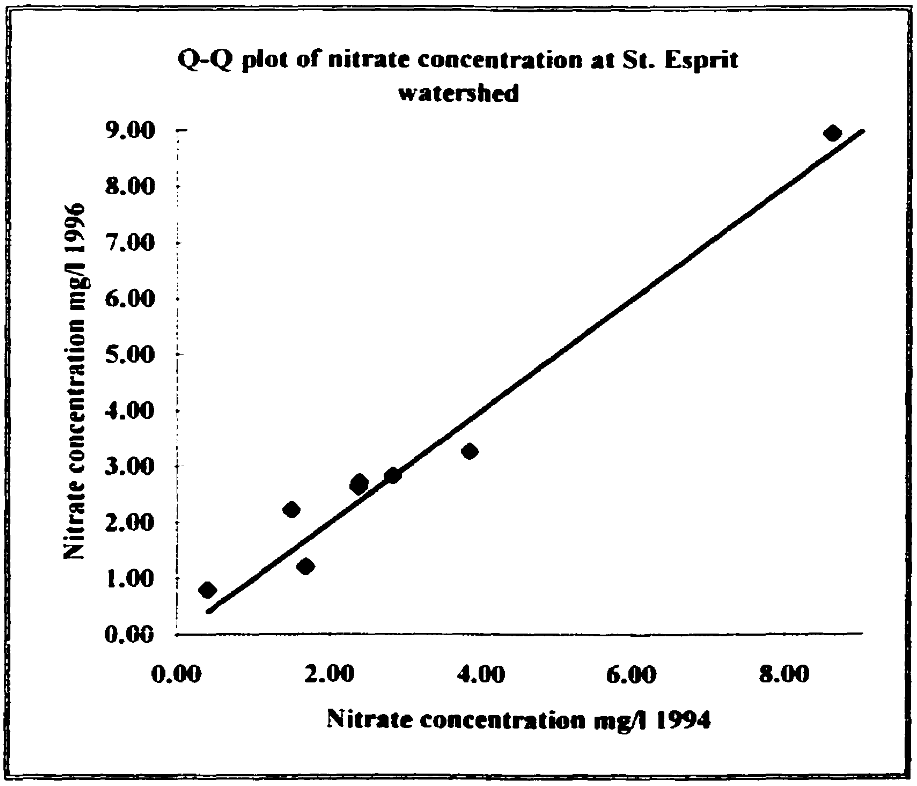


Figure C 2

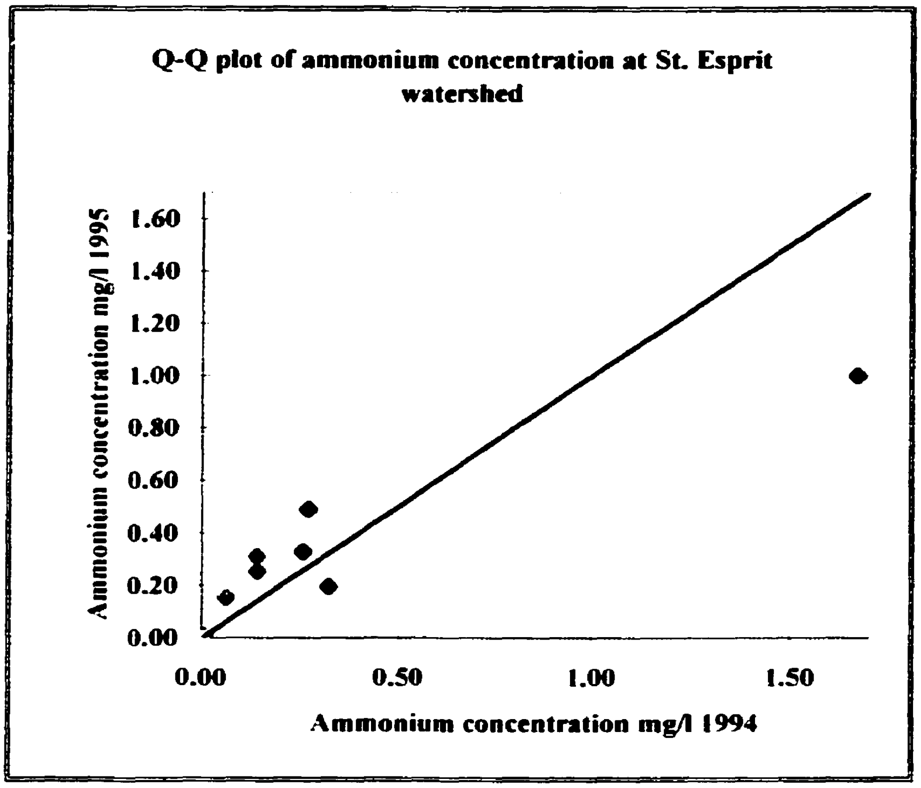


Figure C 3

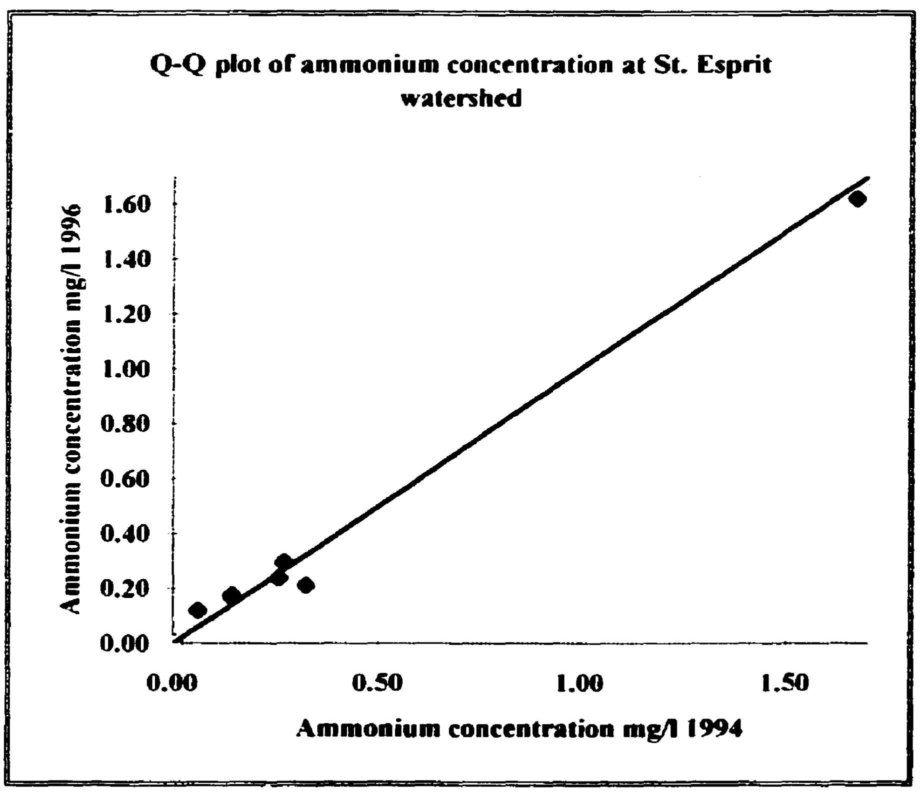


Figure C 4

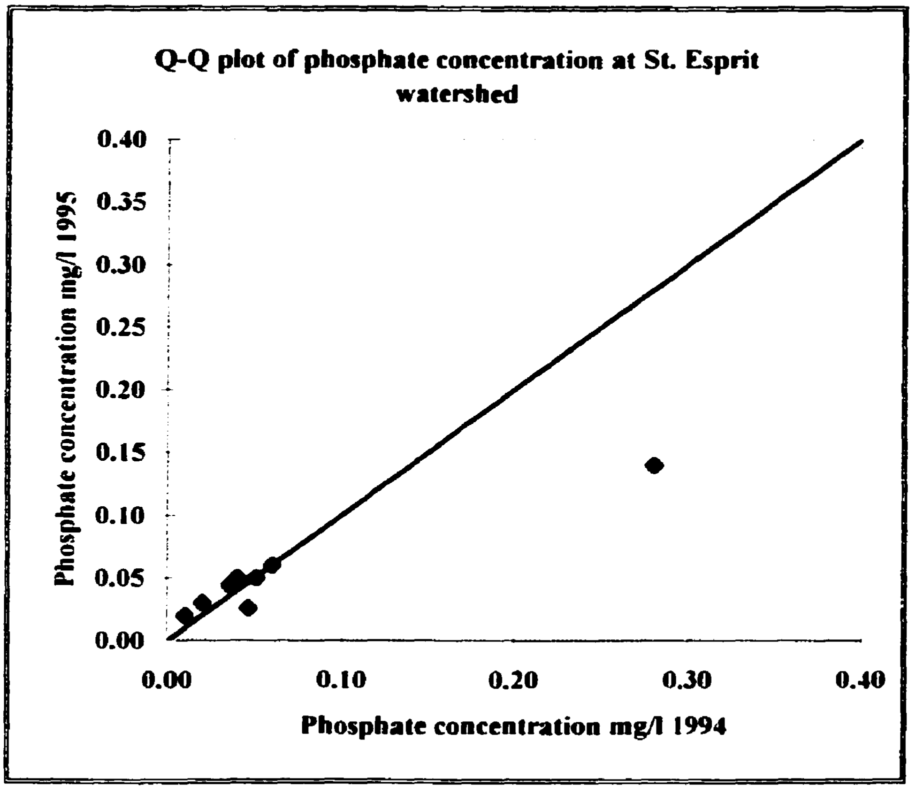


Figure C 5

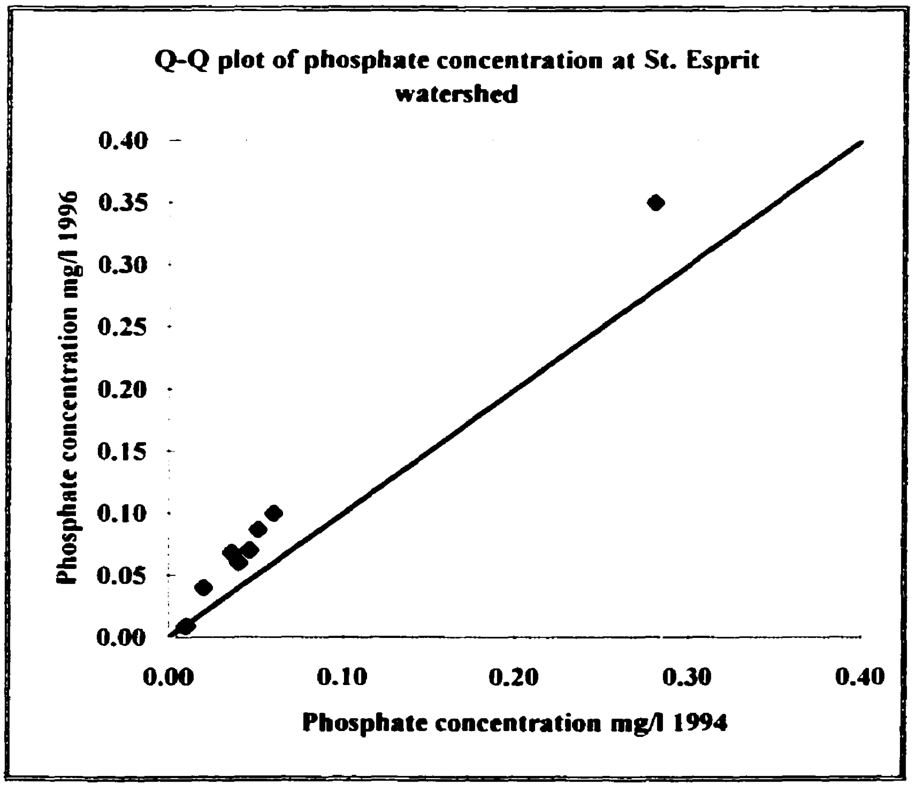


Figure C 6

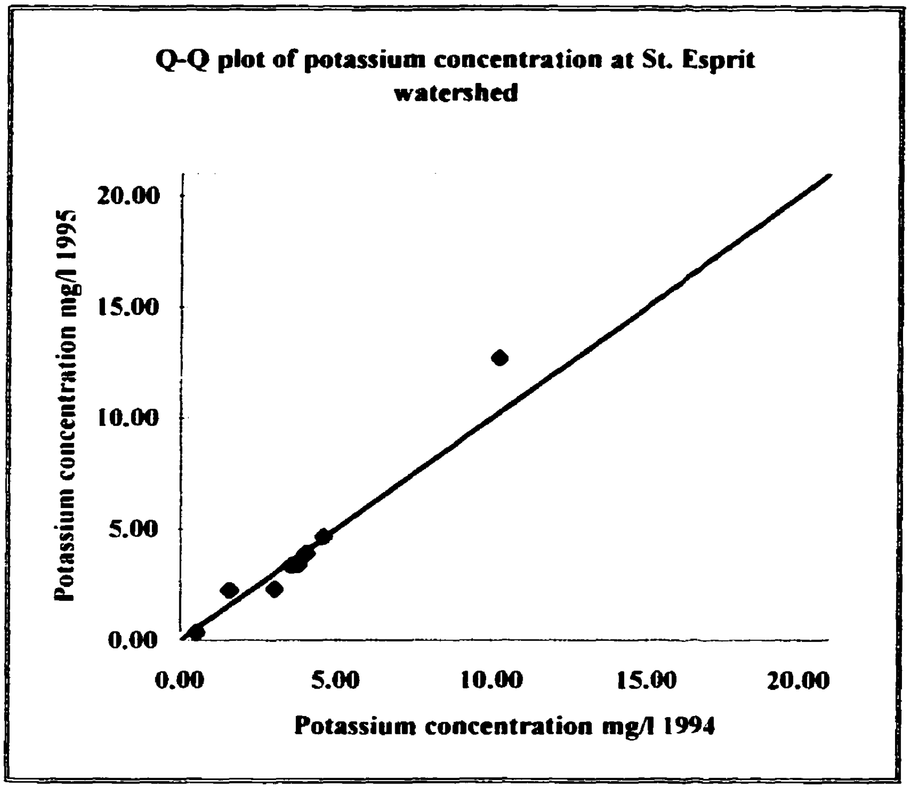


Figure C 7

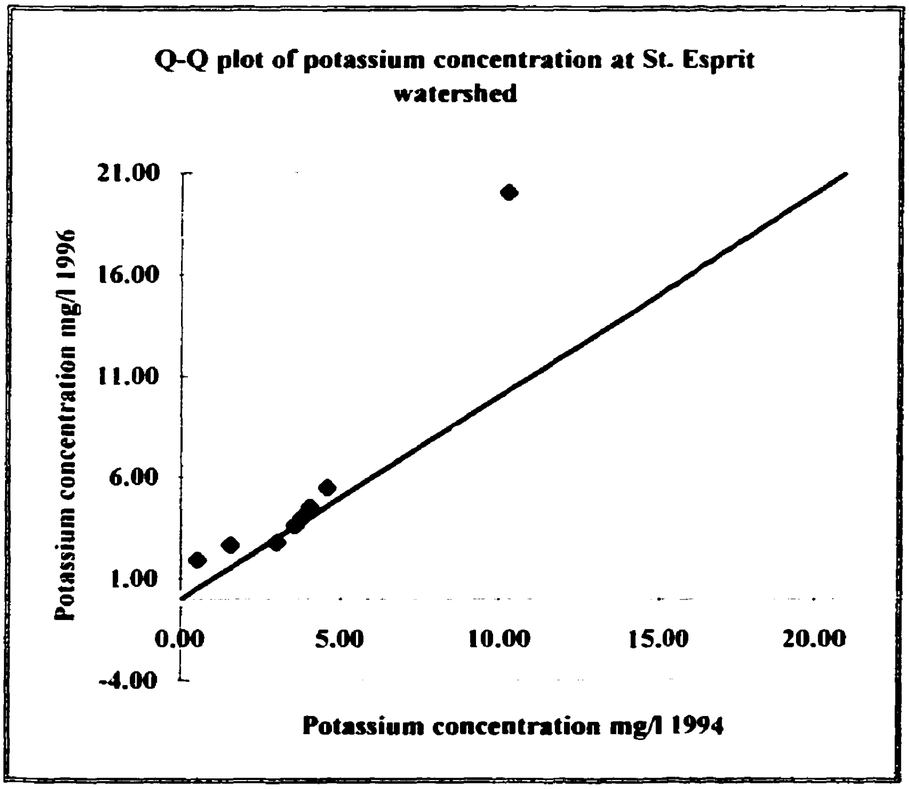


Figure C 8

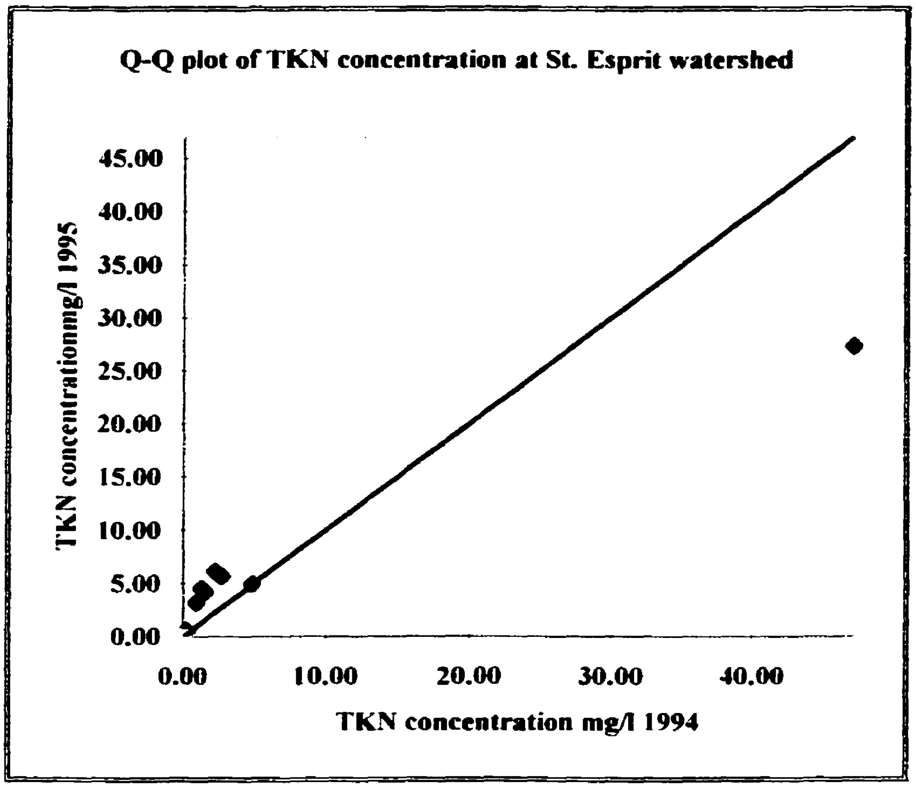


Figure C 9

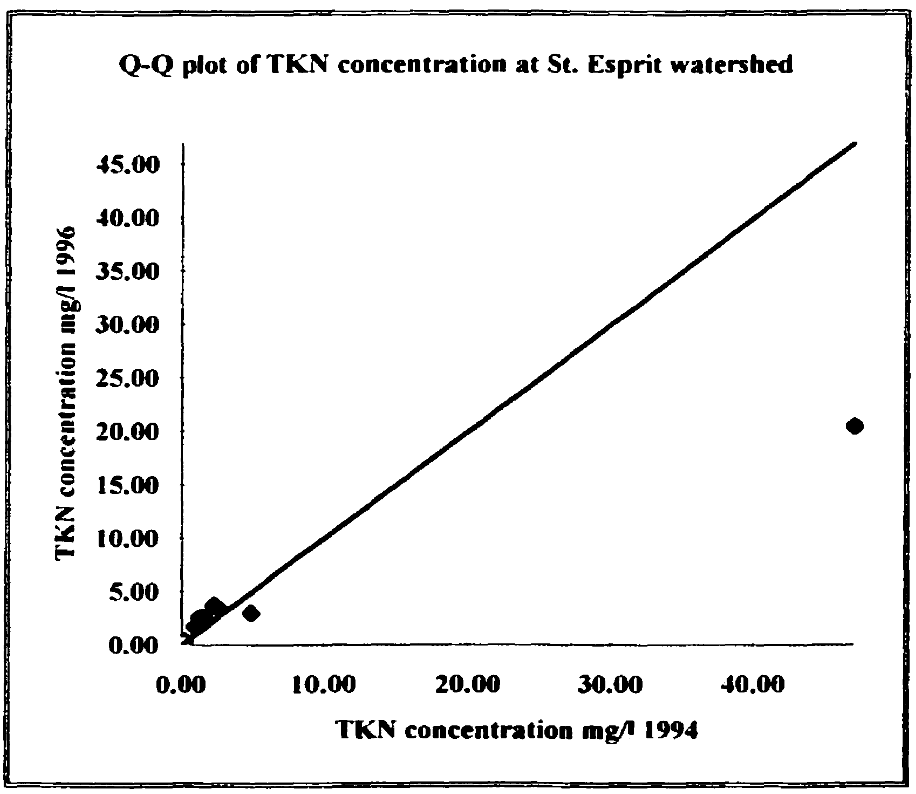


Figure C 10

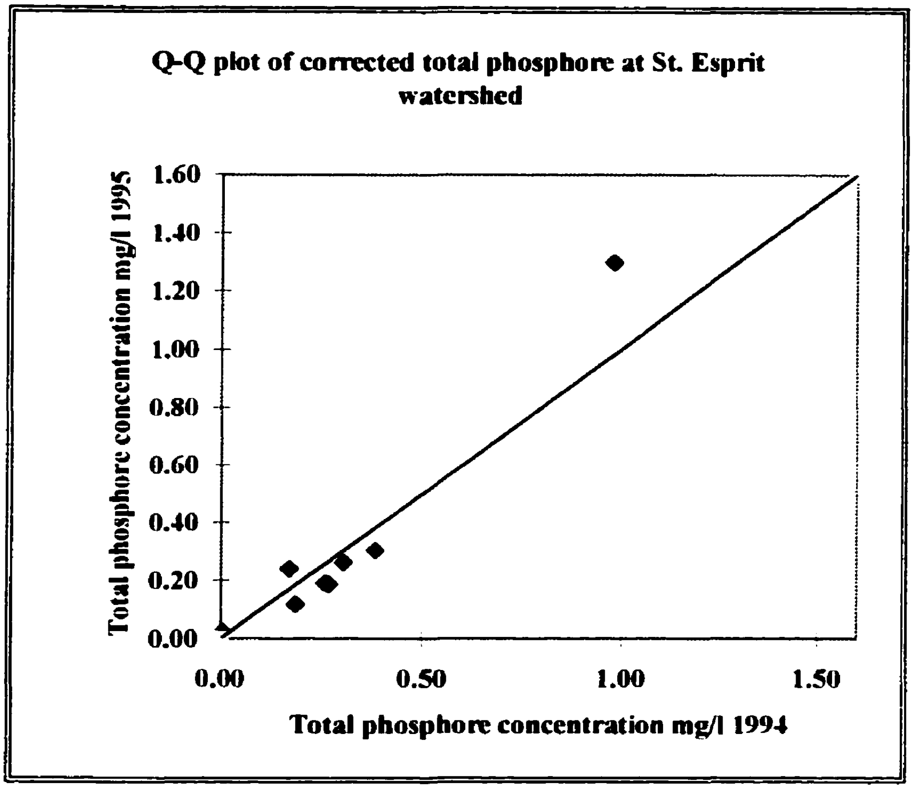


Figure C 11

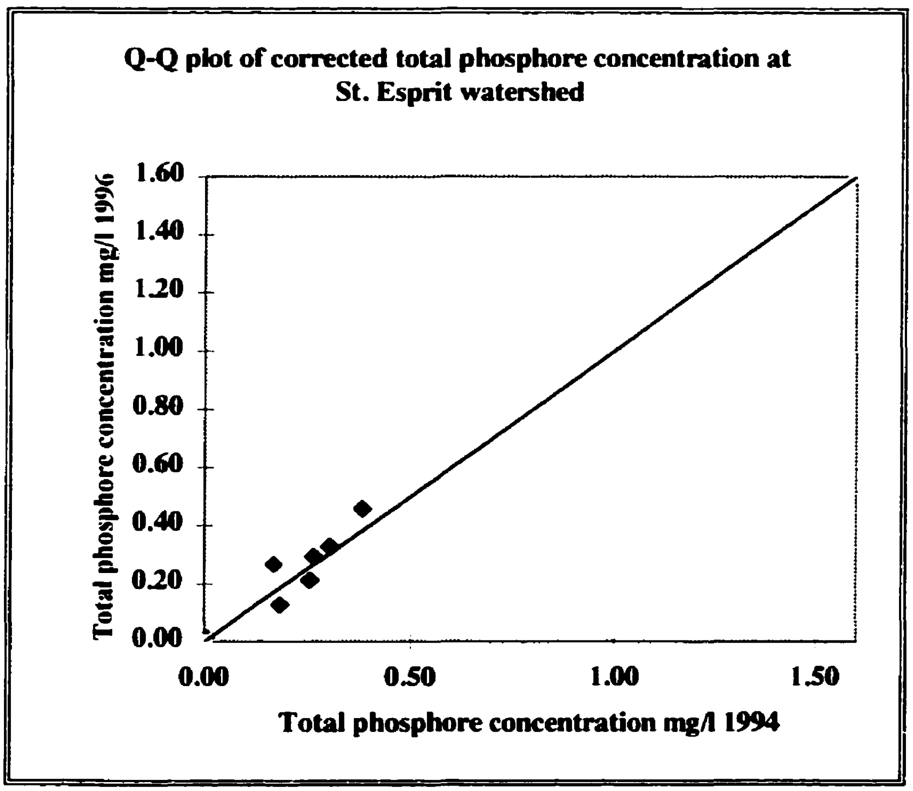


Figure C 12

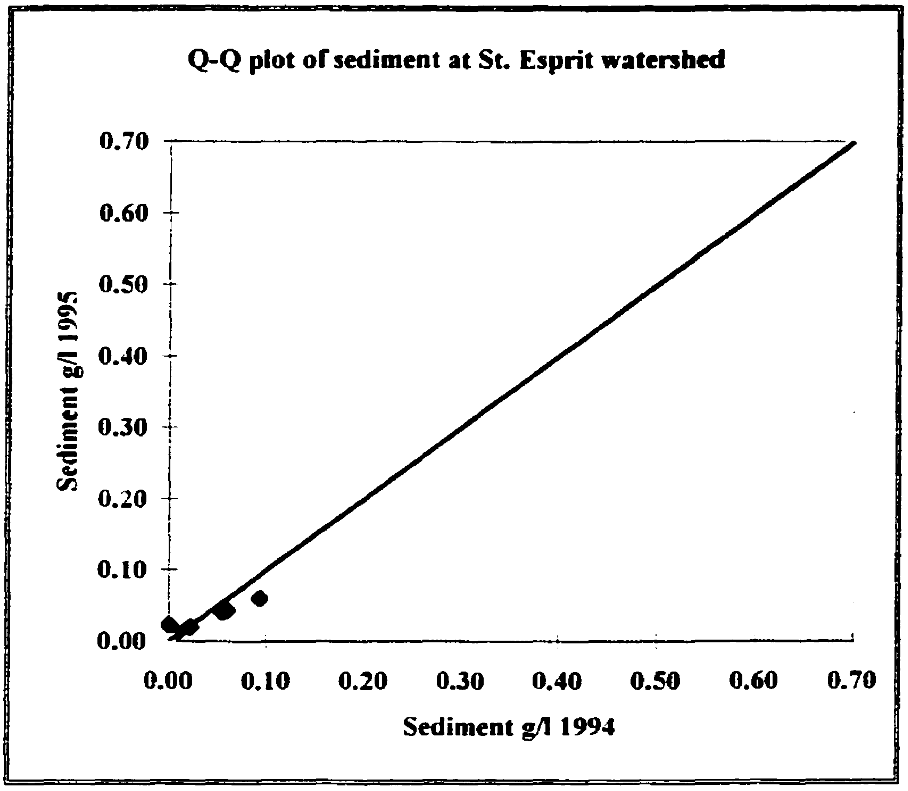


Figure C 13

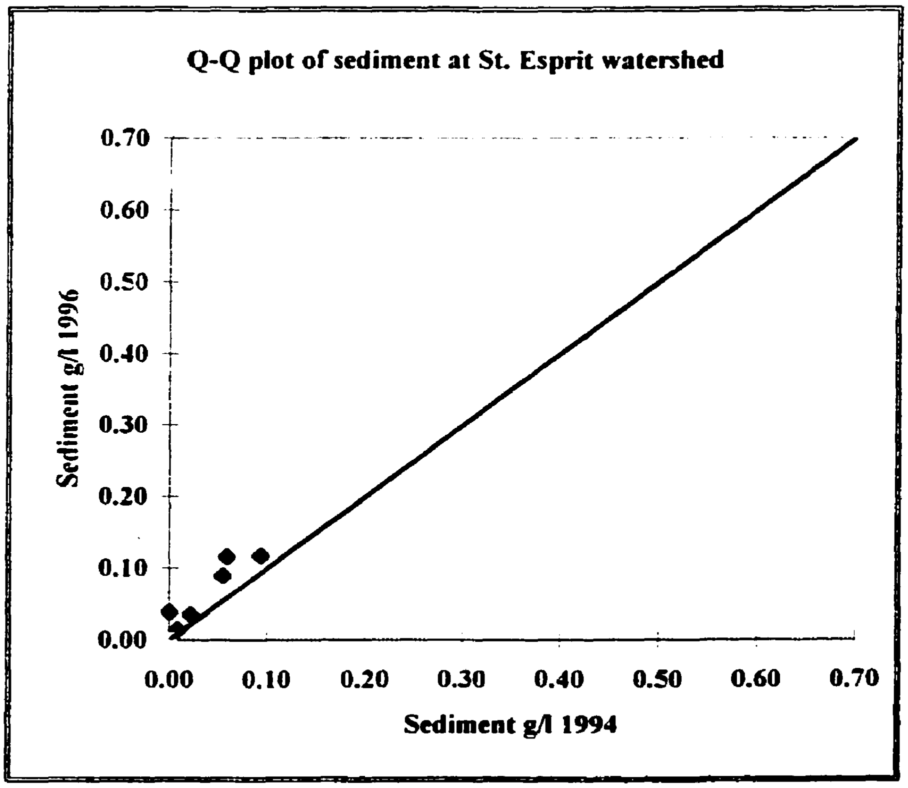


Figure C 14

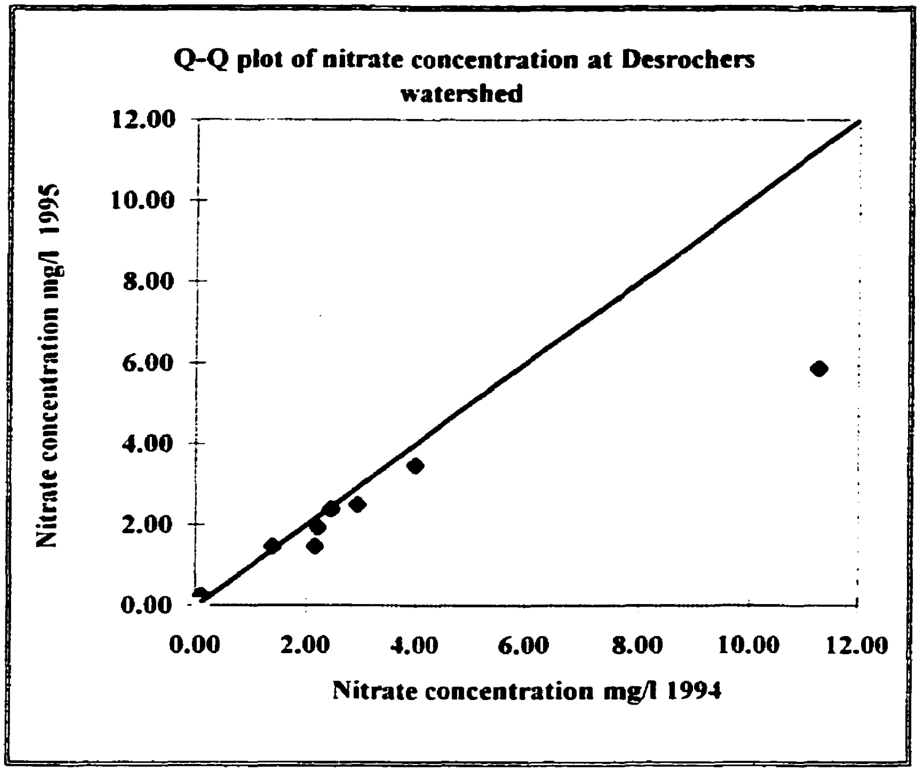


Figure C 15

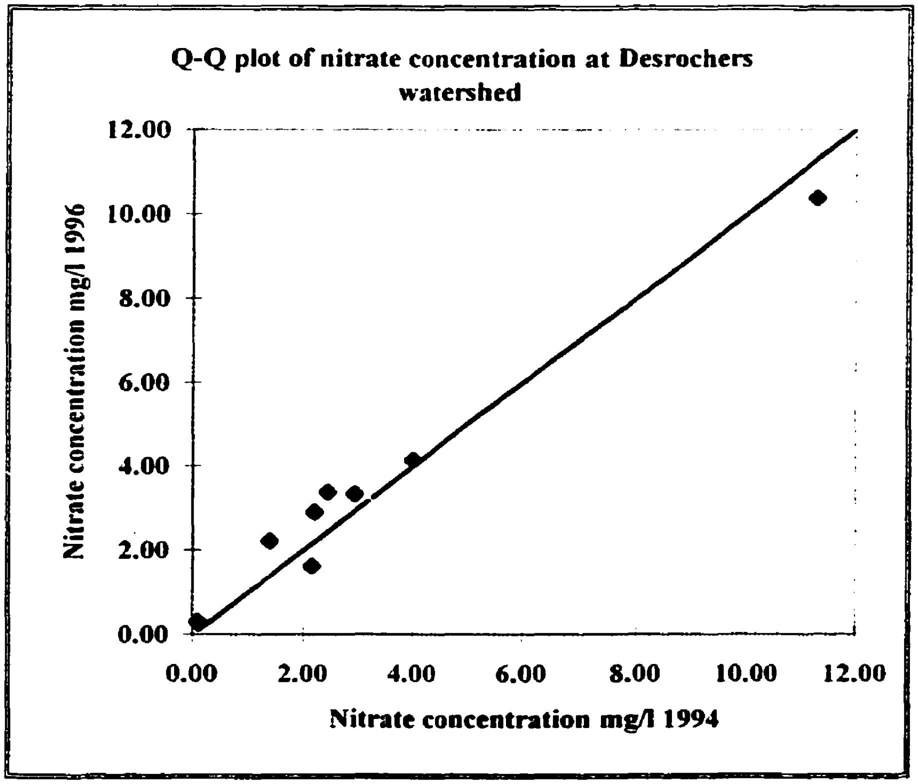


Figure C 16

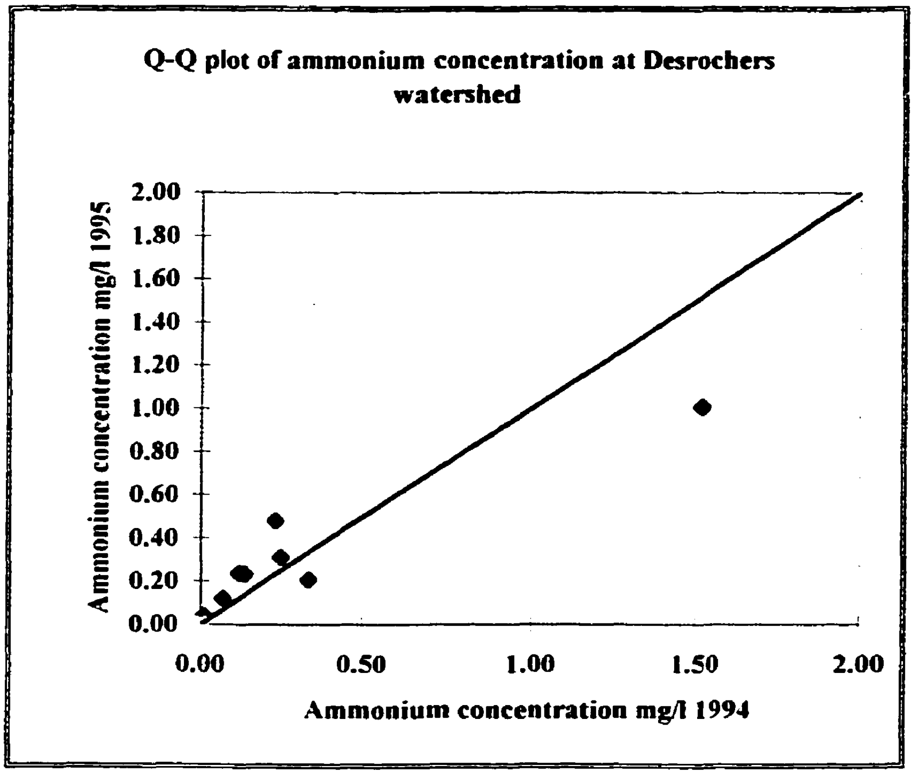
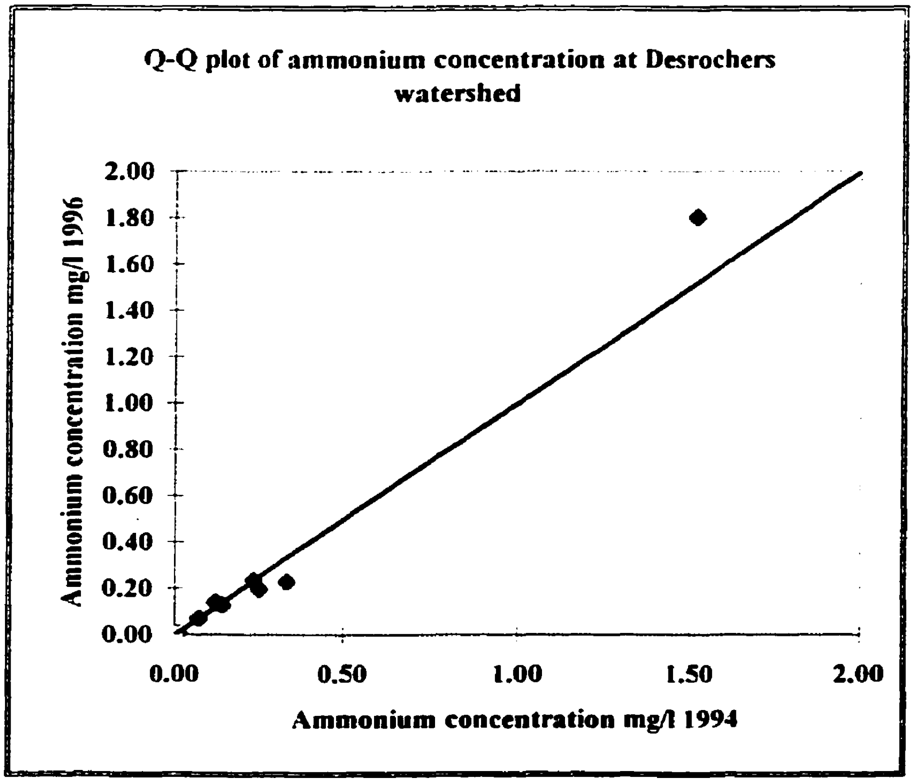


Figure C 17



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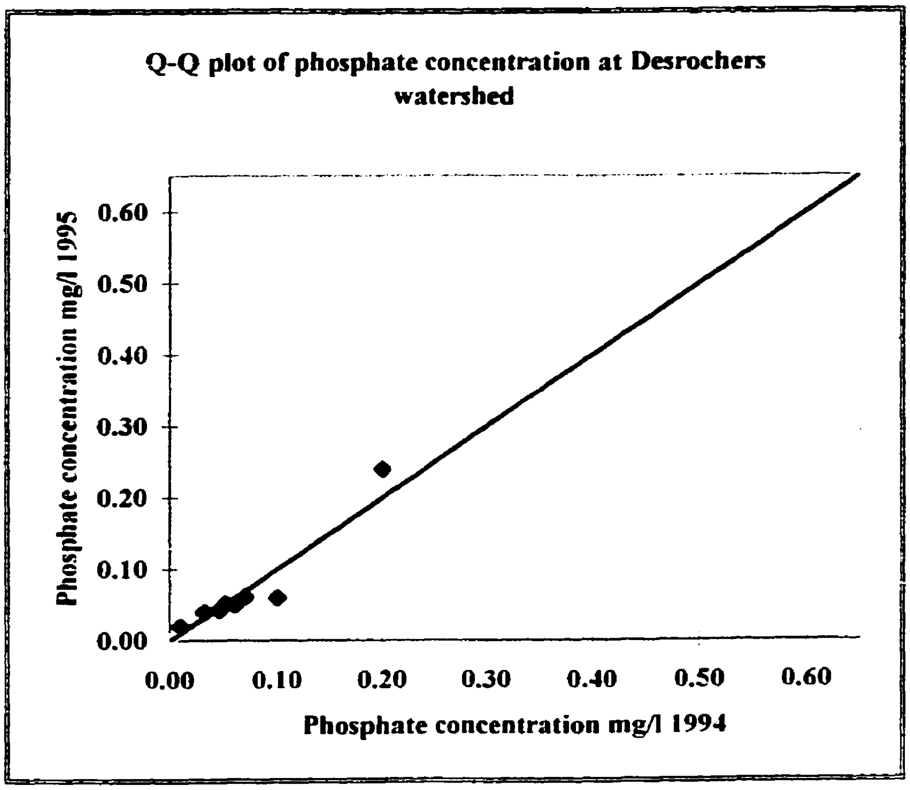

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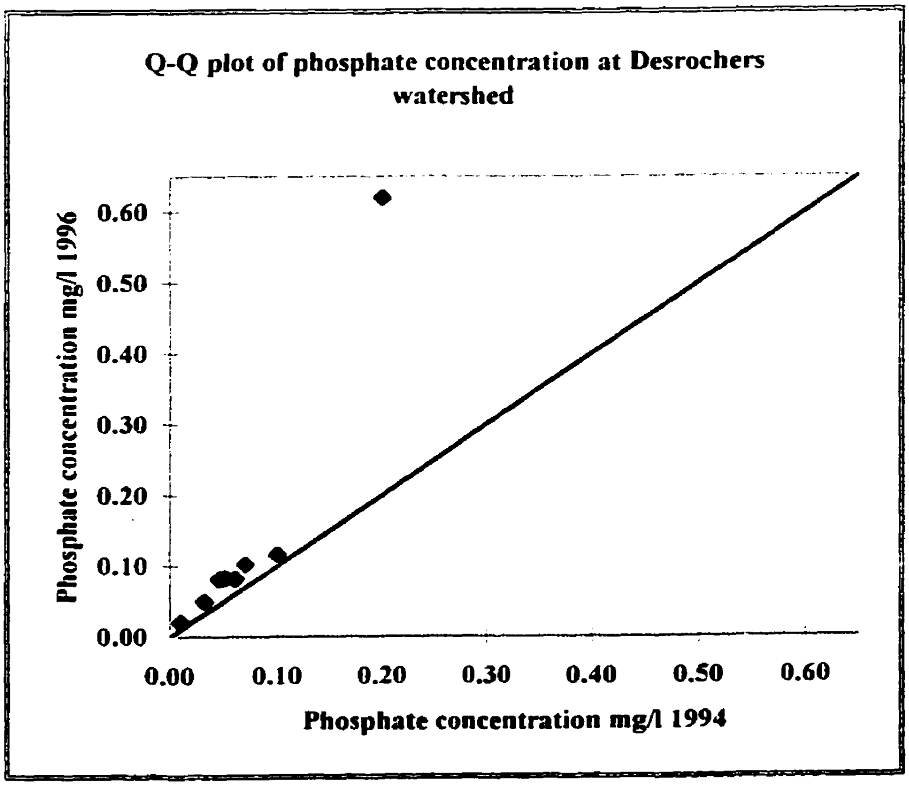

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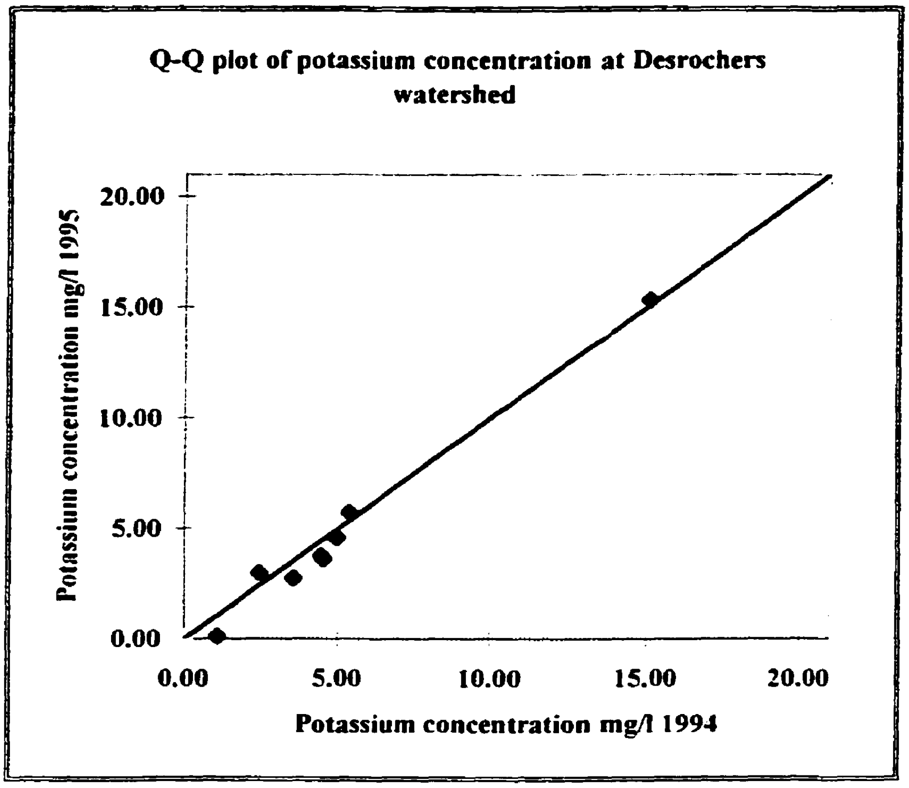

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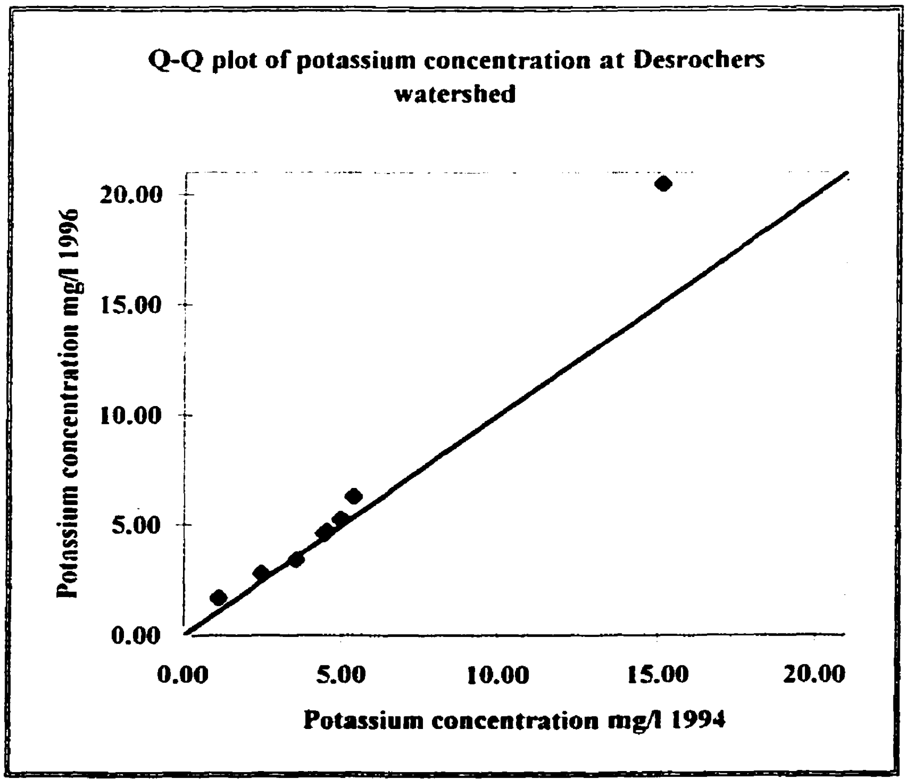

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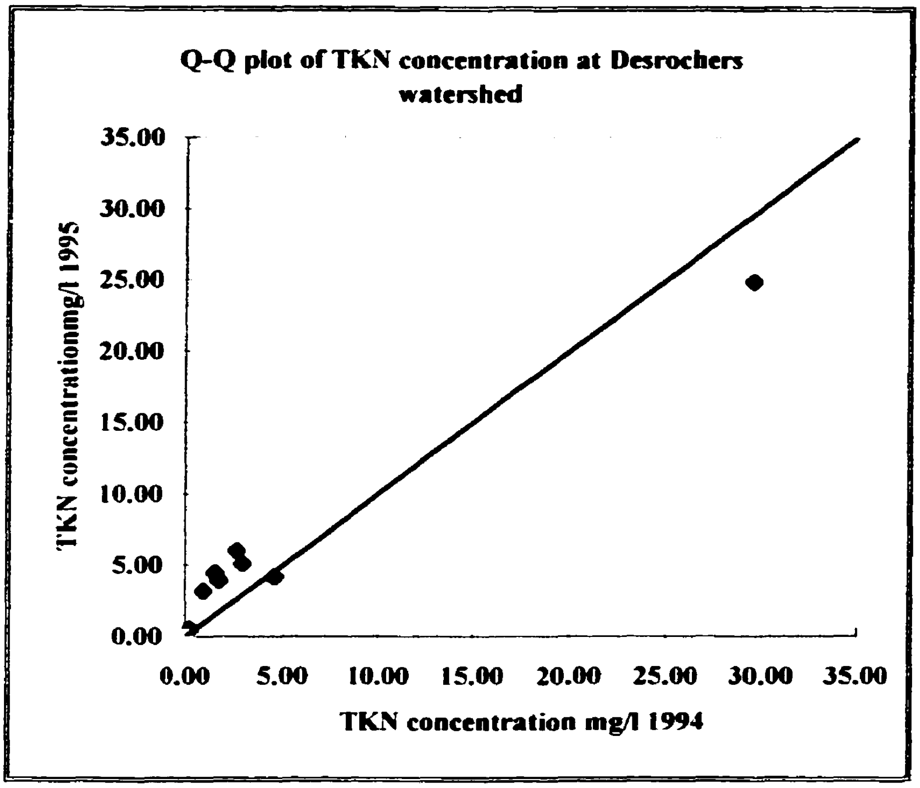

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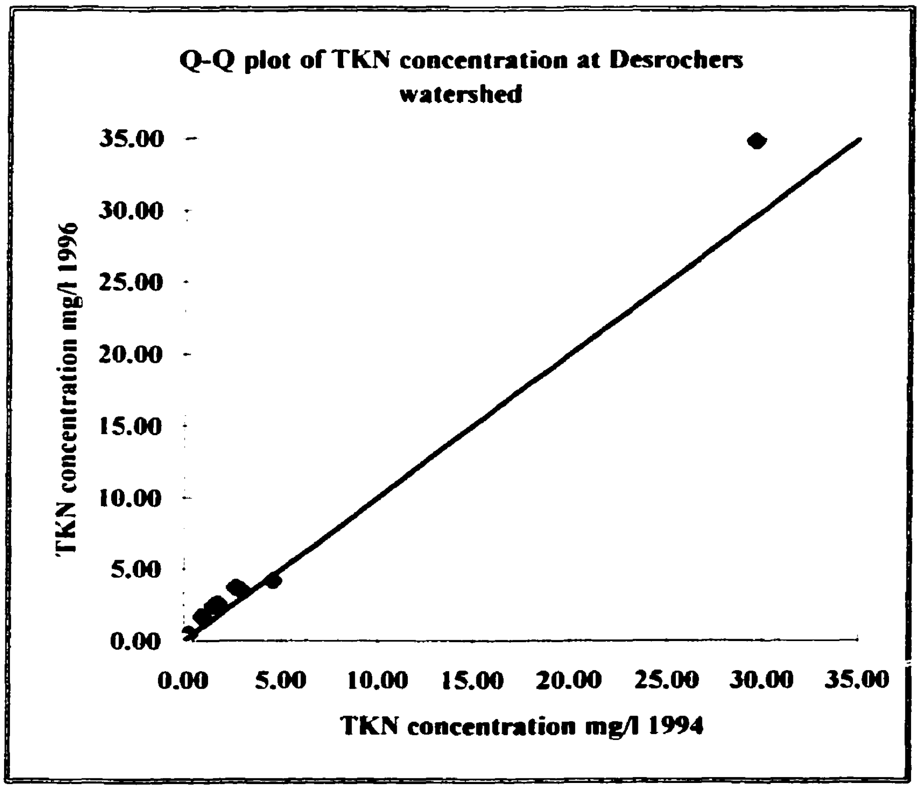

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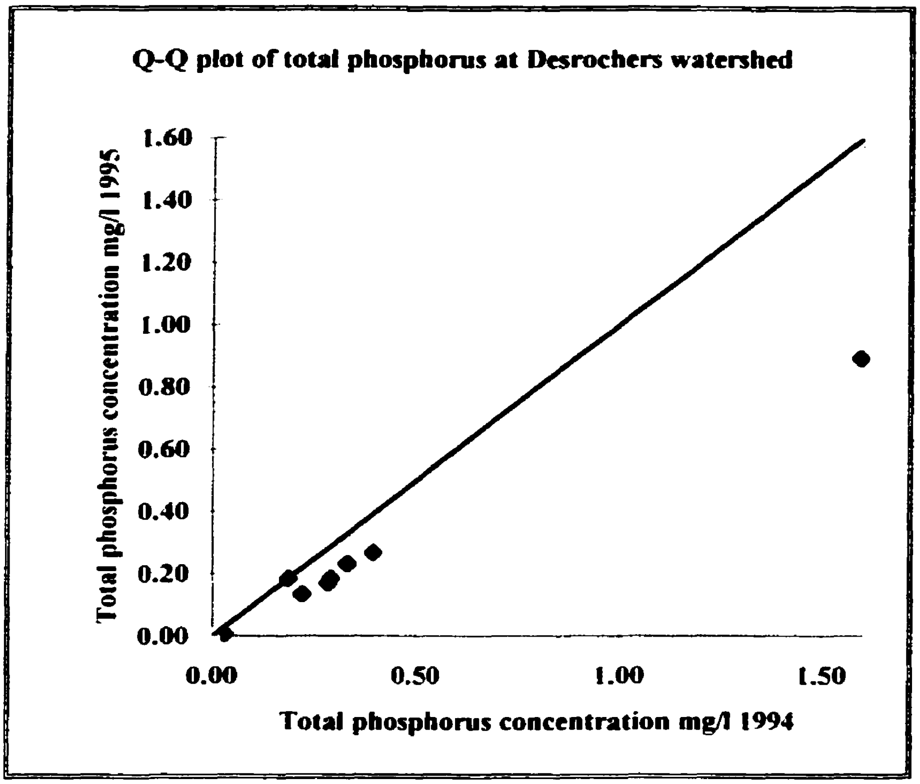

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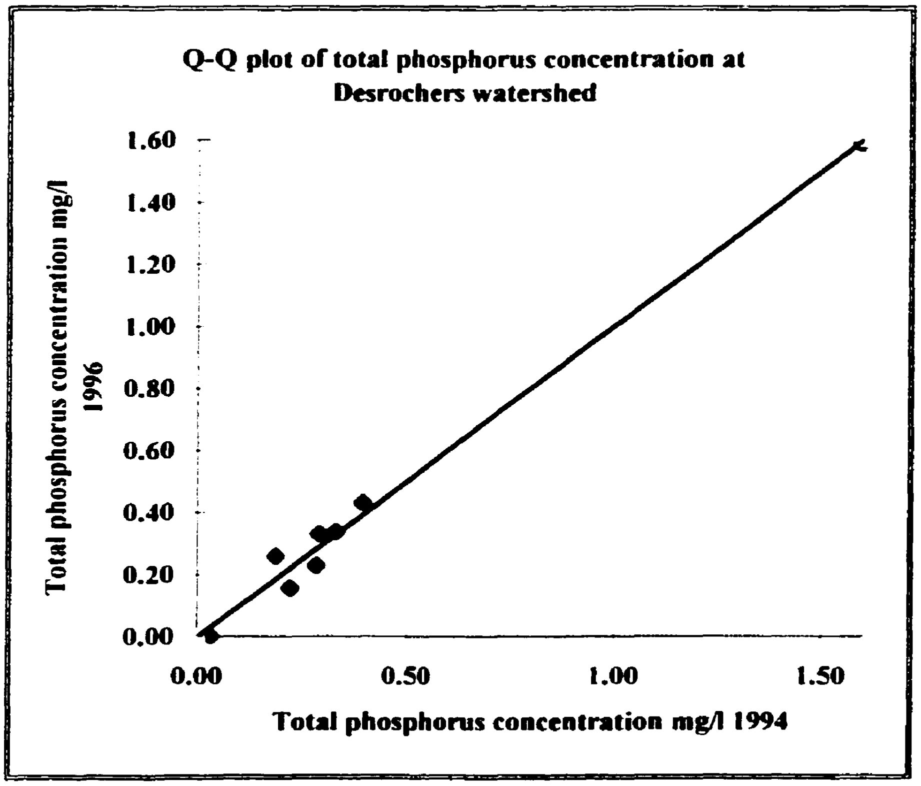

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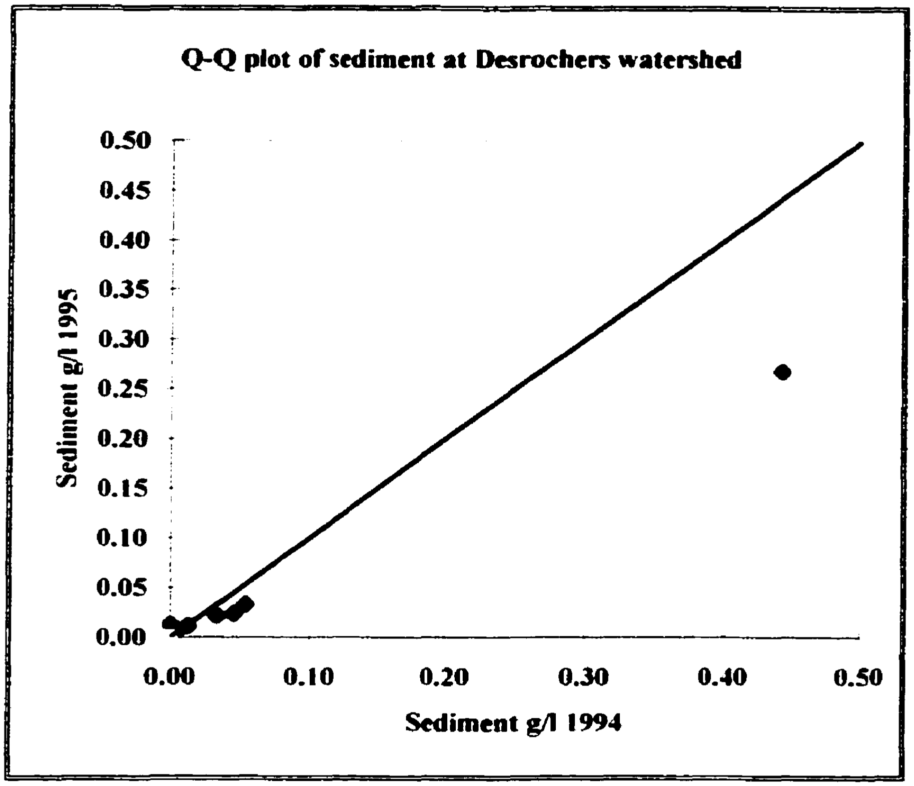

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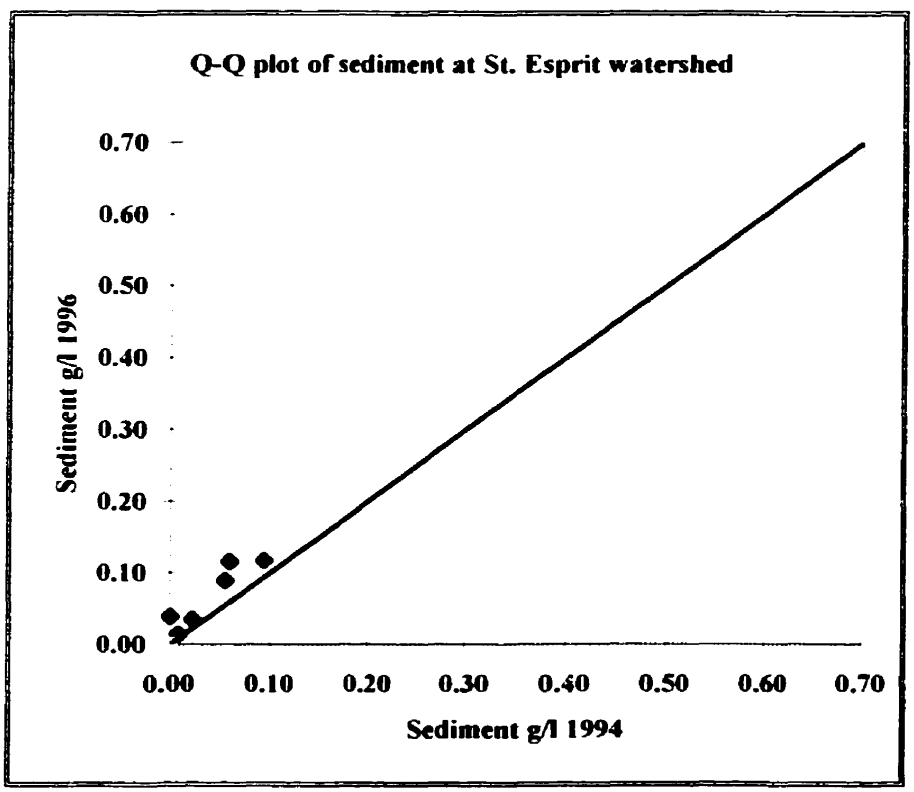

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Appendix D

Graphical Display of the non-parametric test for trend for nitrate concentrations at St. Esprit and Desrochers

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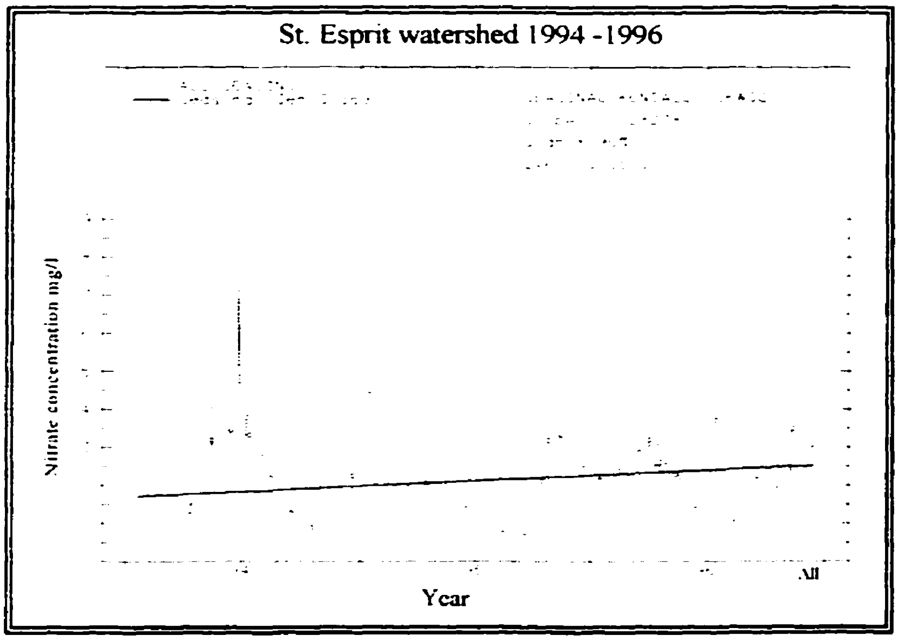

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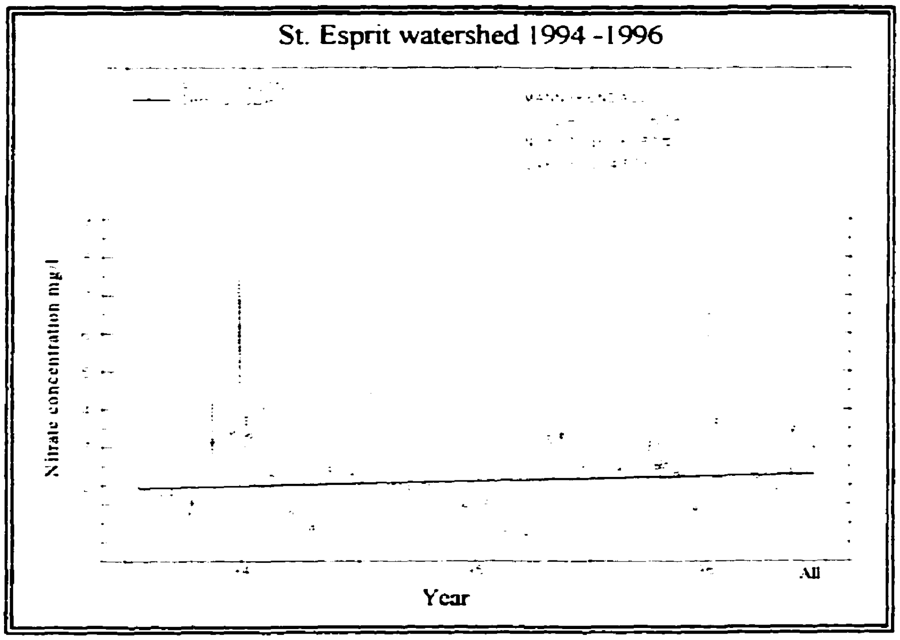

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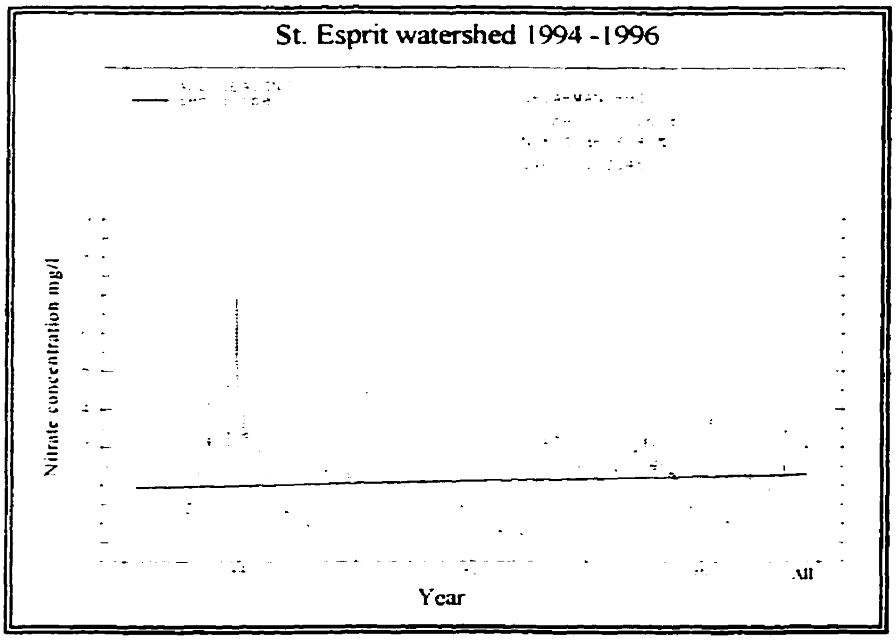

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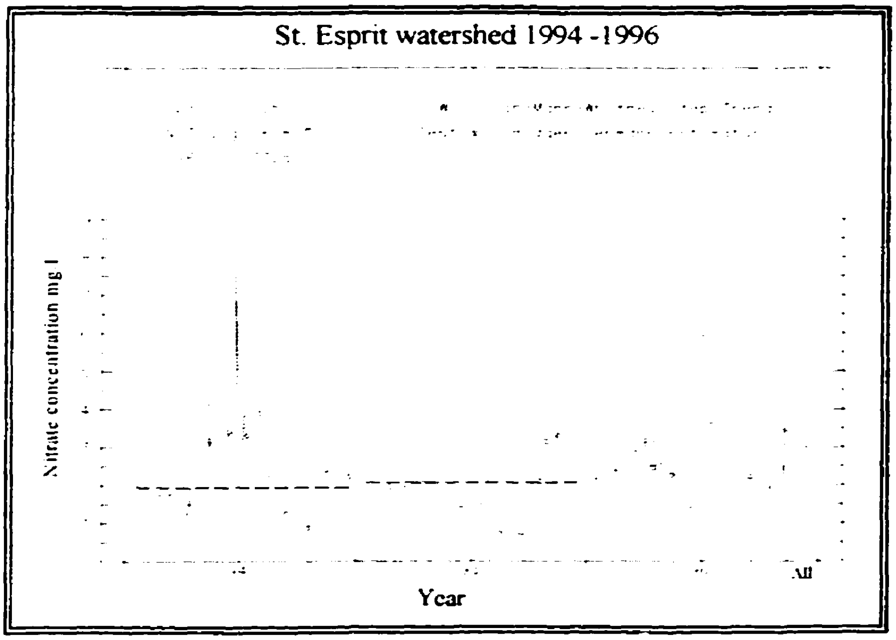

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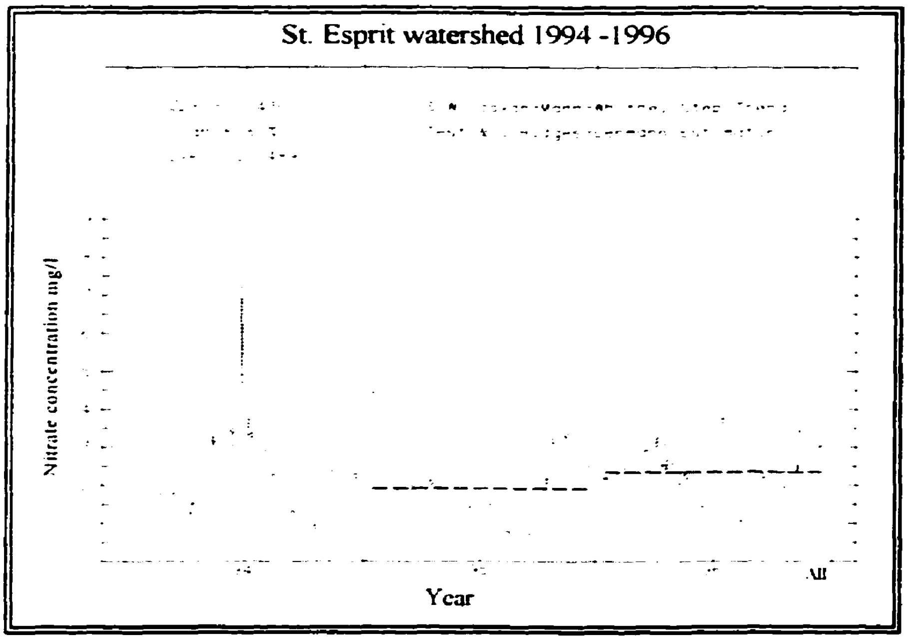

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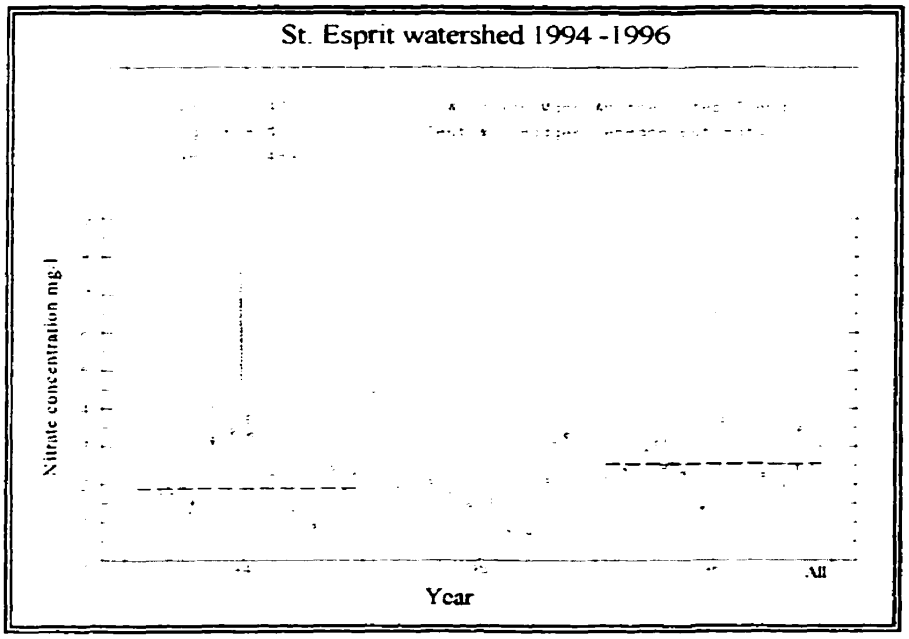

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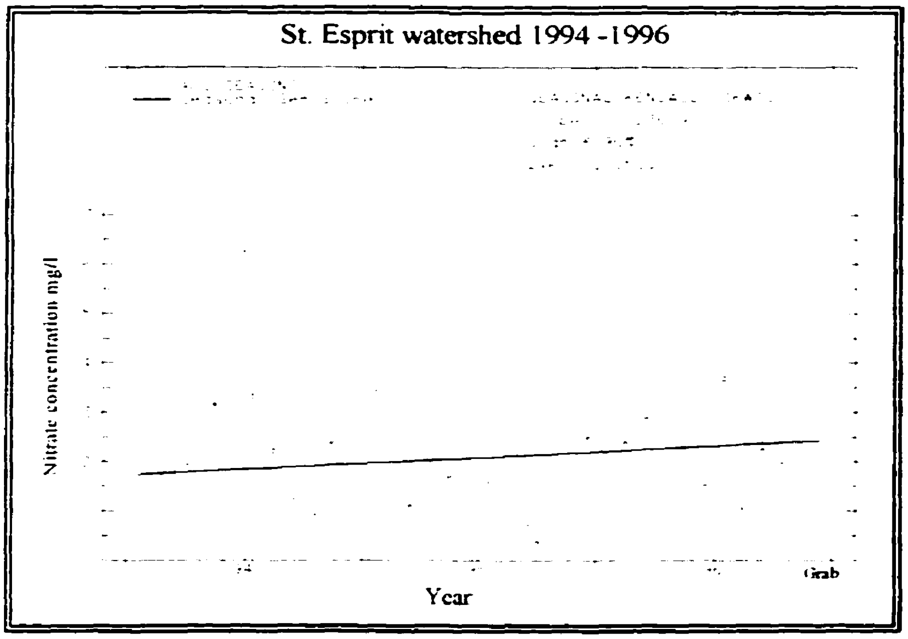

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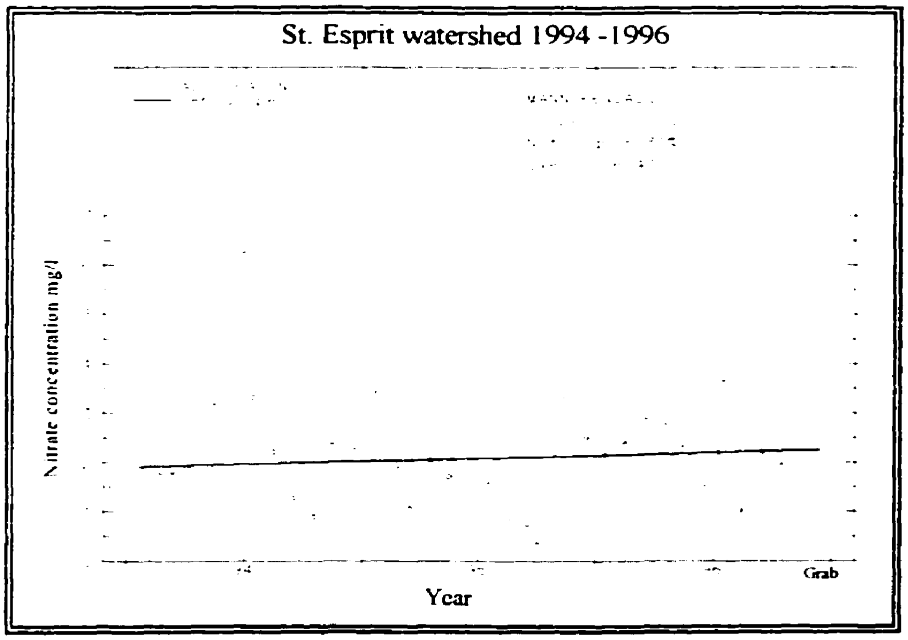

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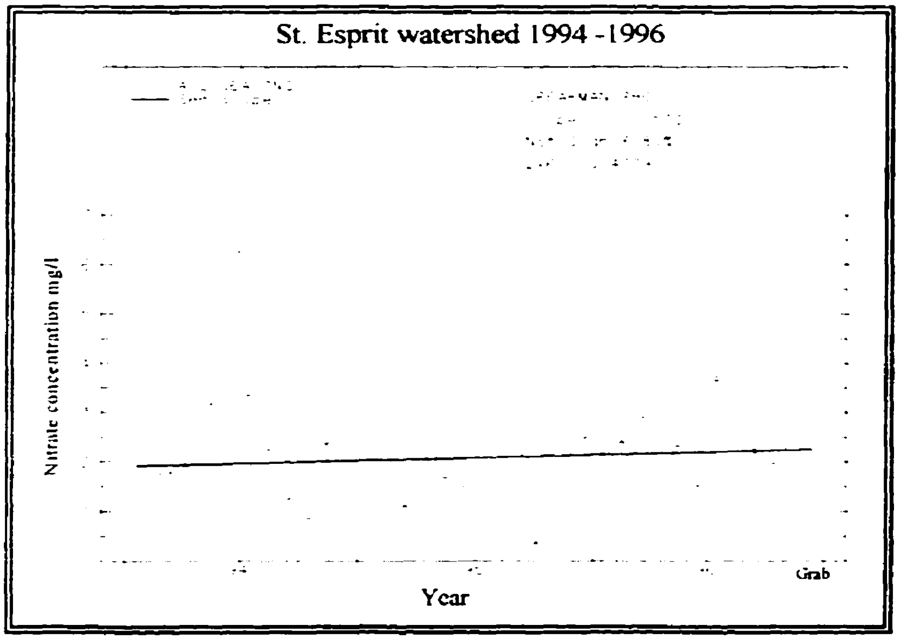

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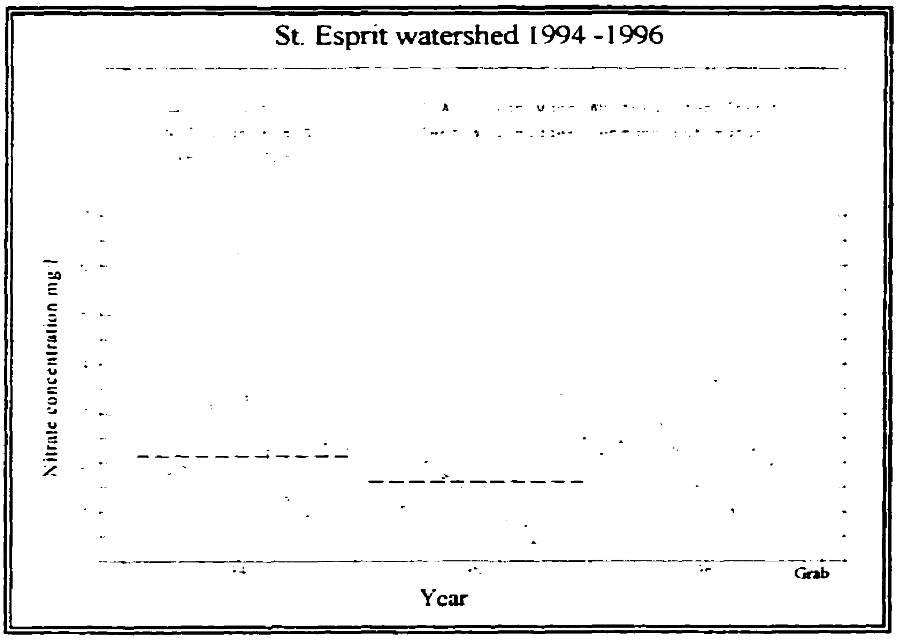

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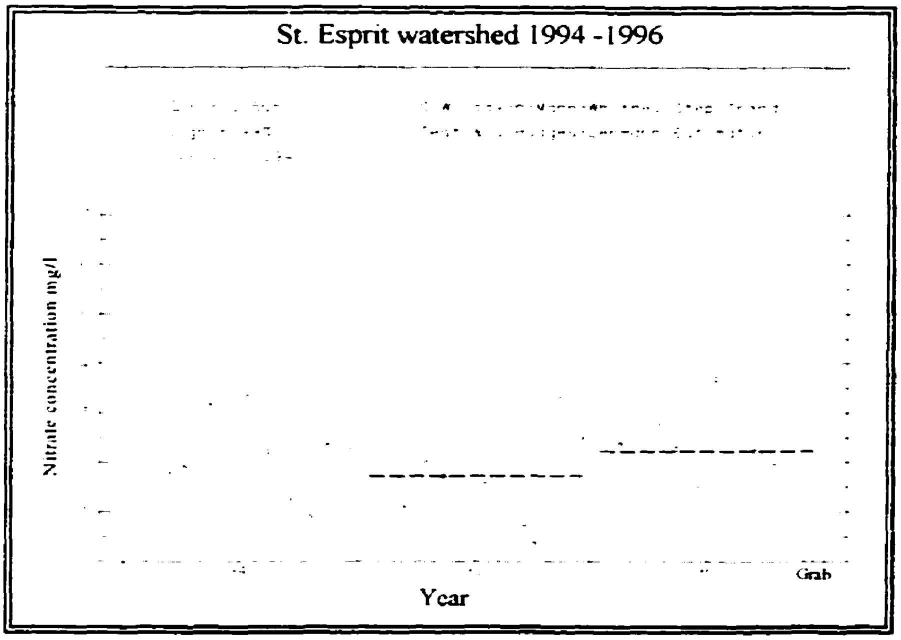

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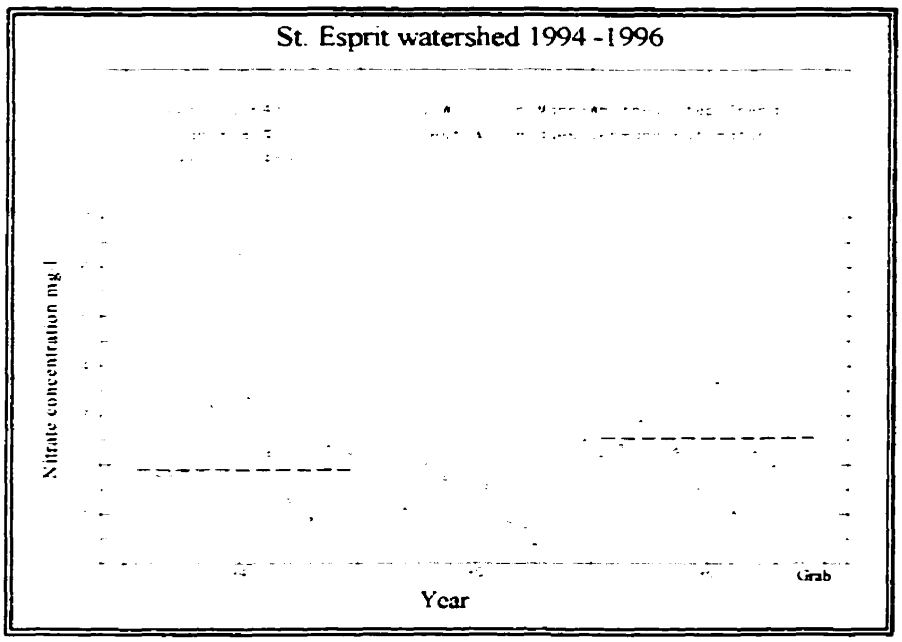

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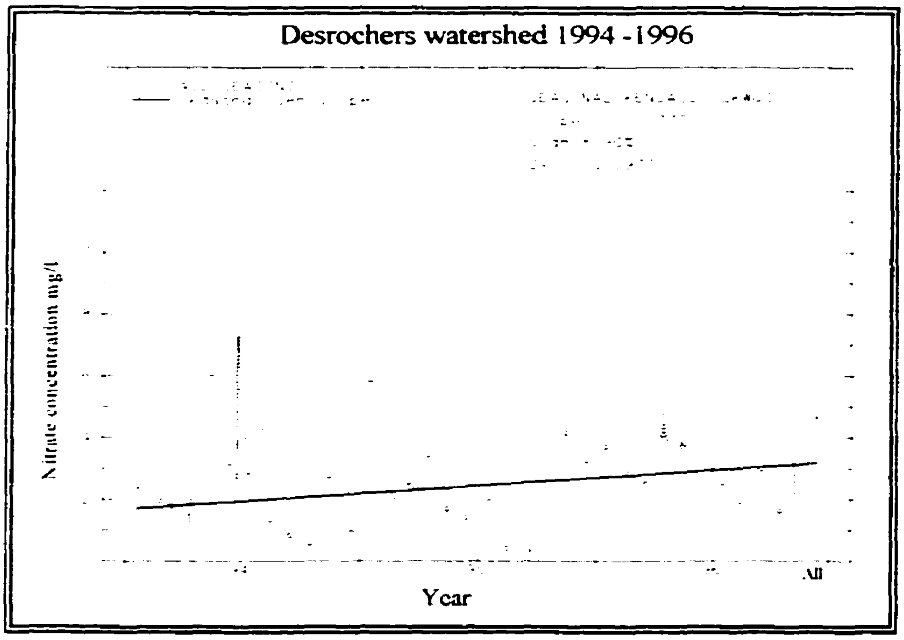

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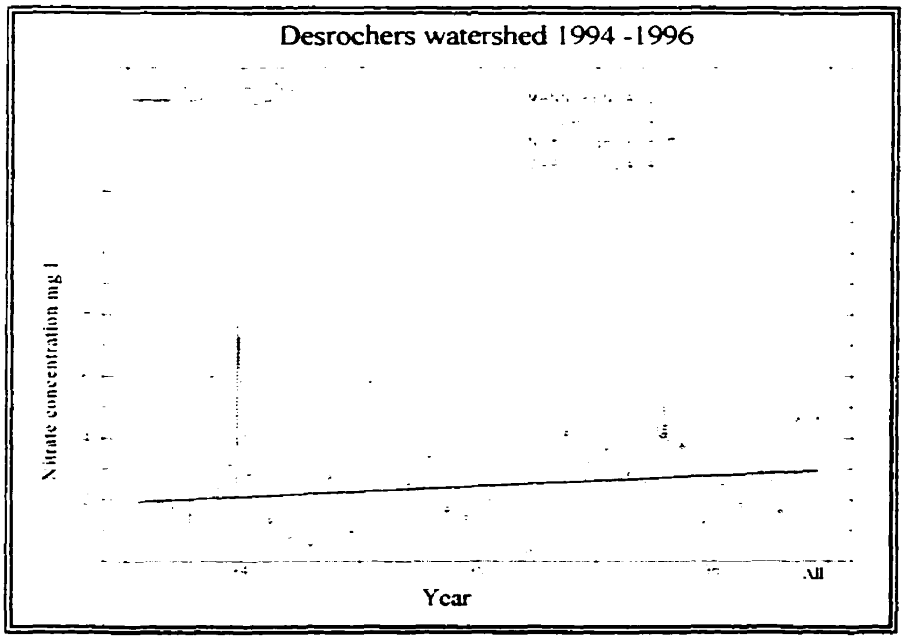

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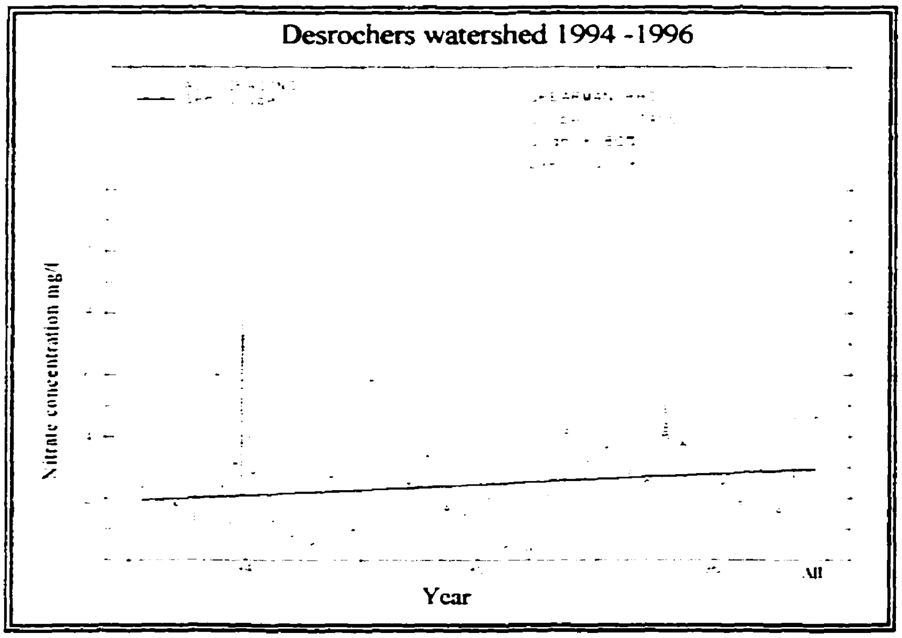

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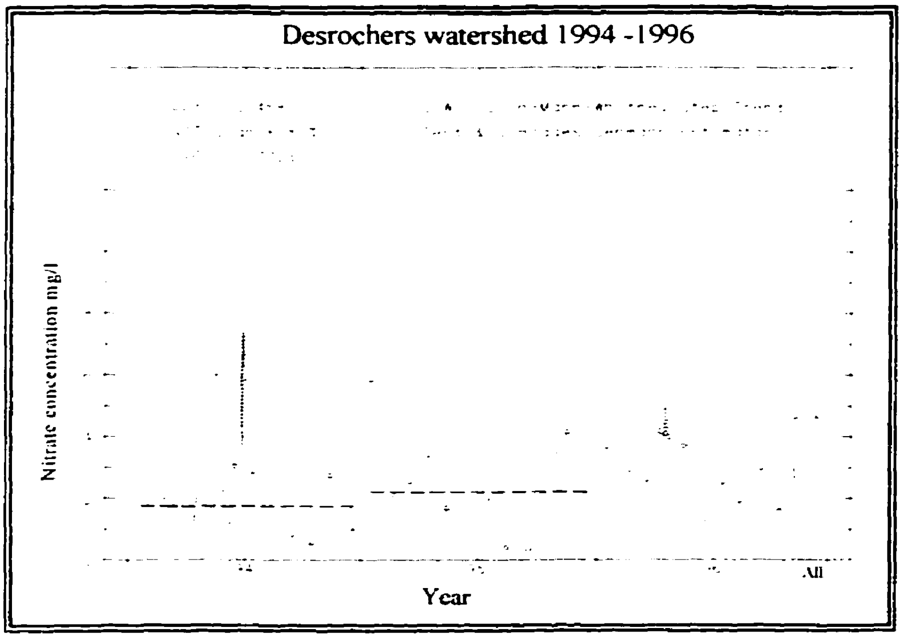

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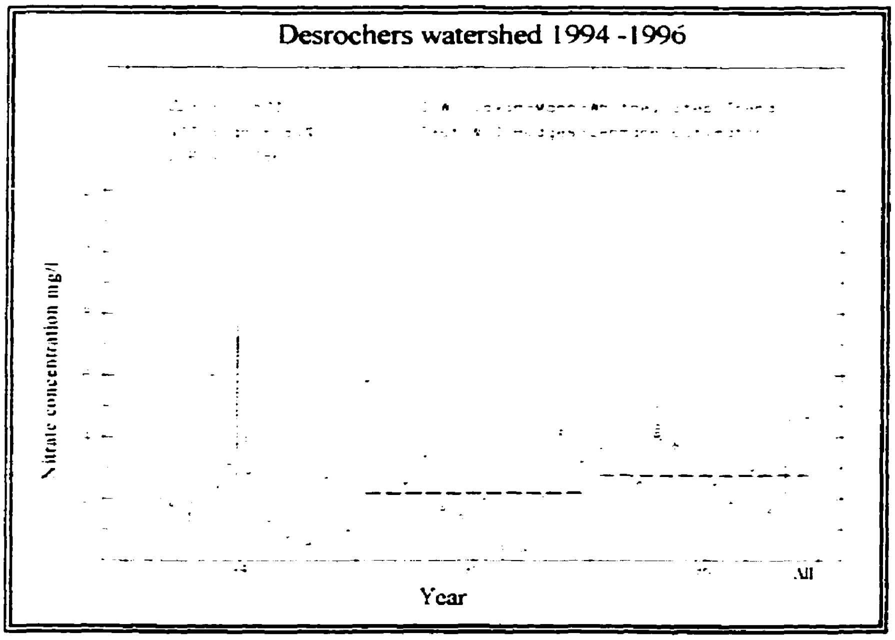

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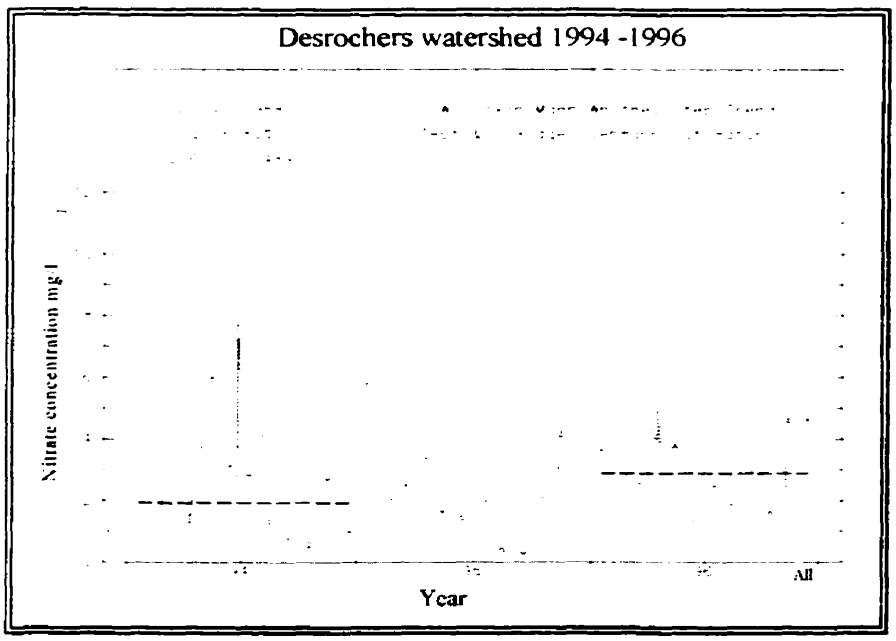

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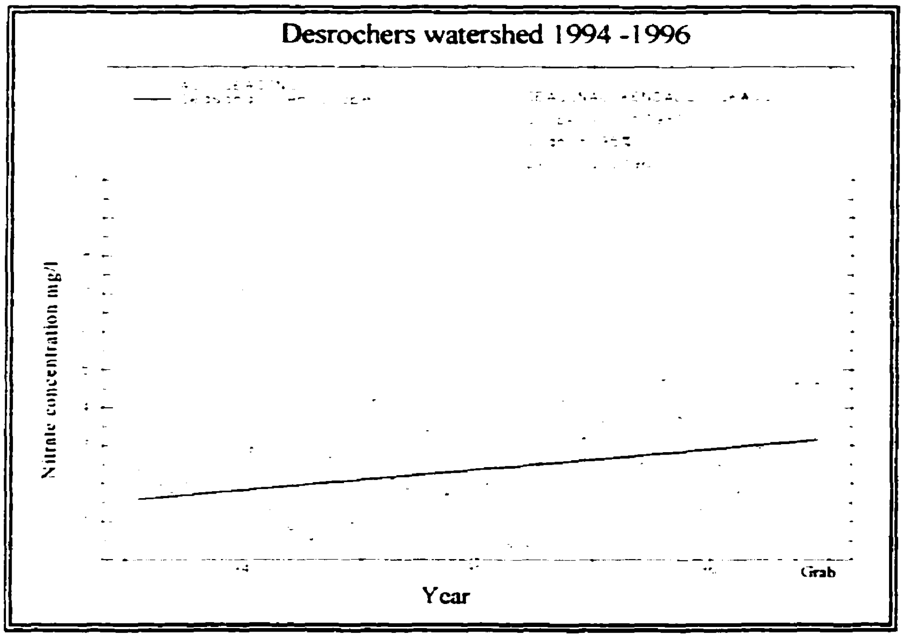

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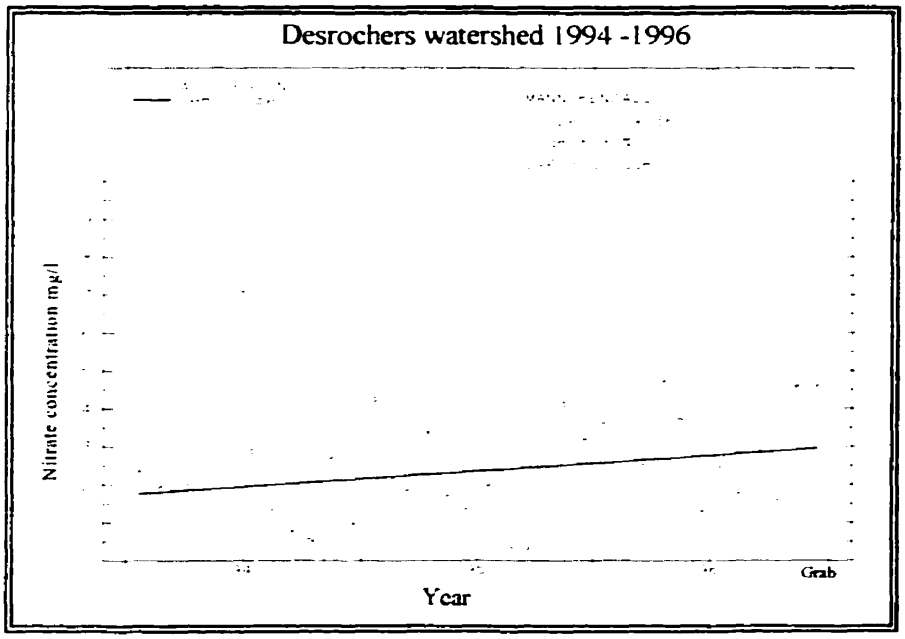

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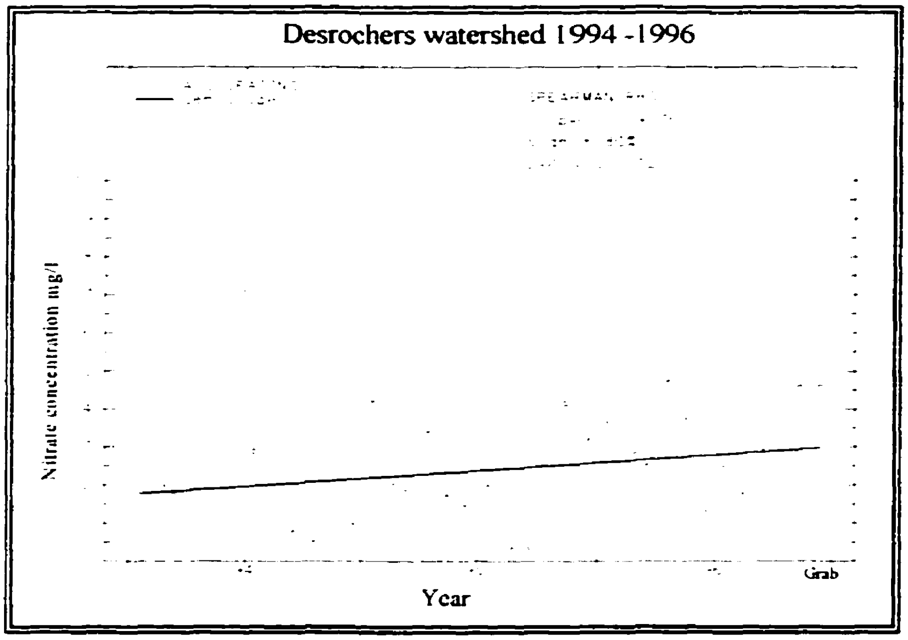

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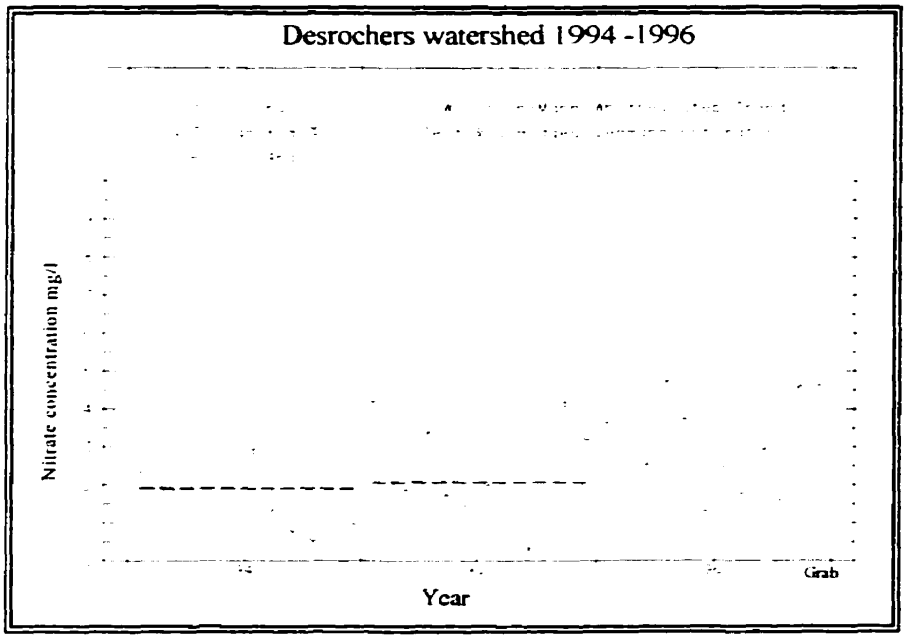

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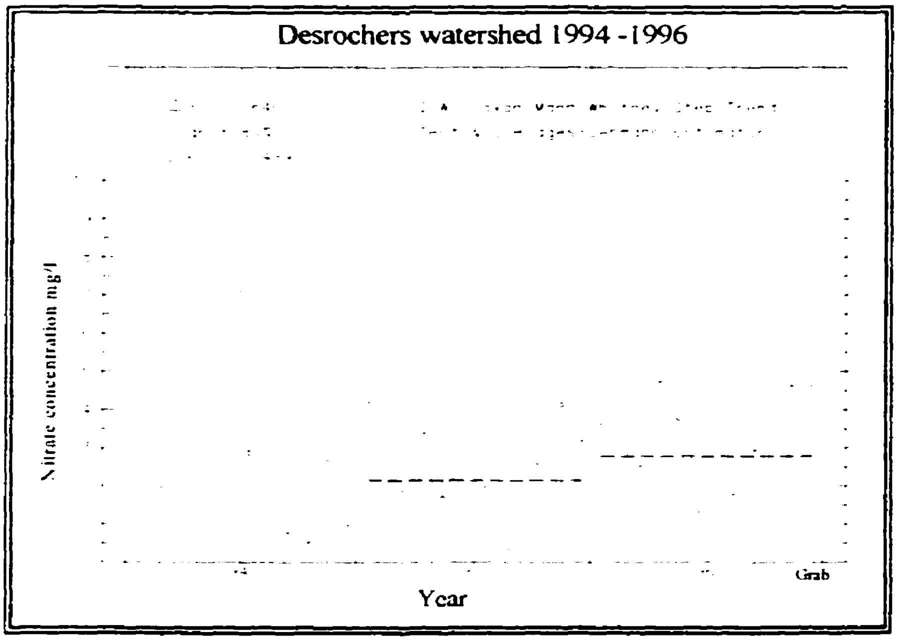

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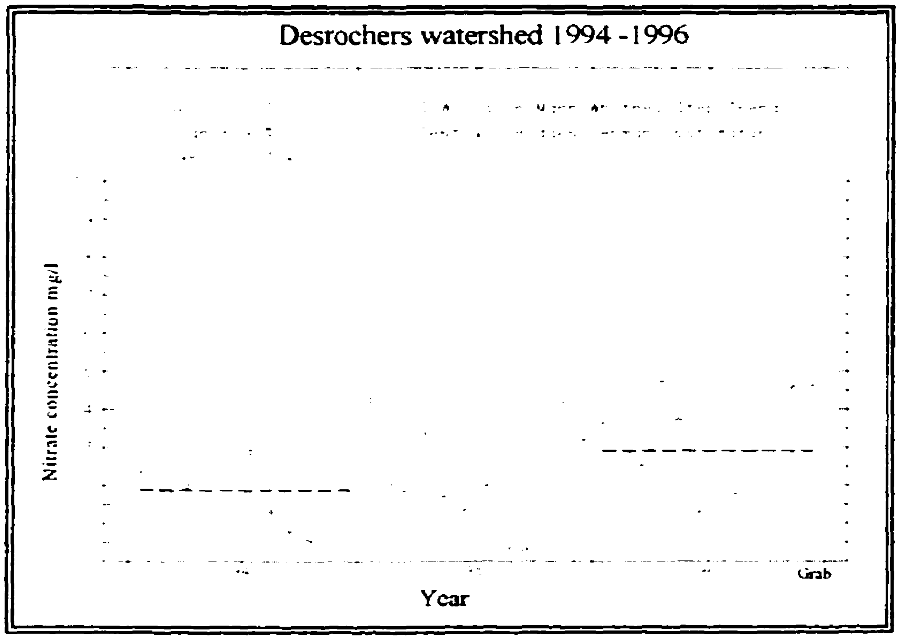

Figure D24

Appendix E

Graphical Display of the non-parametric test for trend for ammonium concentrations St. Esprit and Desrochers

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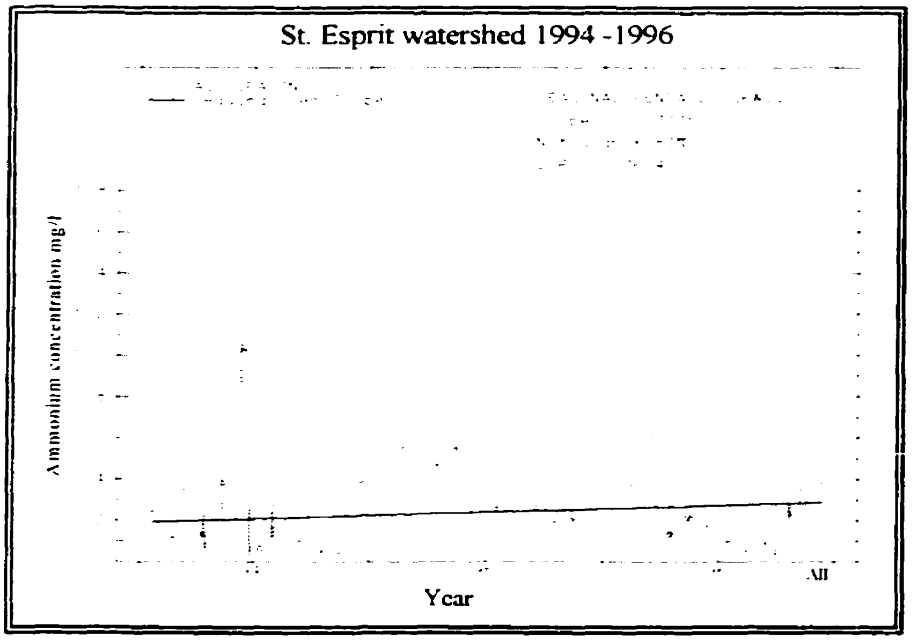

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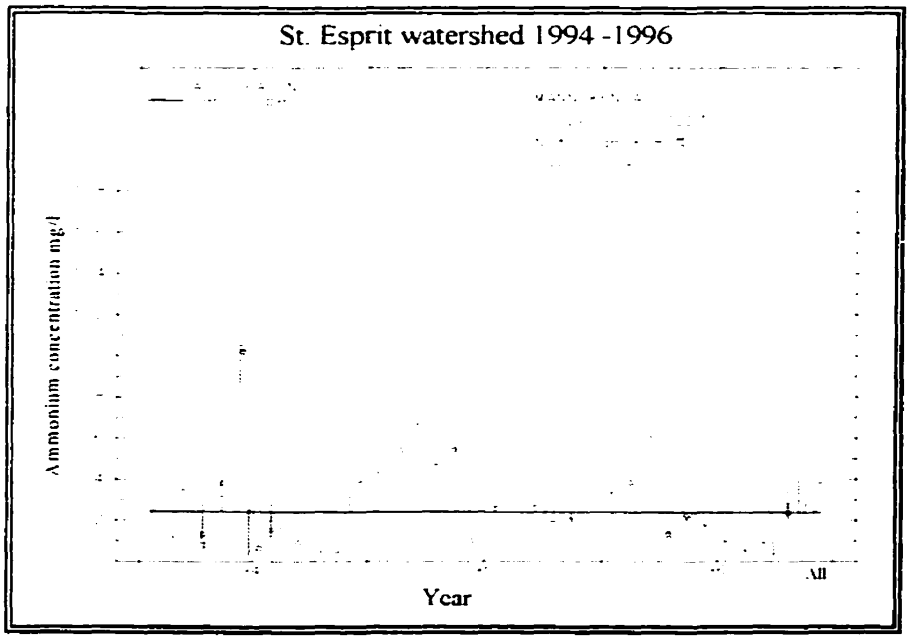

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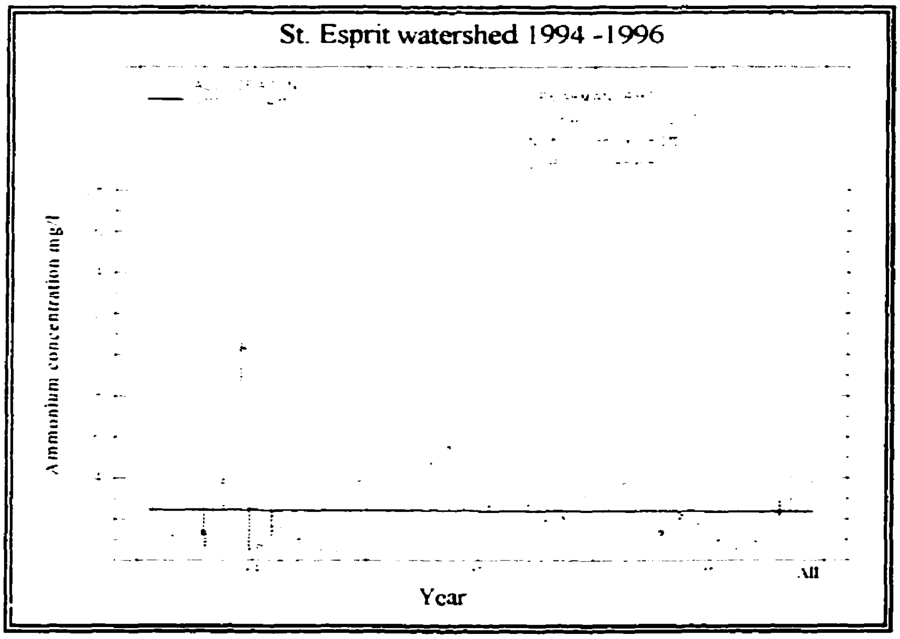

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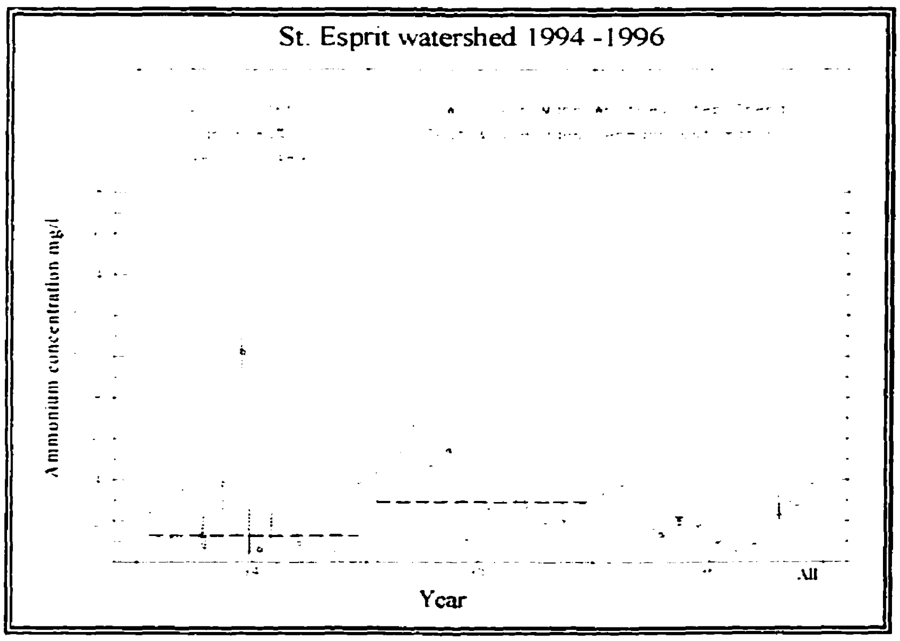

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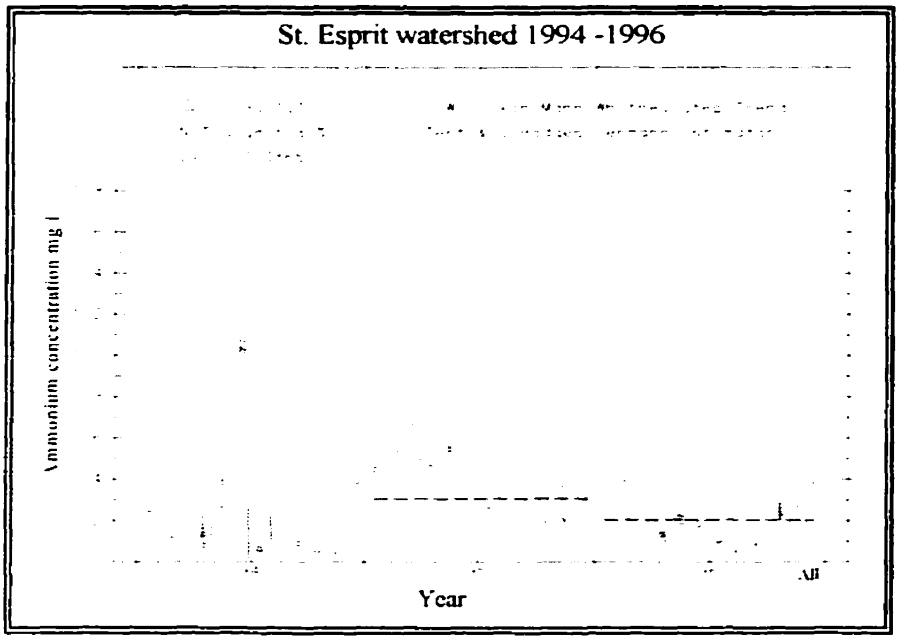

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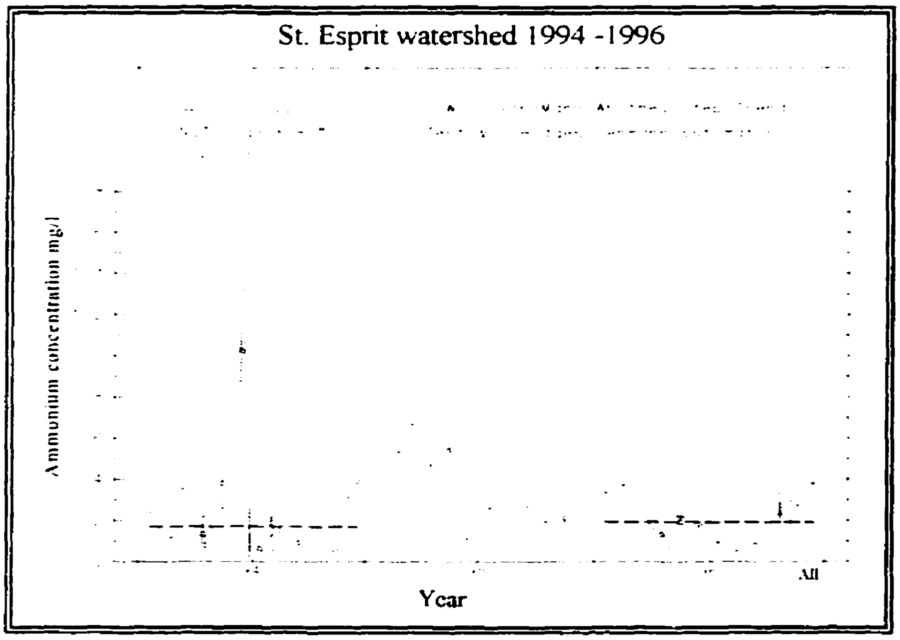

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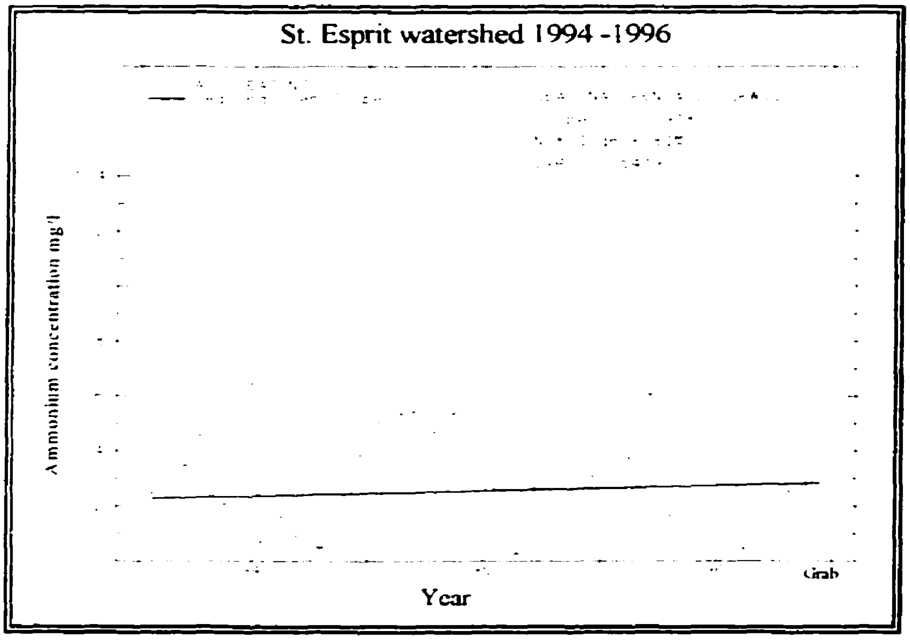

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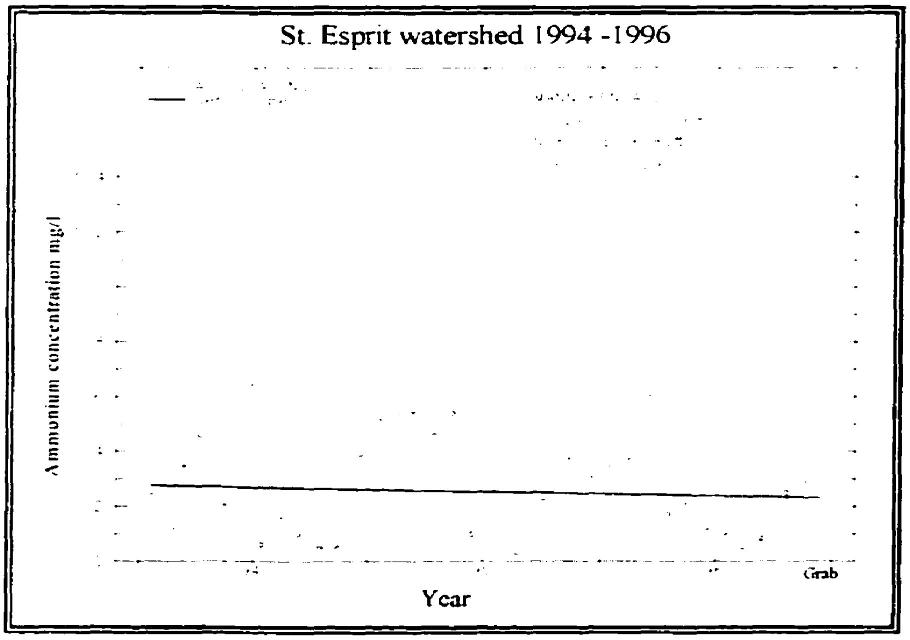

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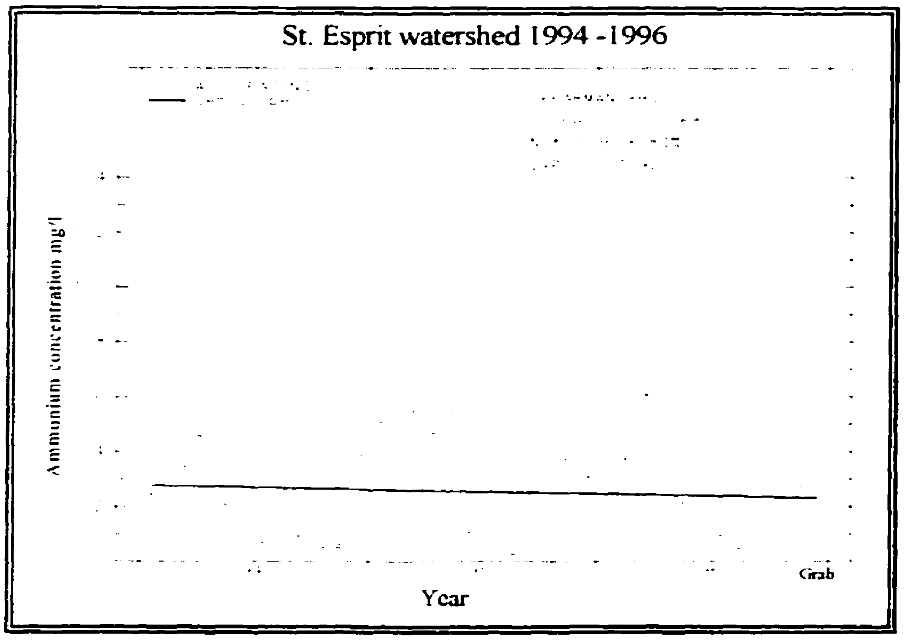

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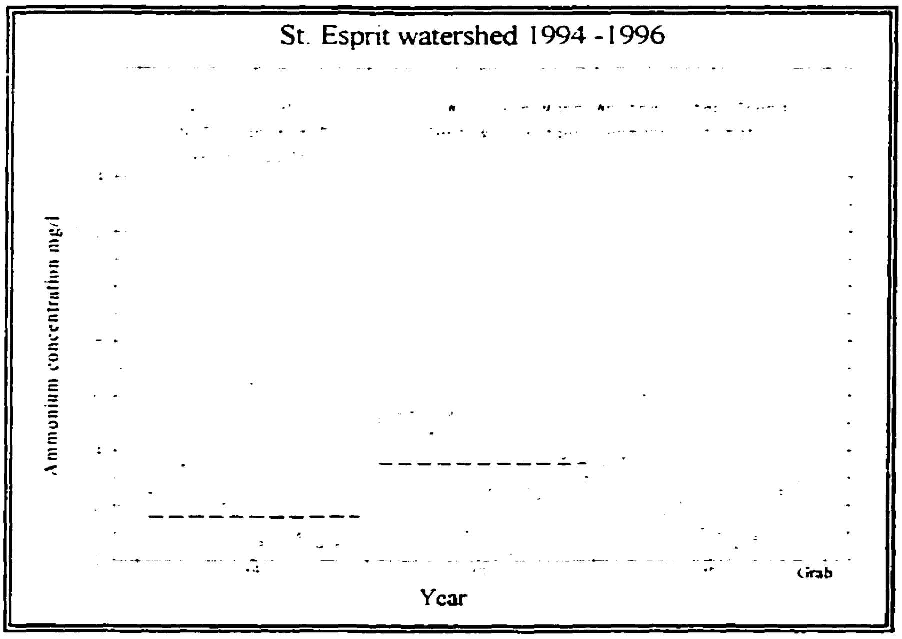

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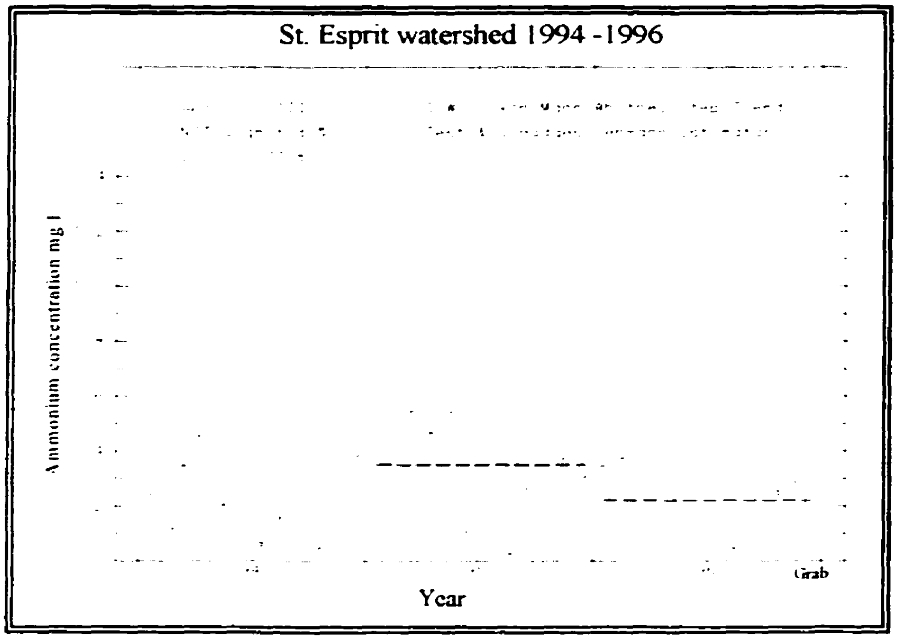

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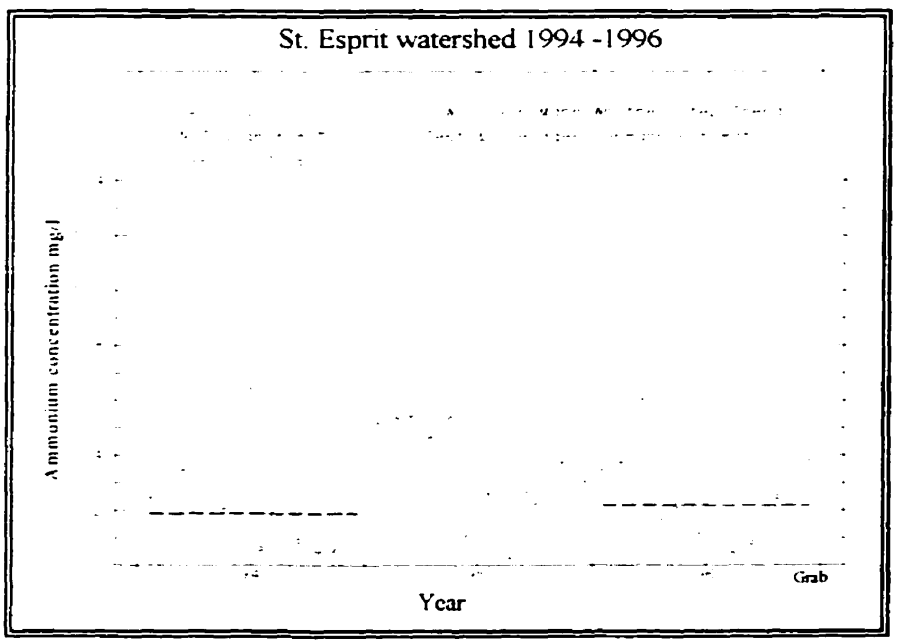

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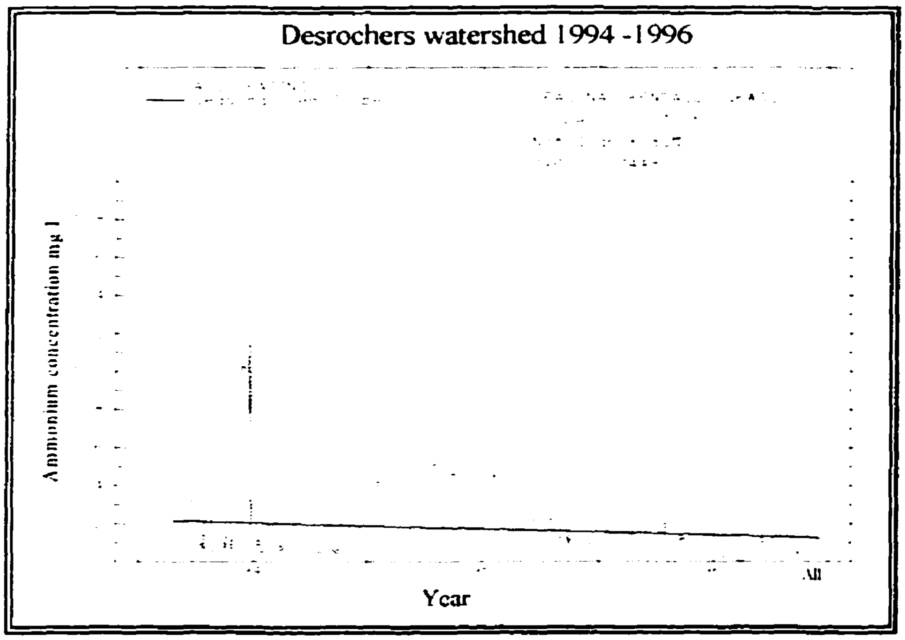

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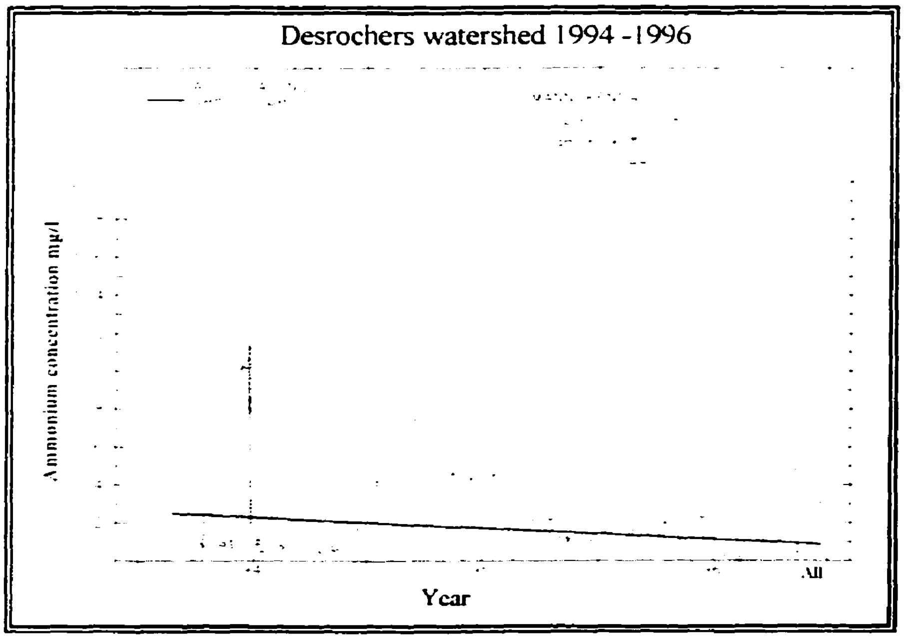

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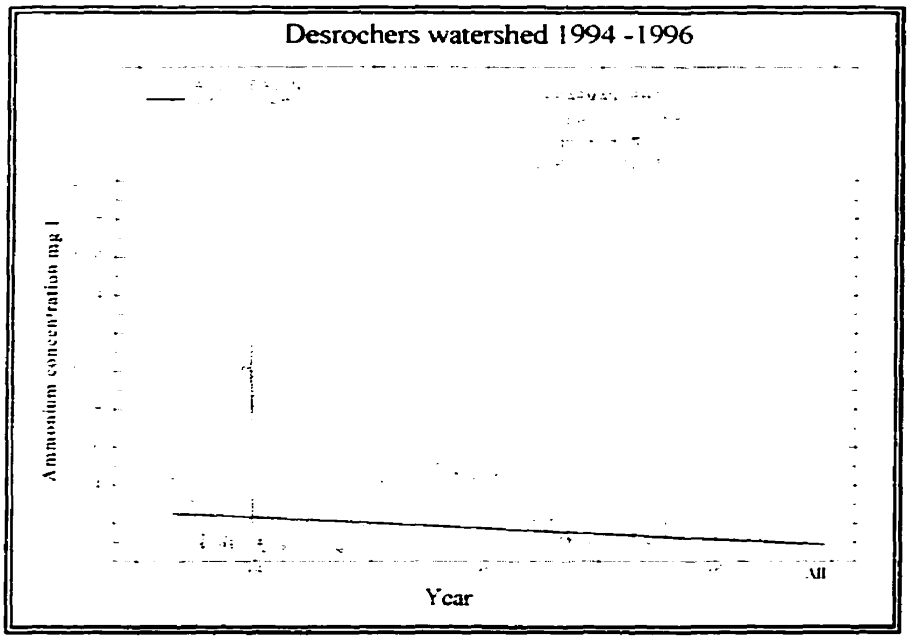

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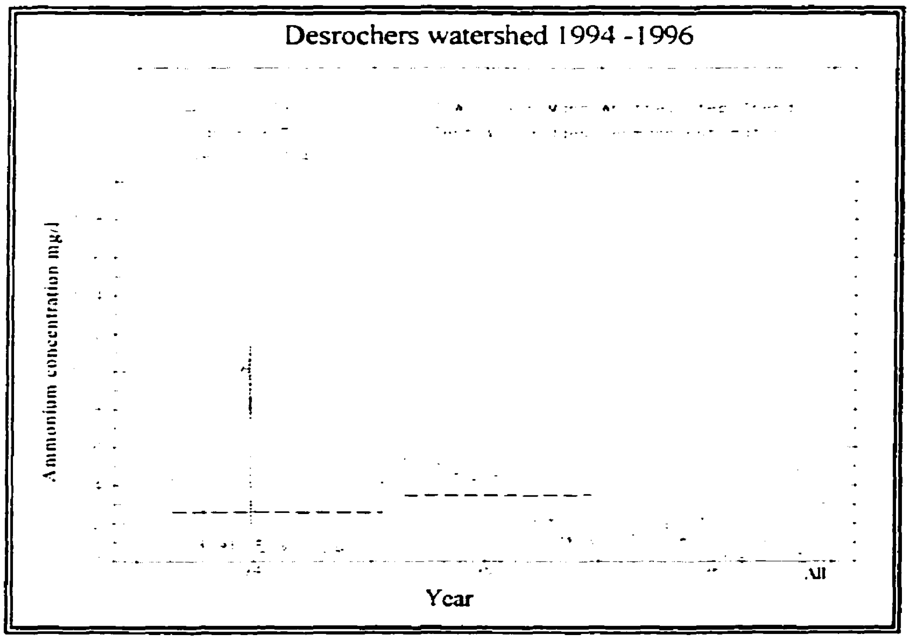

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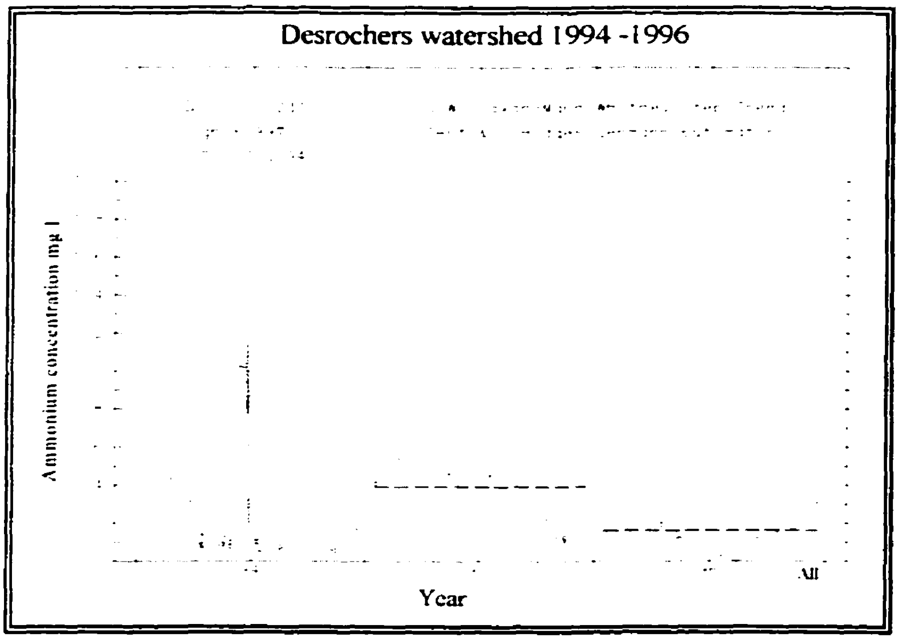

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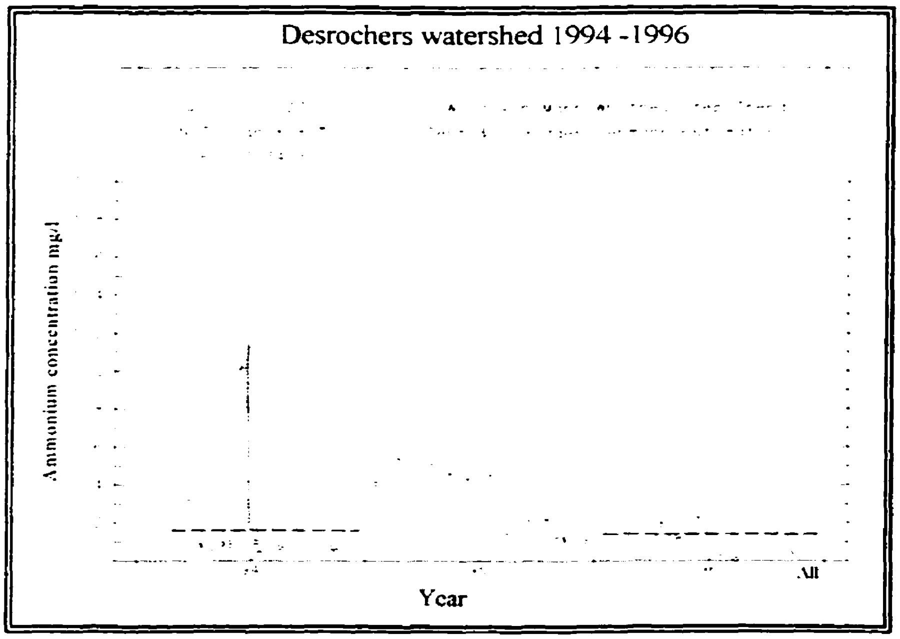

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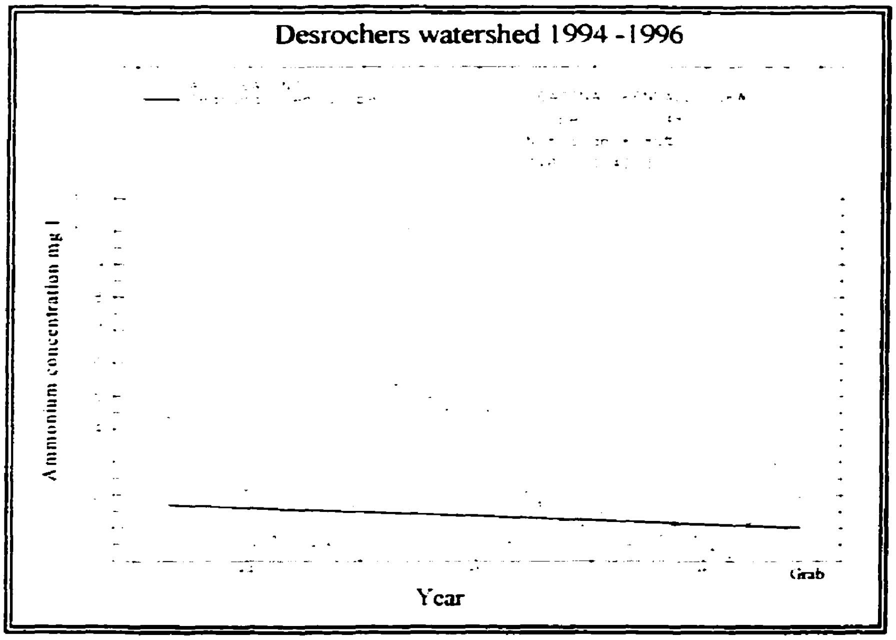

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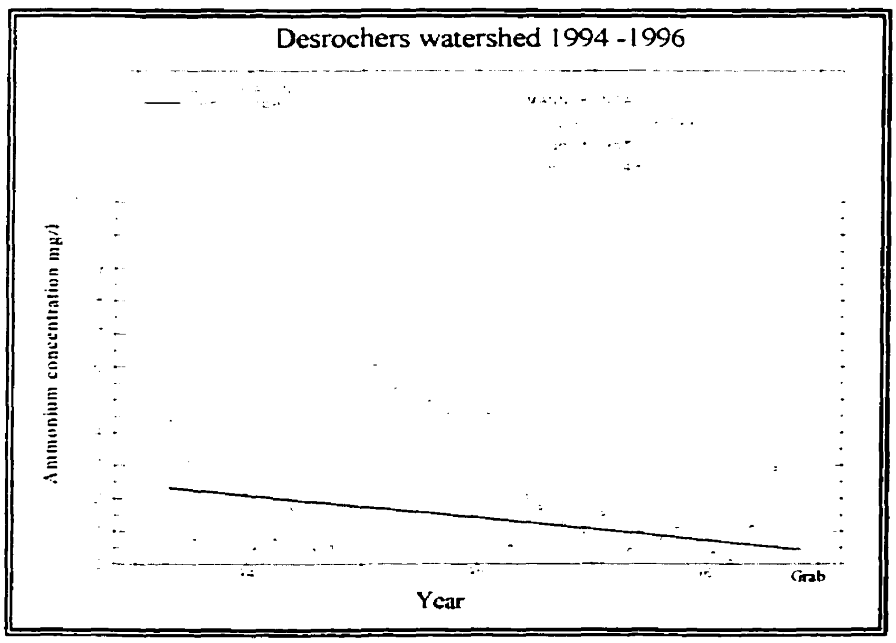

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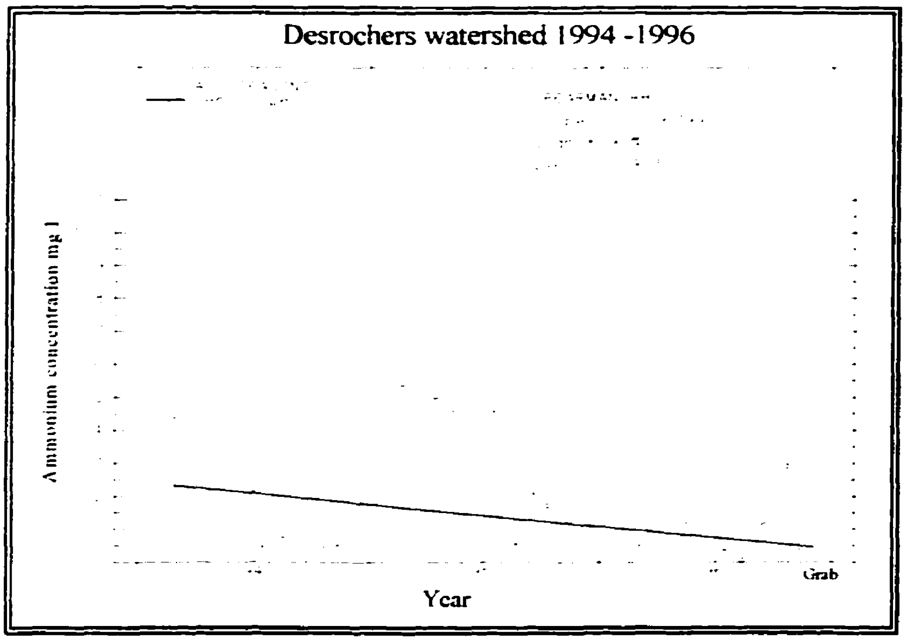

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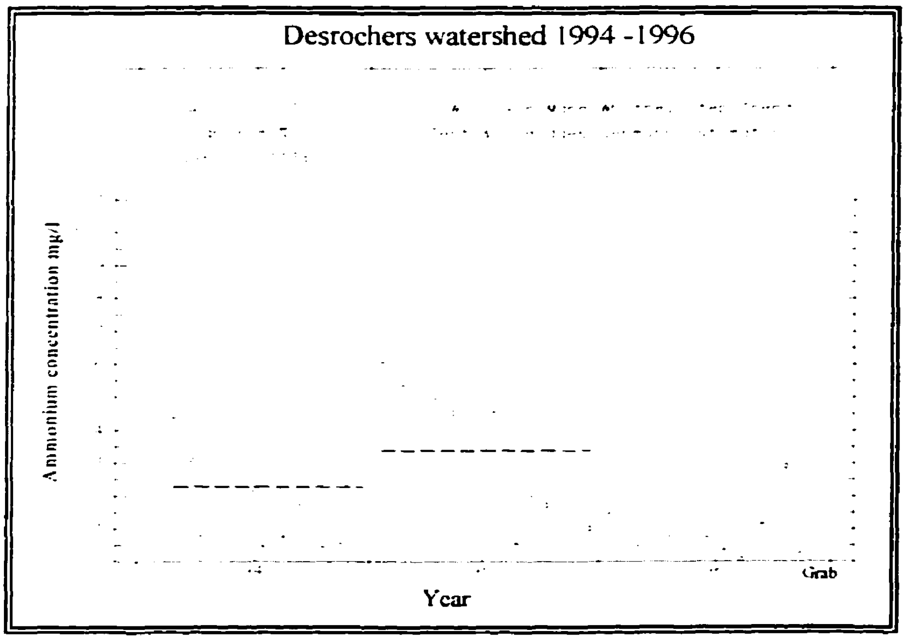

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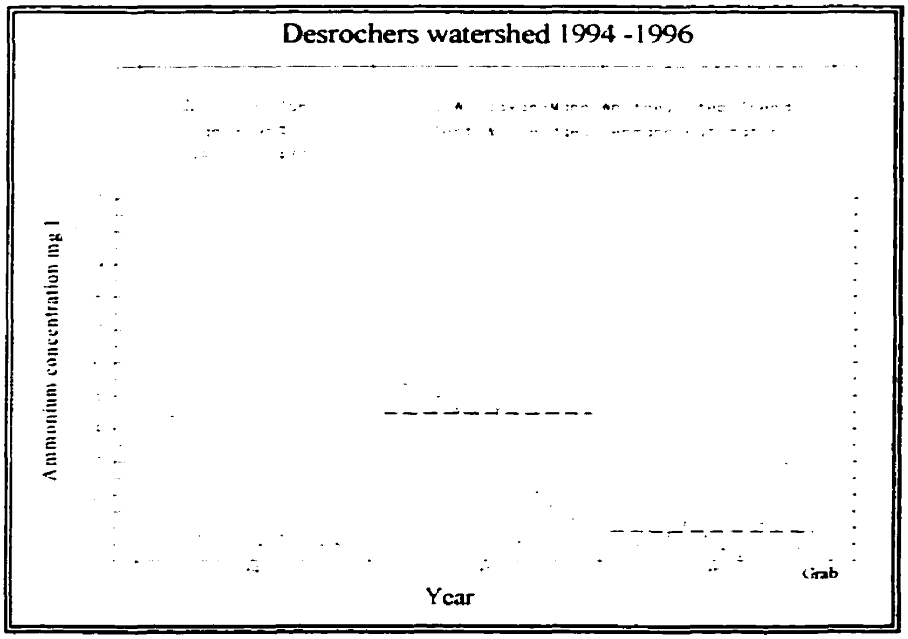

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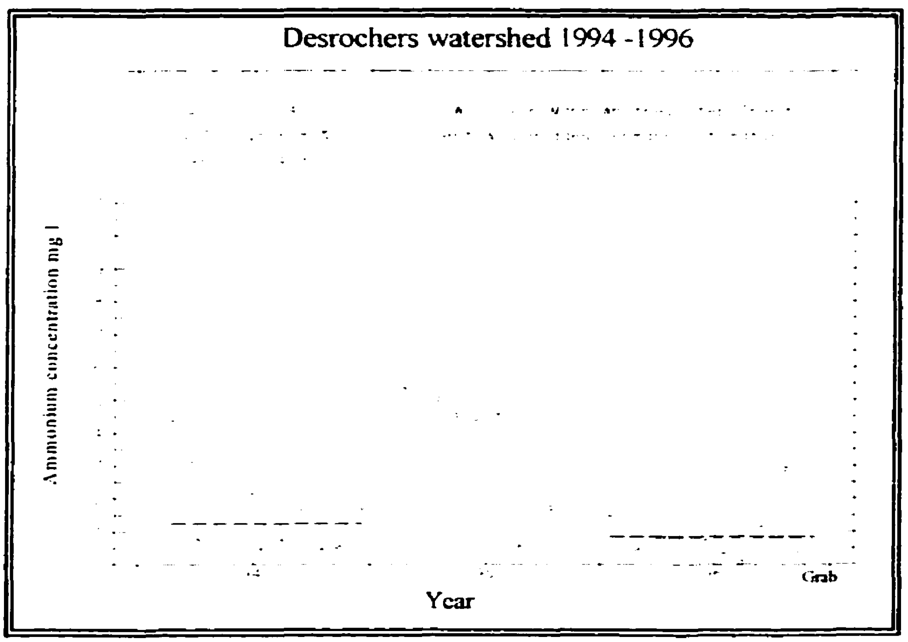

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Appendix F

Graphical Display of the non-parametric test for trend for phosphate concentrations at St. Esprit and Desrochers

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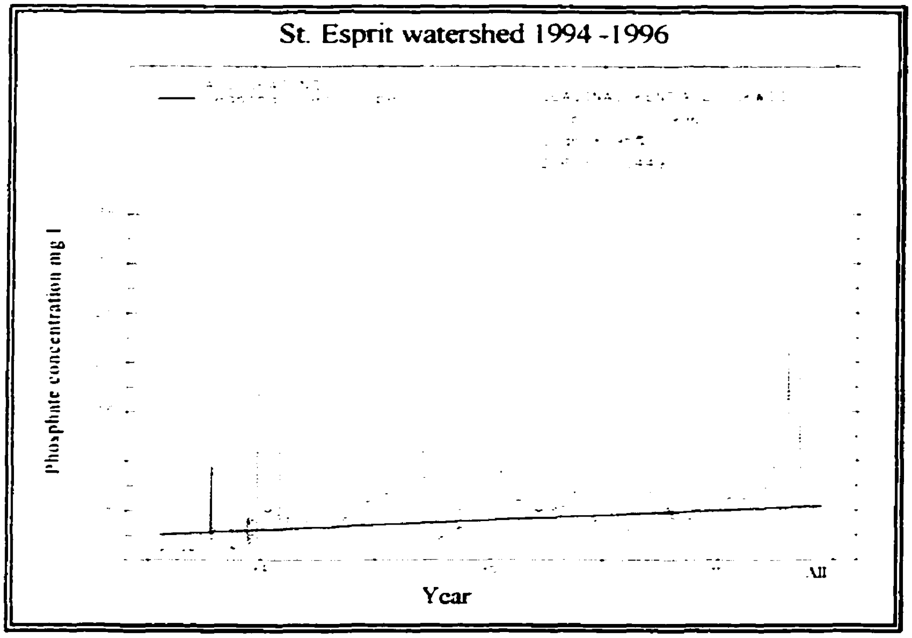

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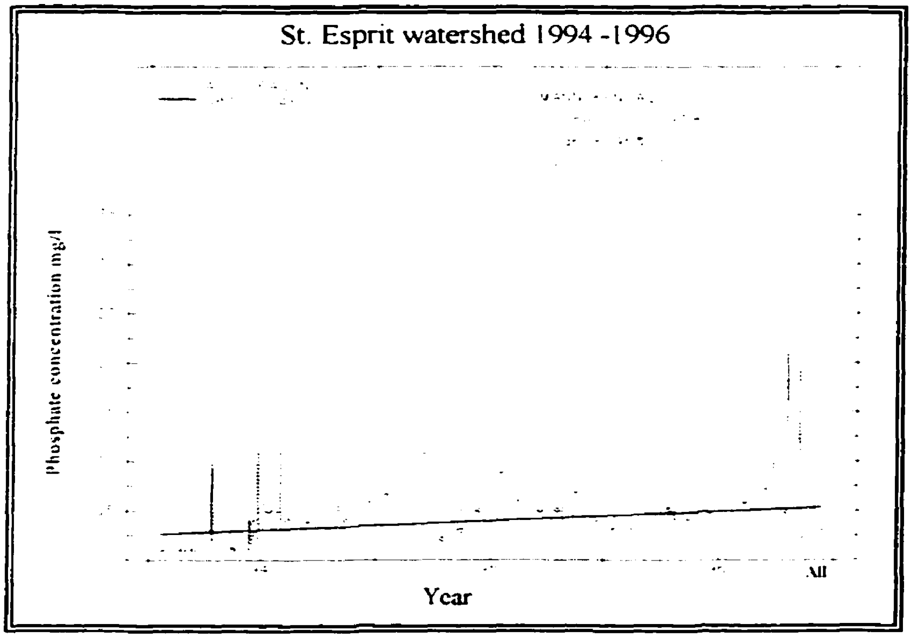

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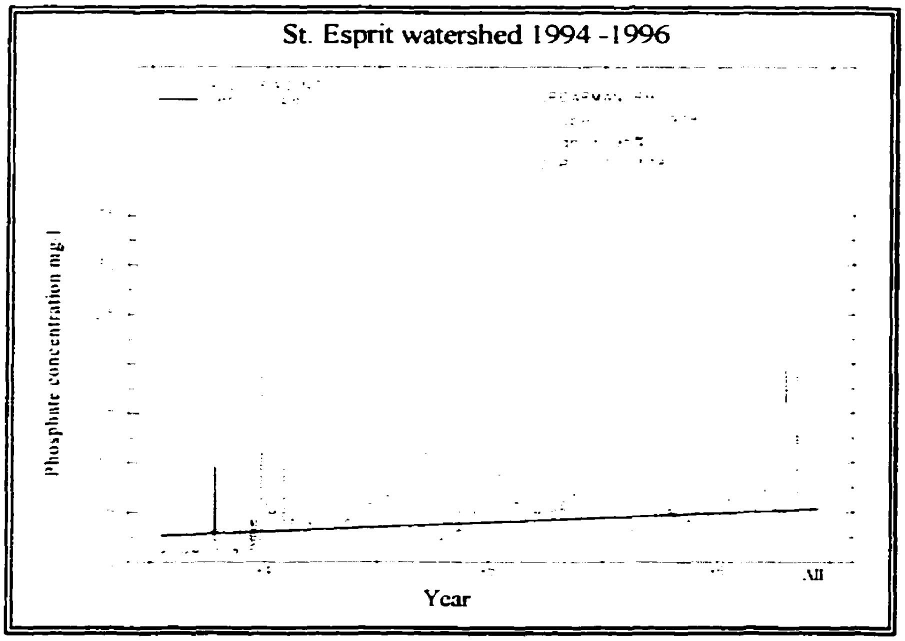

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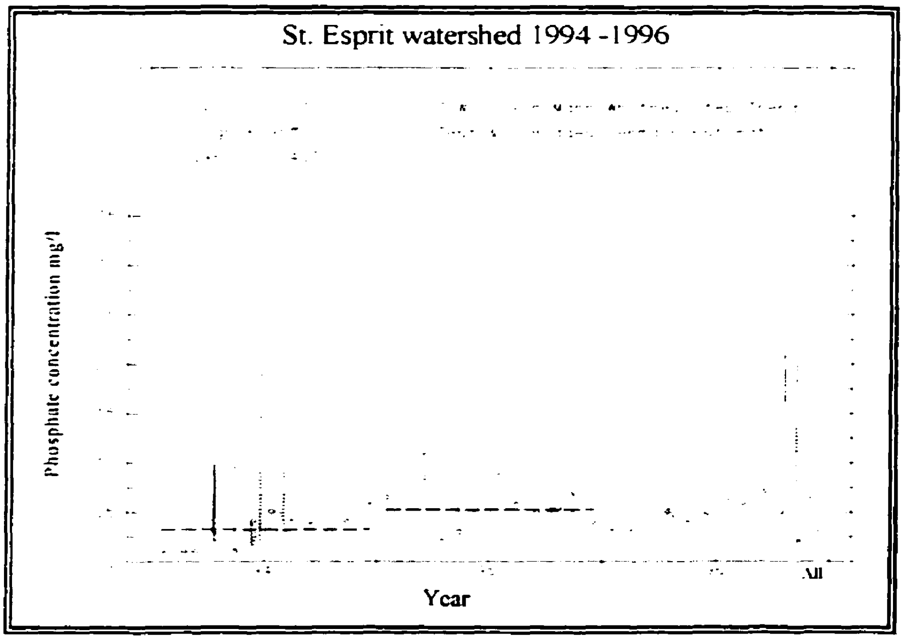

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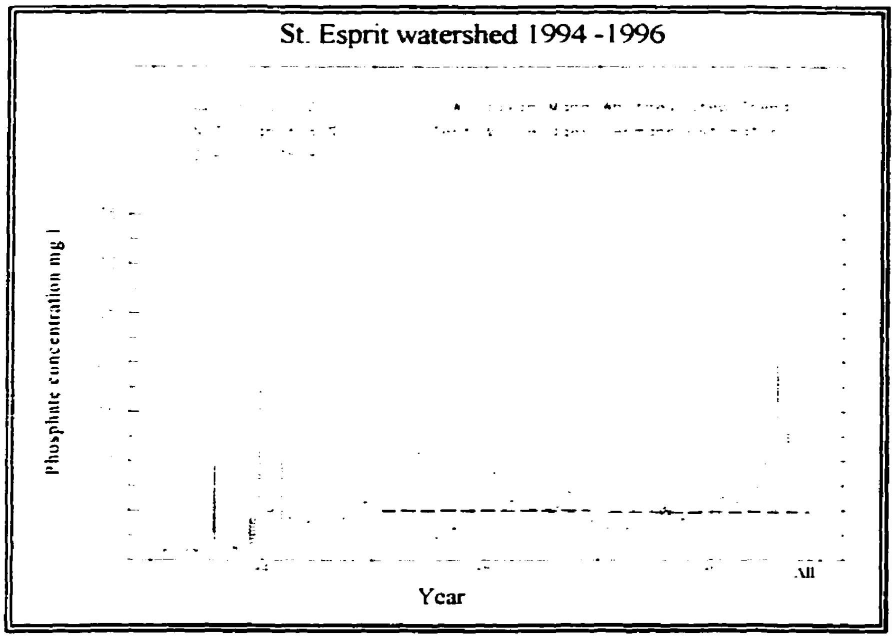

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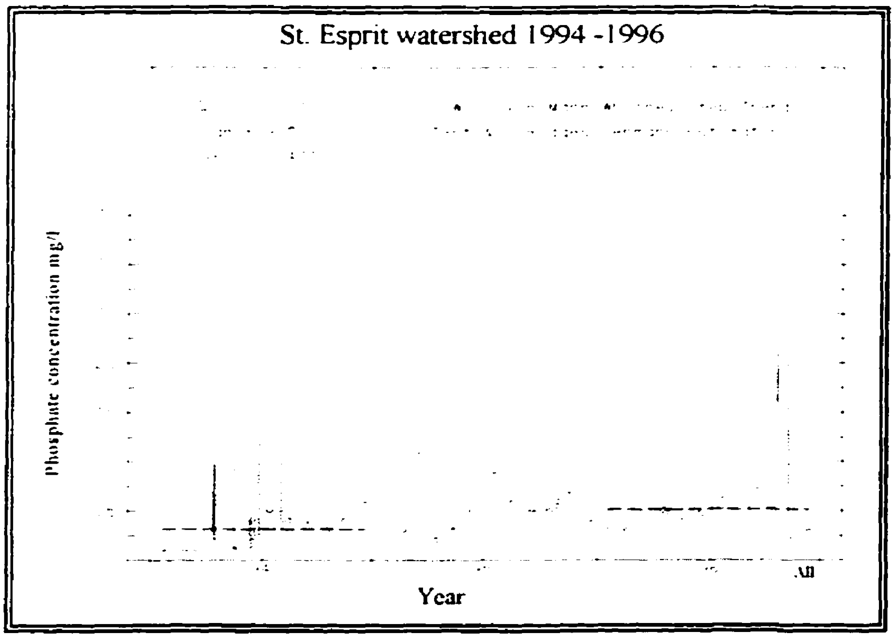

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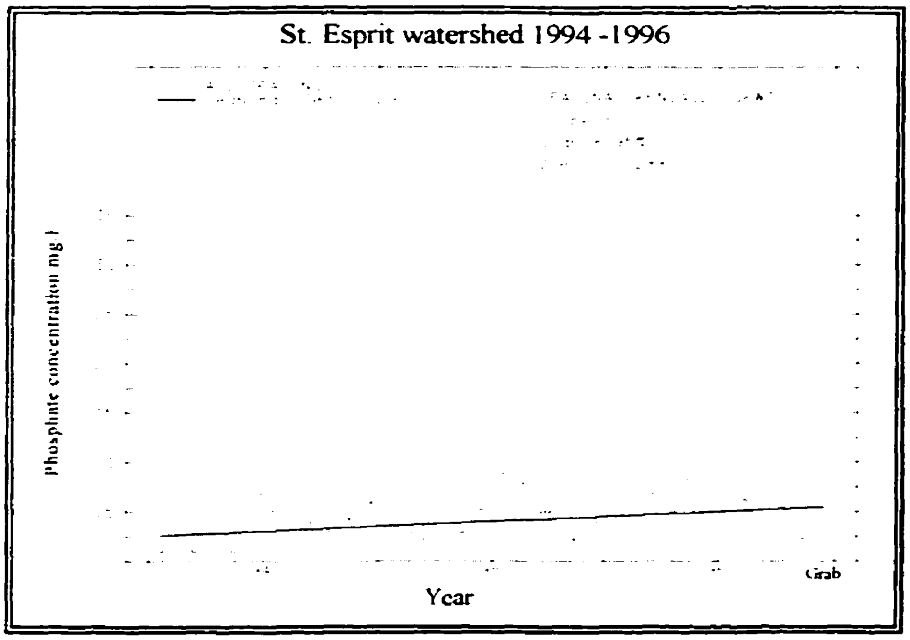

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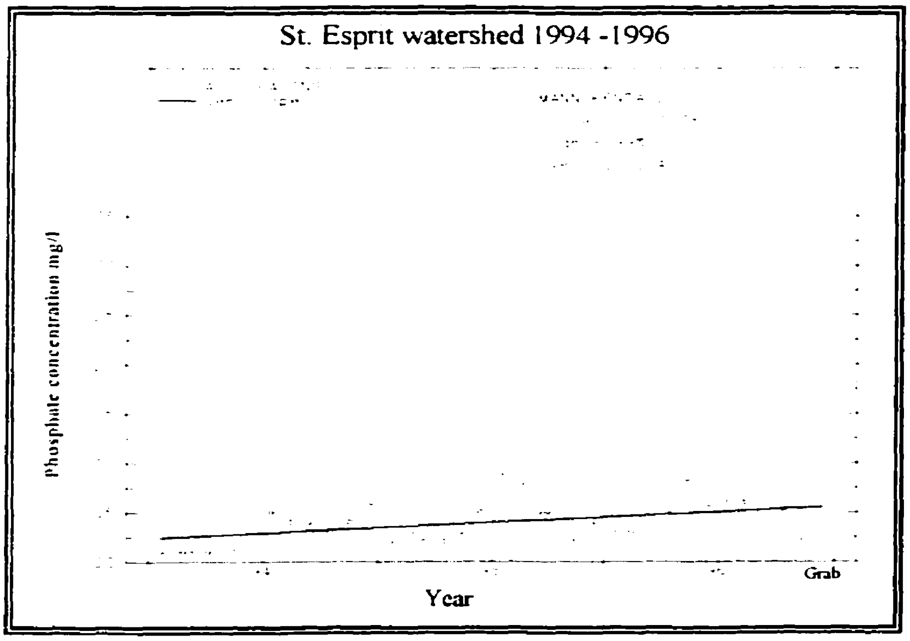

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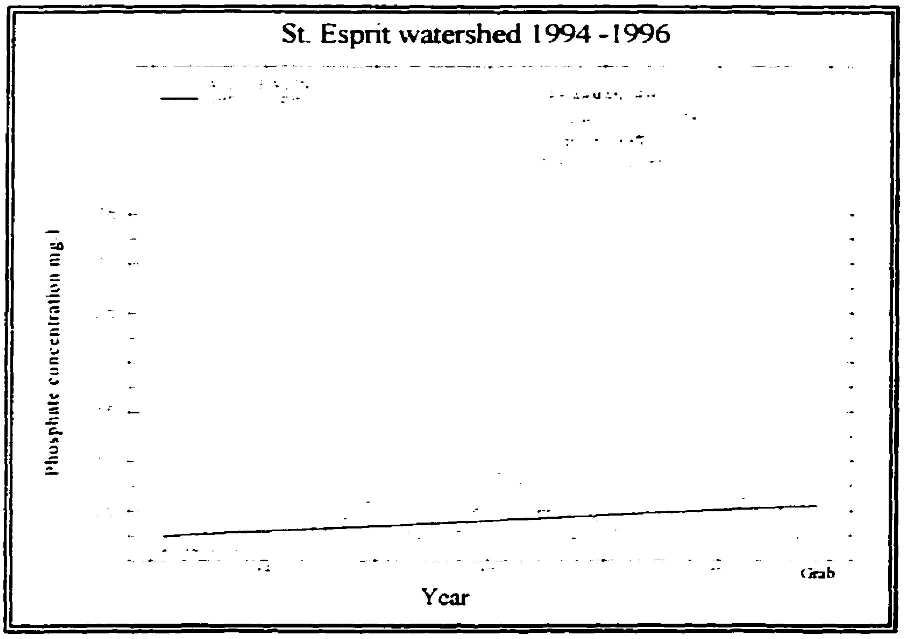

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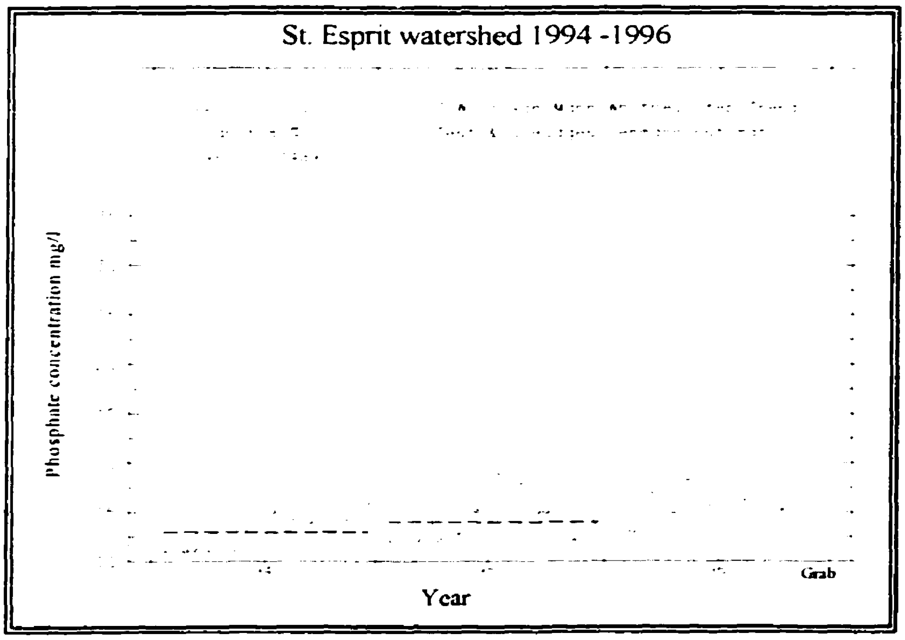

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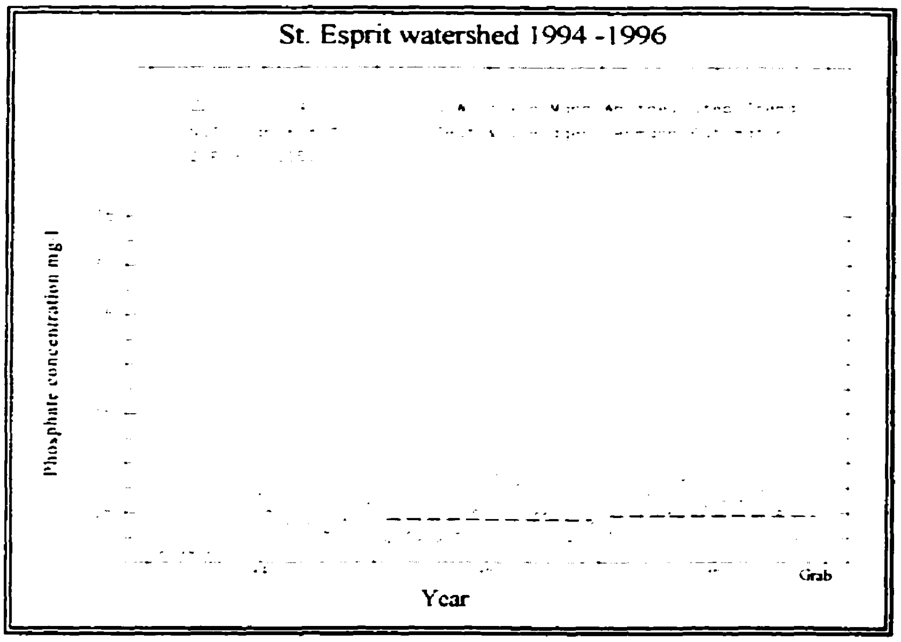

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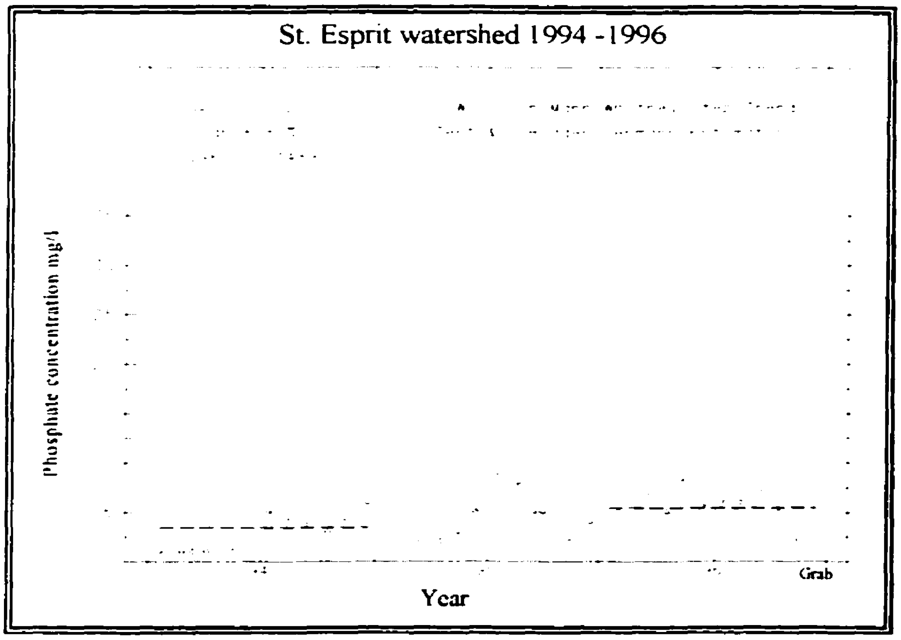

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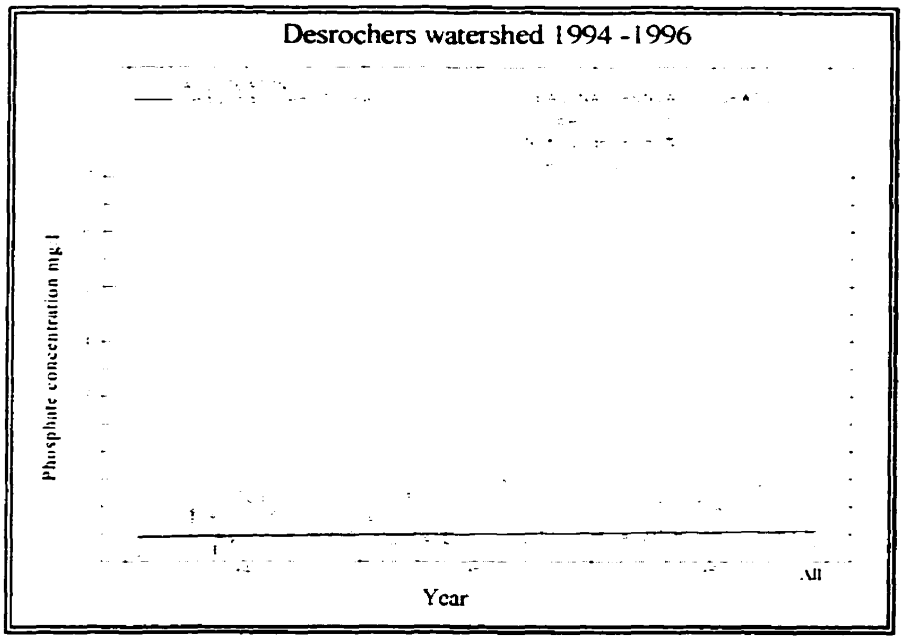

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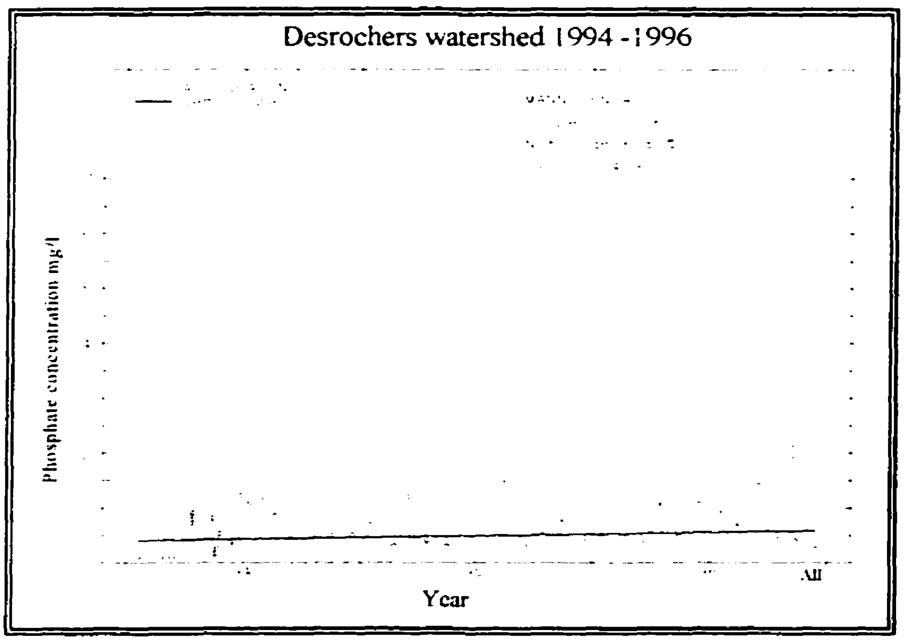

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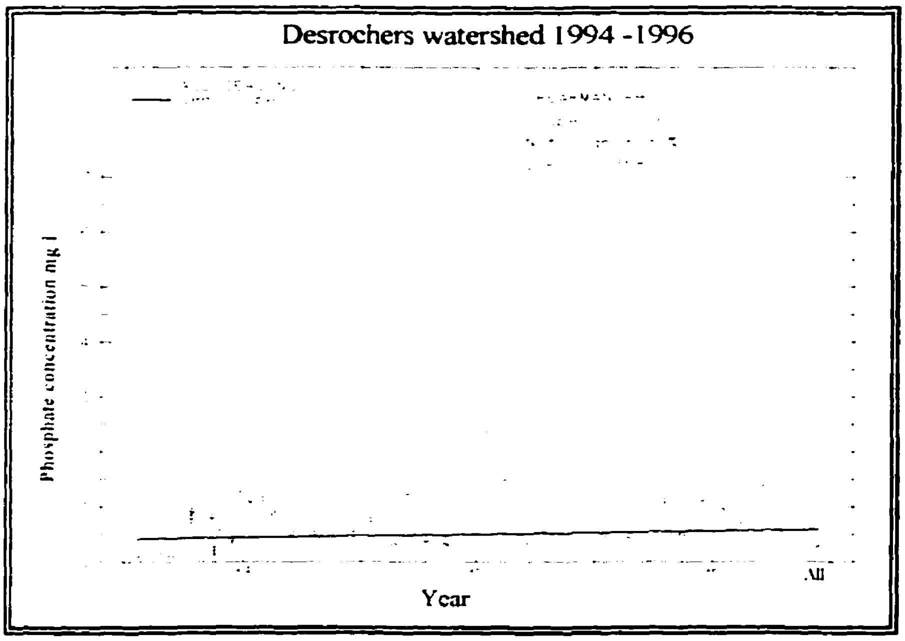

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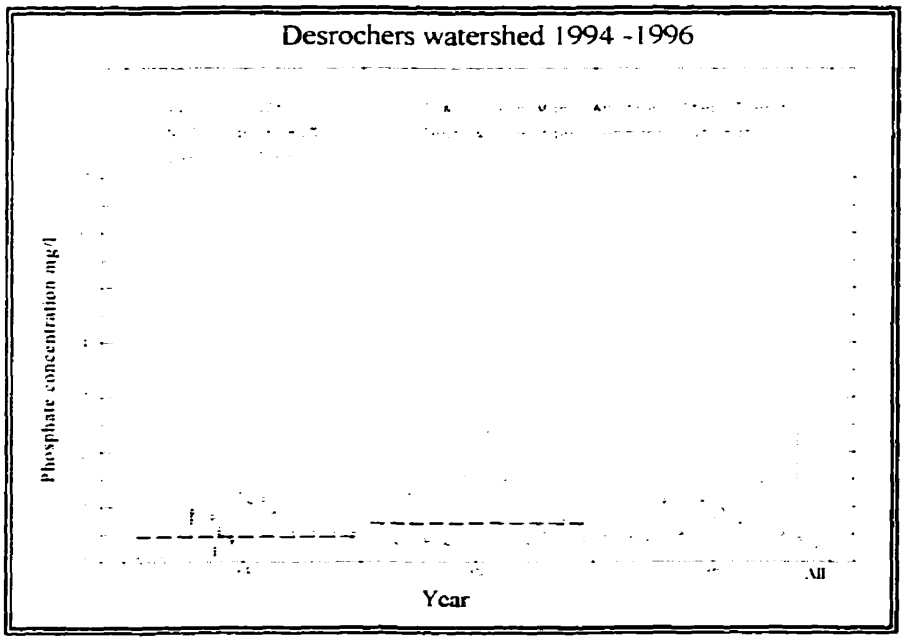

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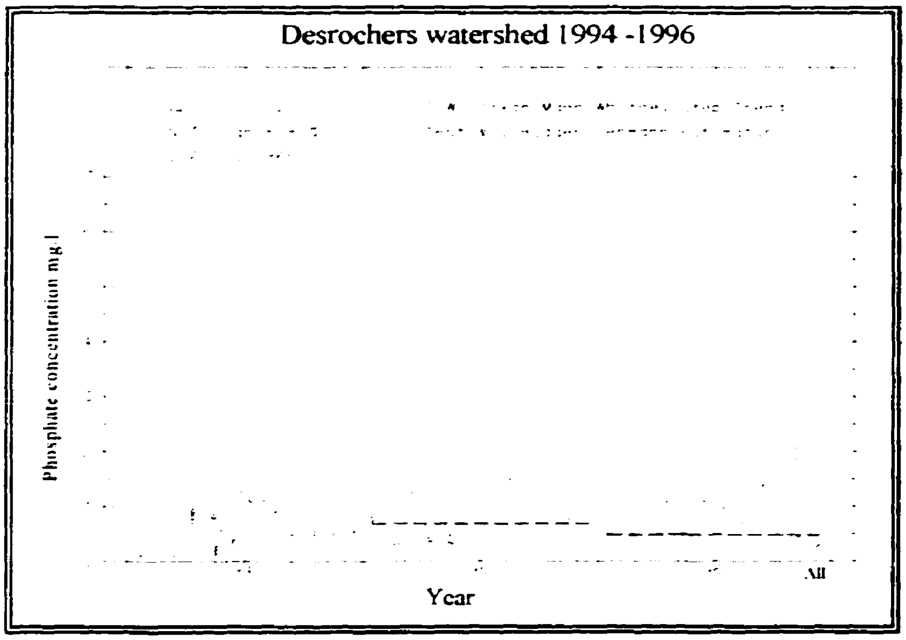

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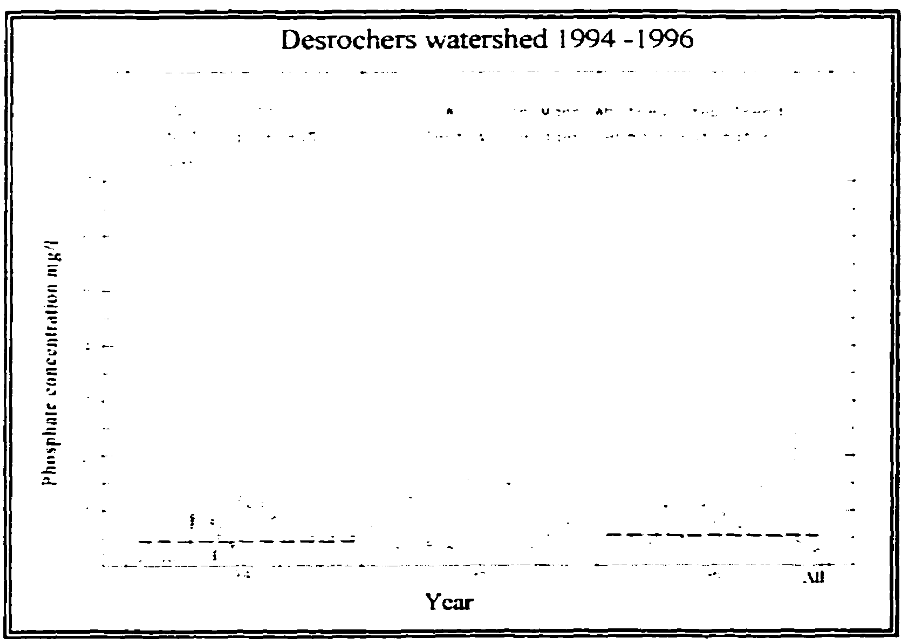

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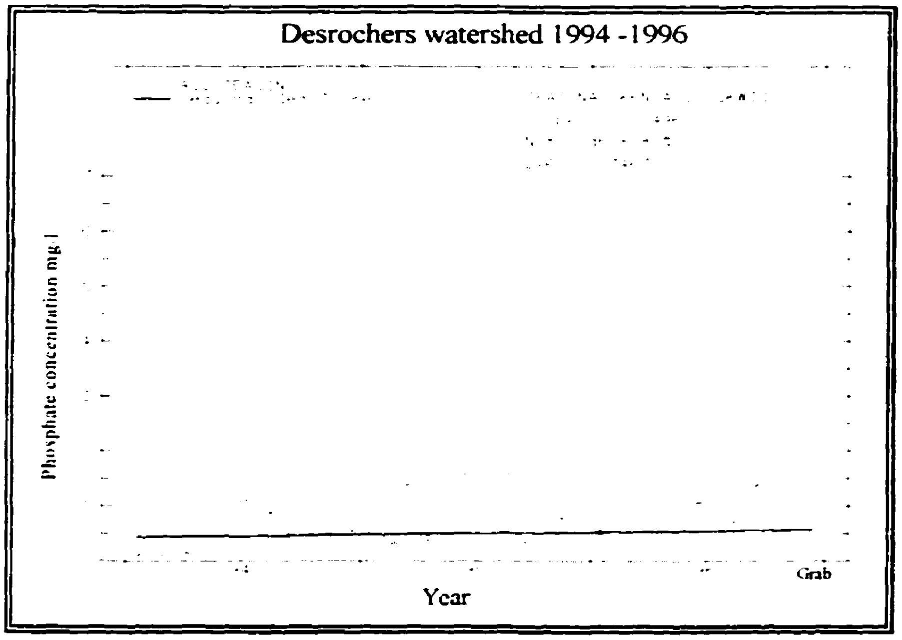

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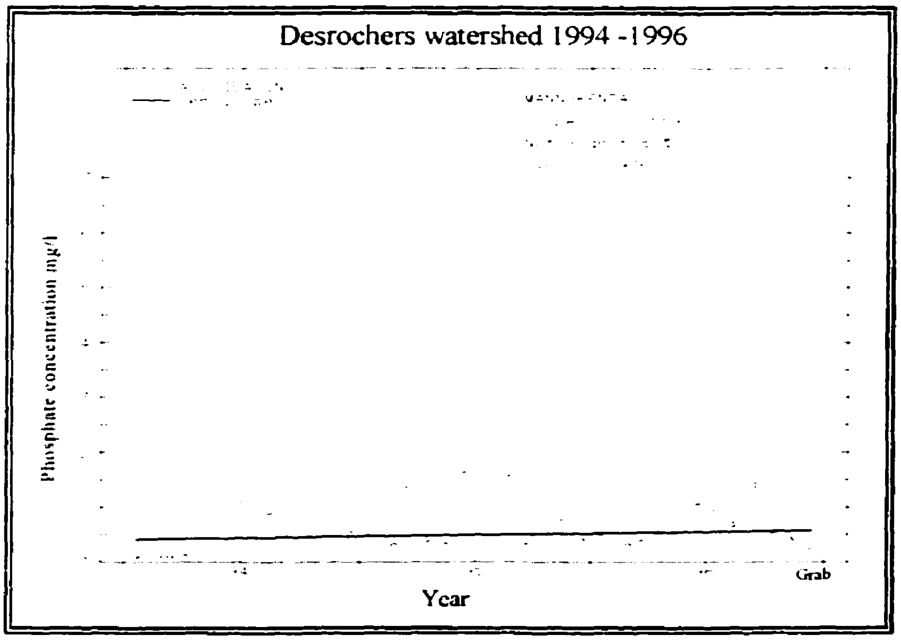

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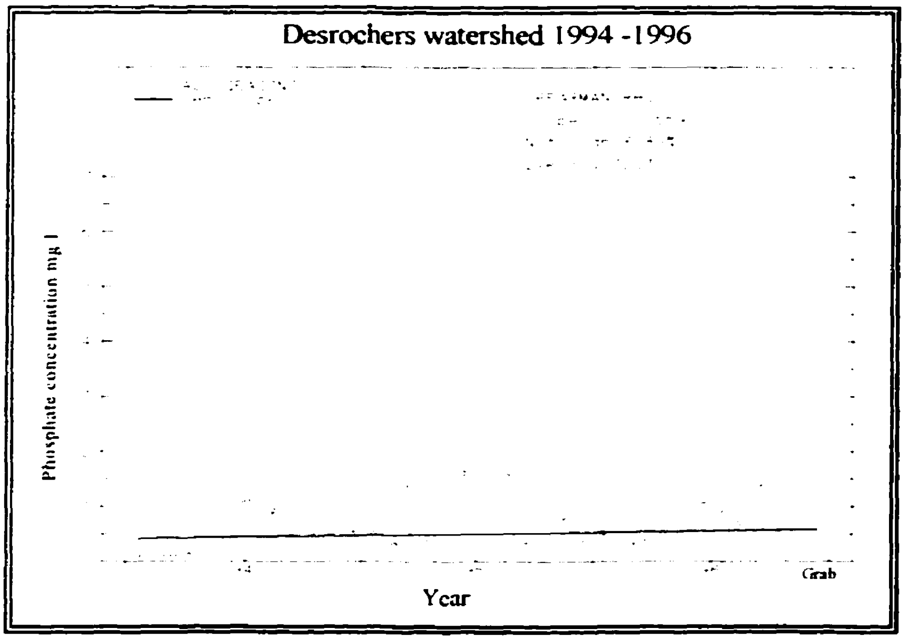

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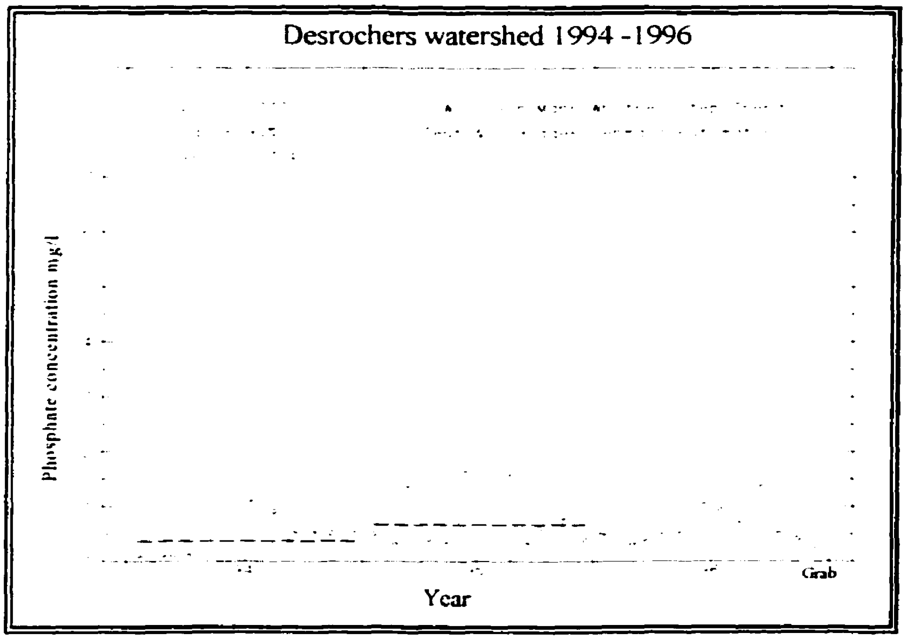

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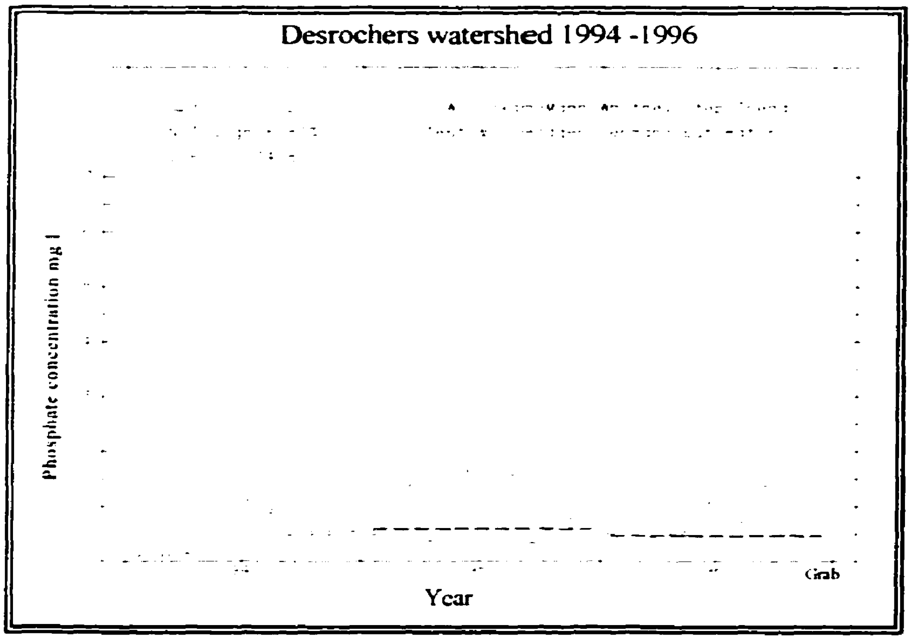

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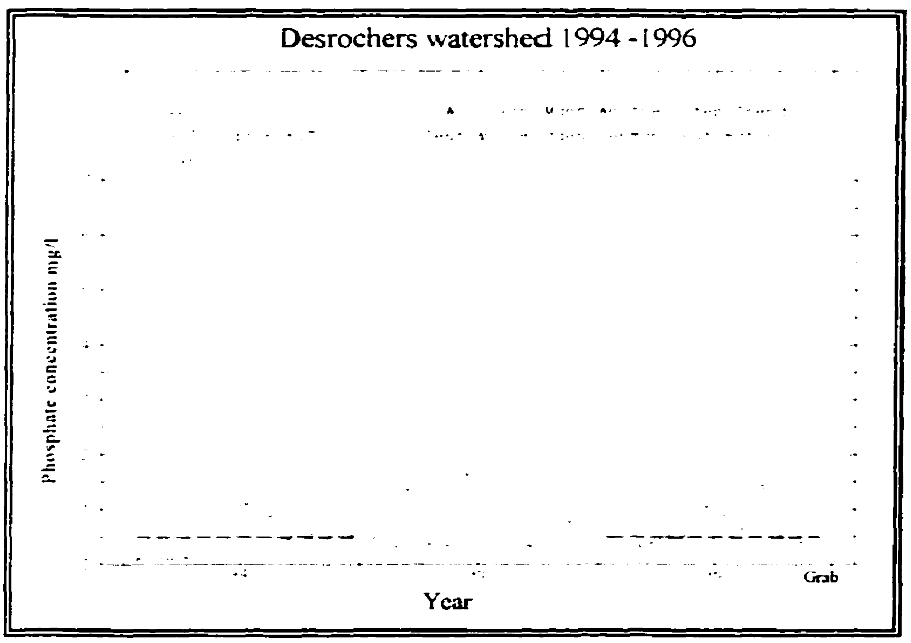

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Appendix G

Graphical Display of the non-parametric test for trend for potassium concentrations at St. Esprit and Desrochers

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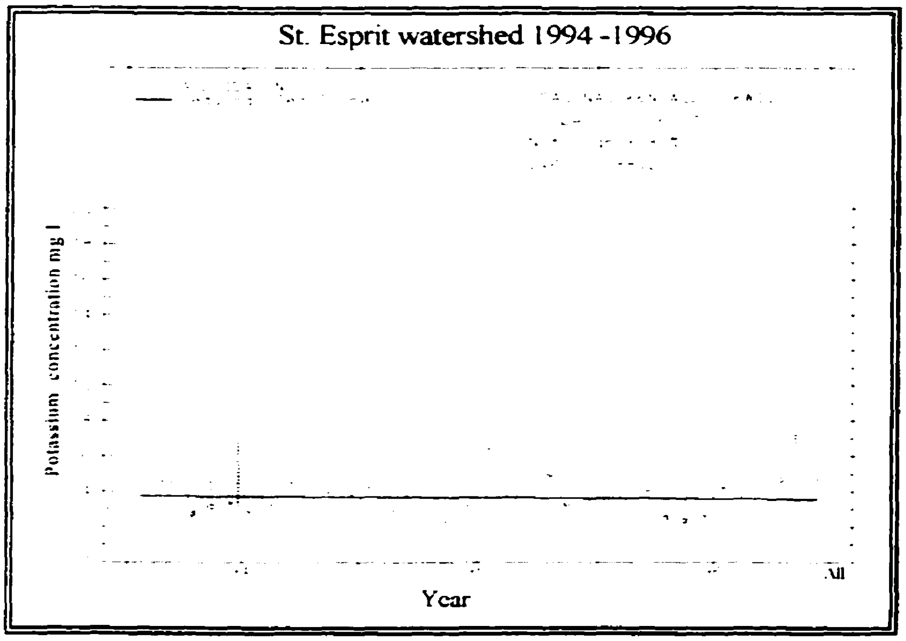

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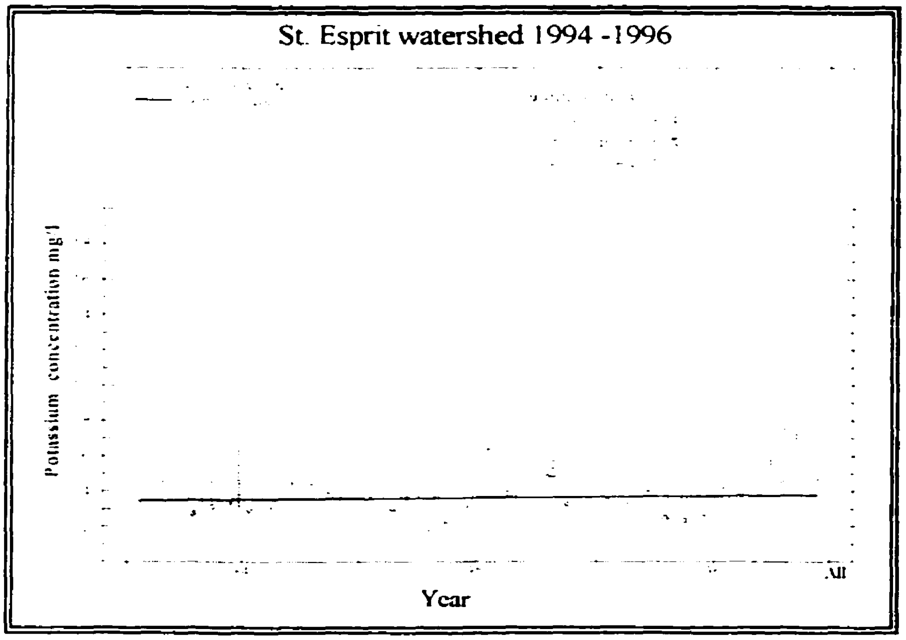

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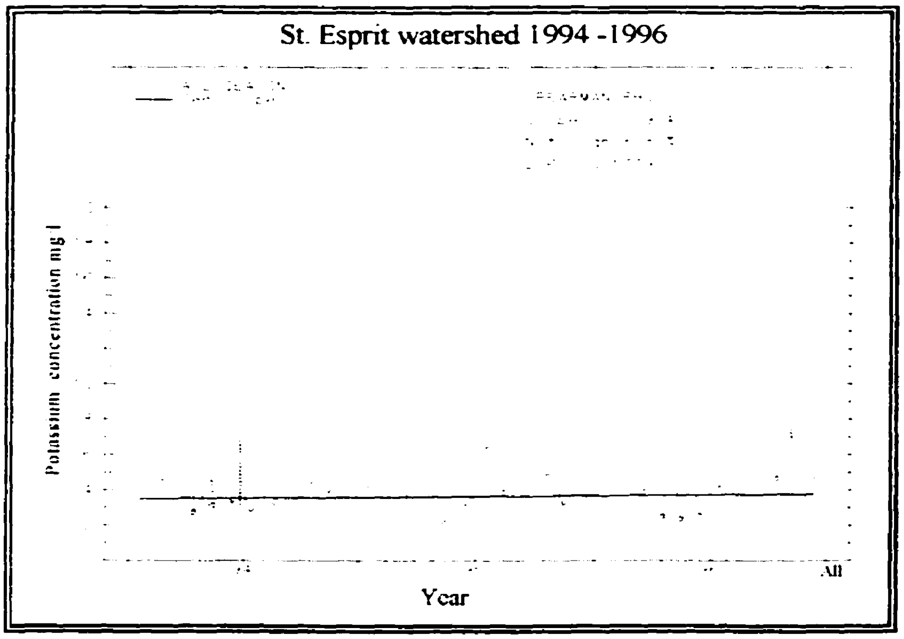

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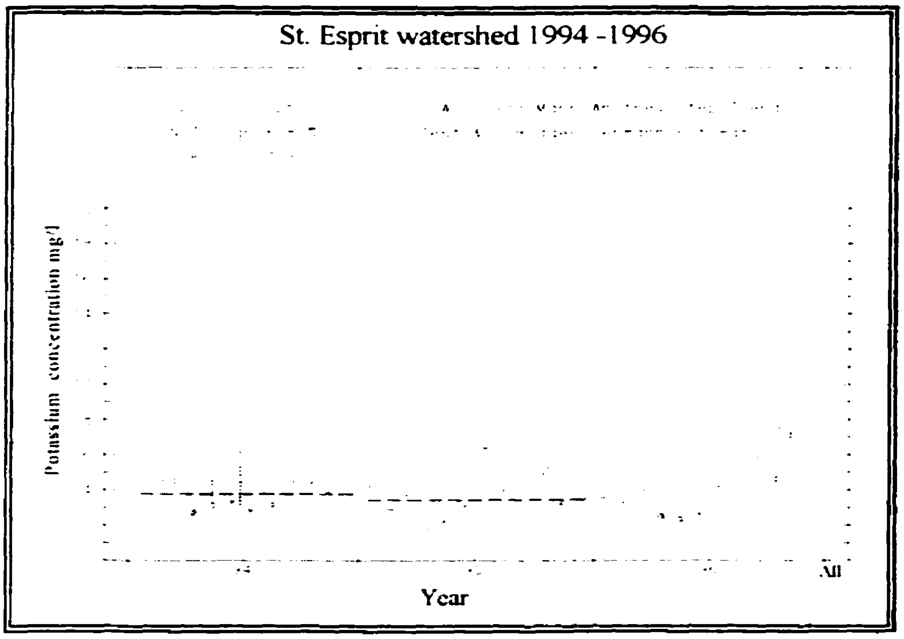

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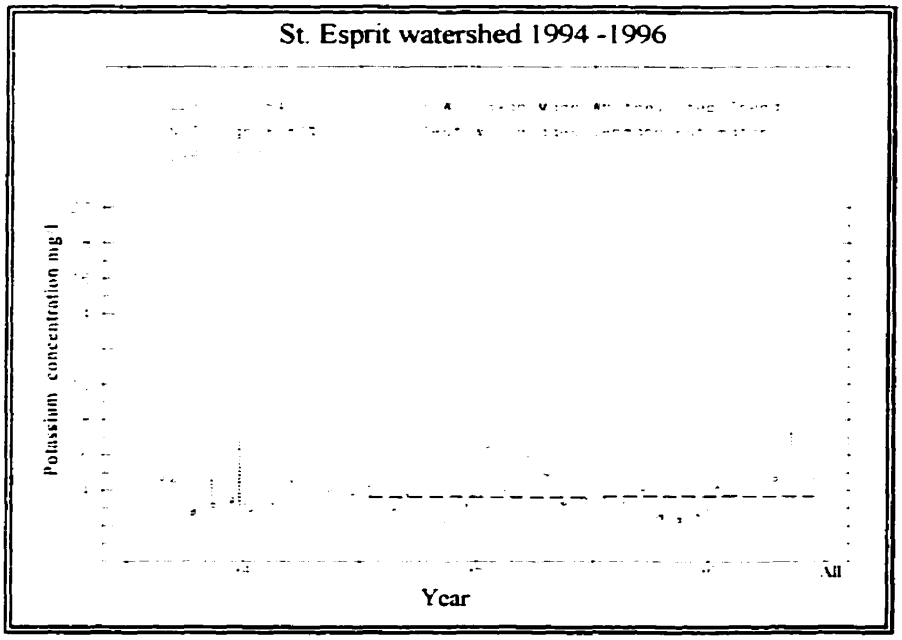

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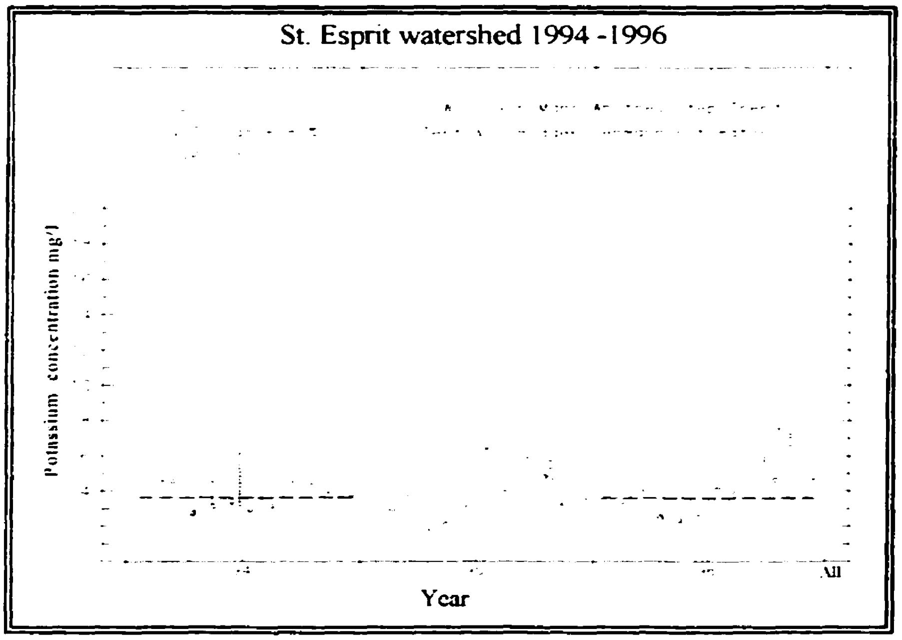

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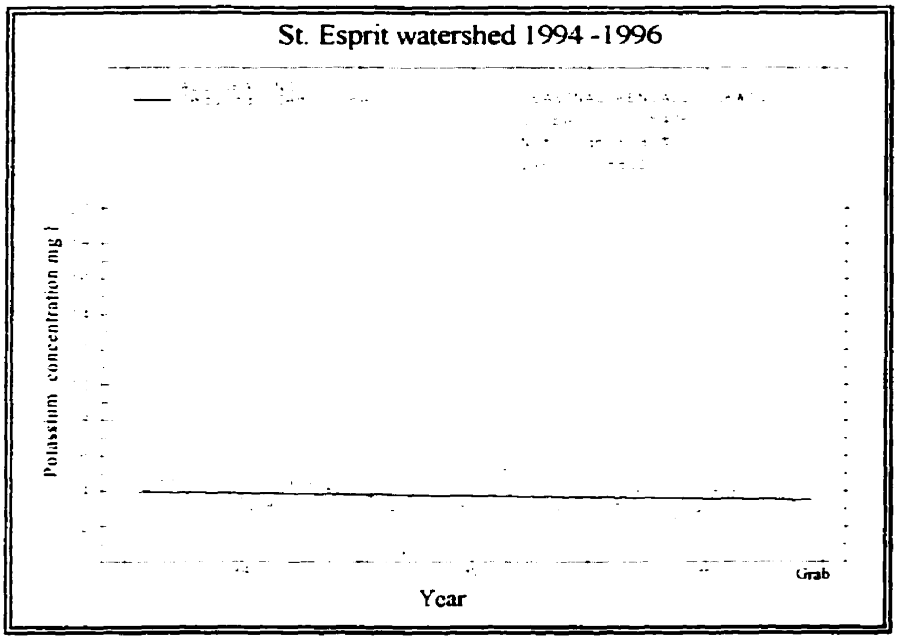

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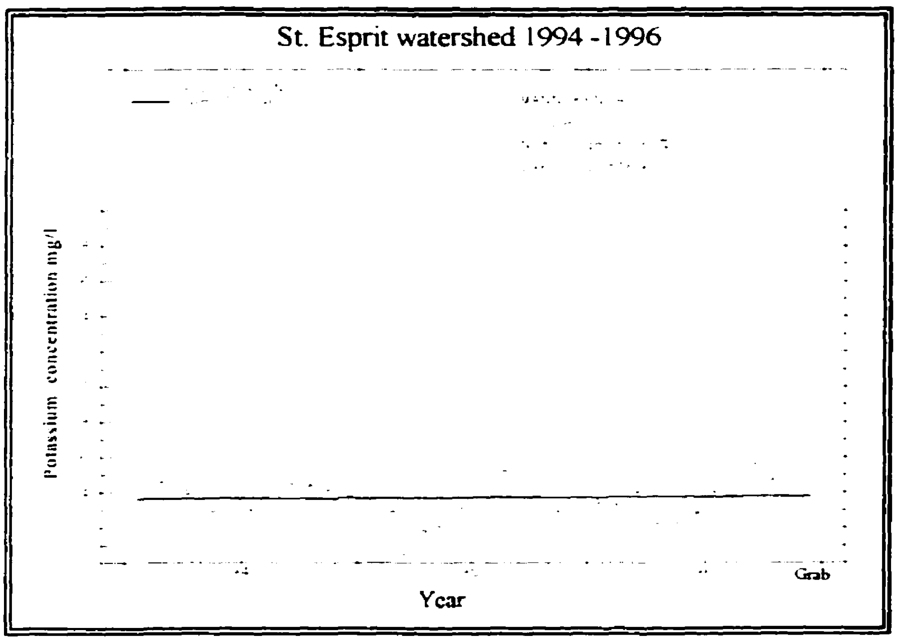

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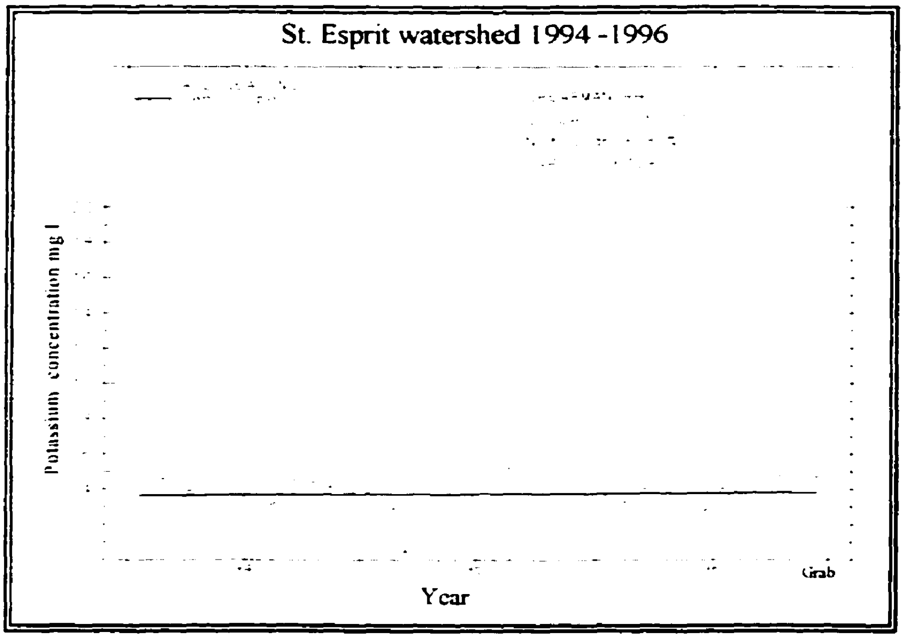

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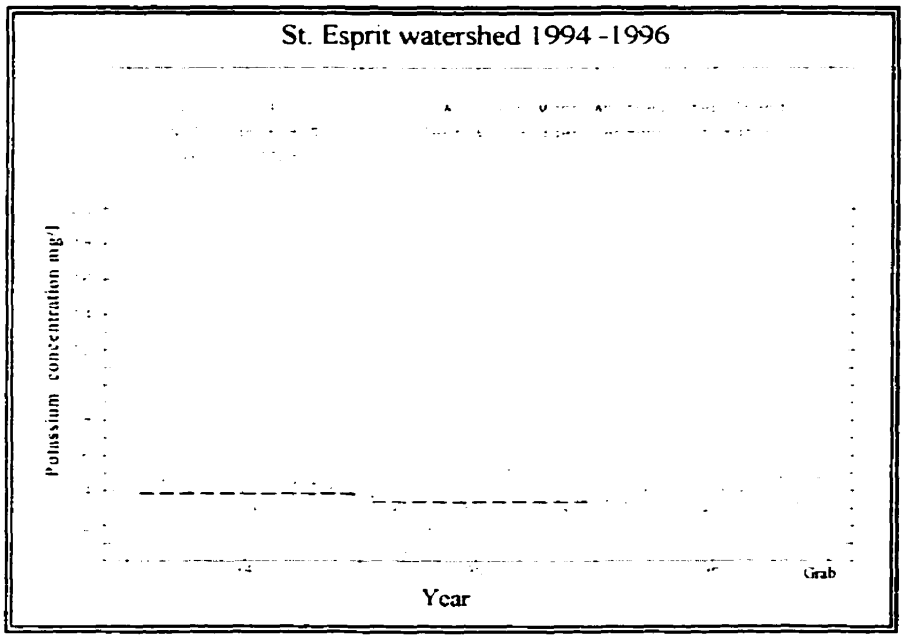

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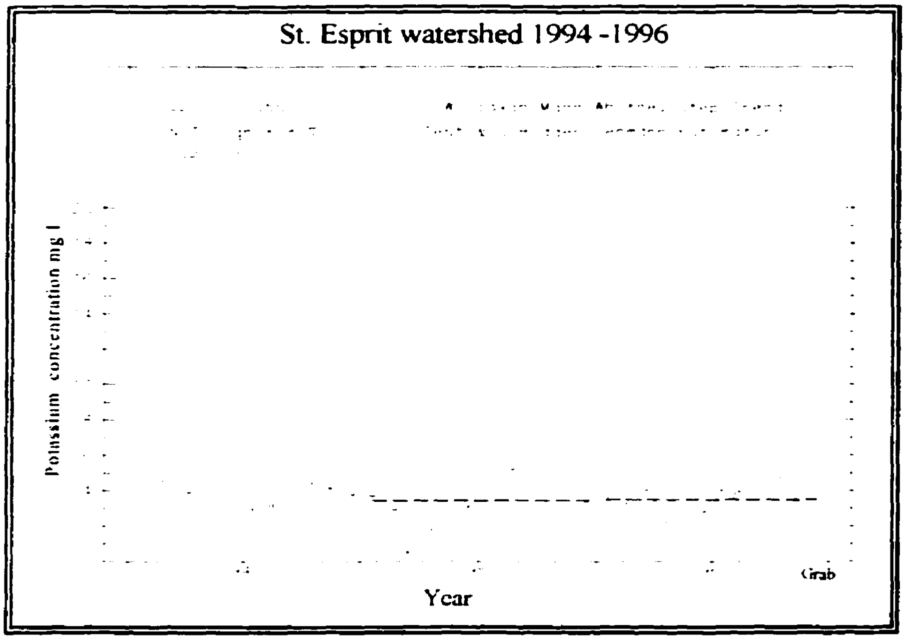

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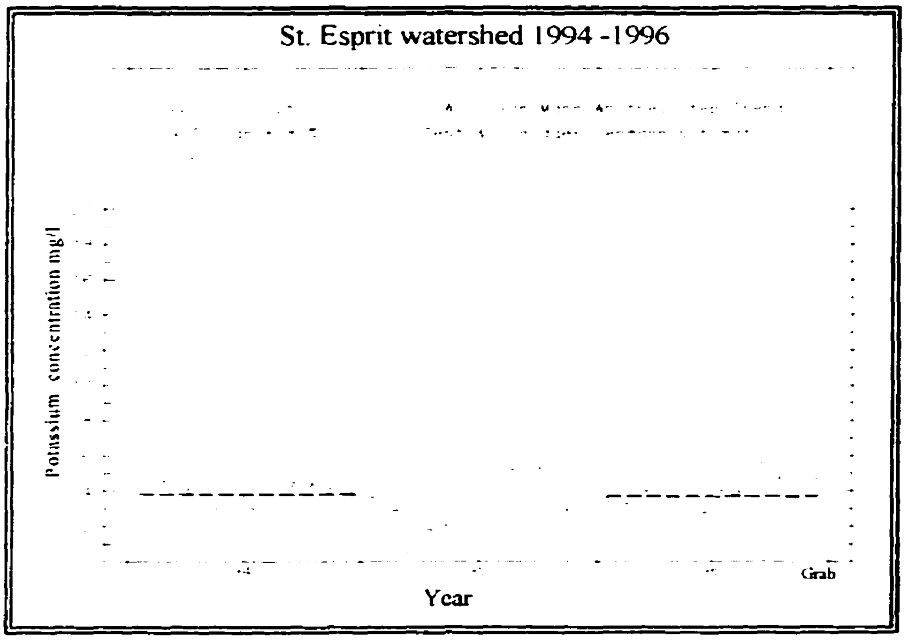

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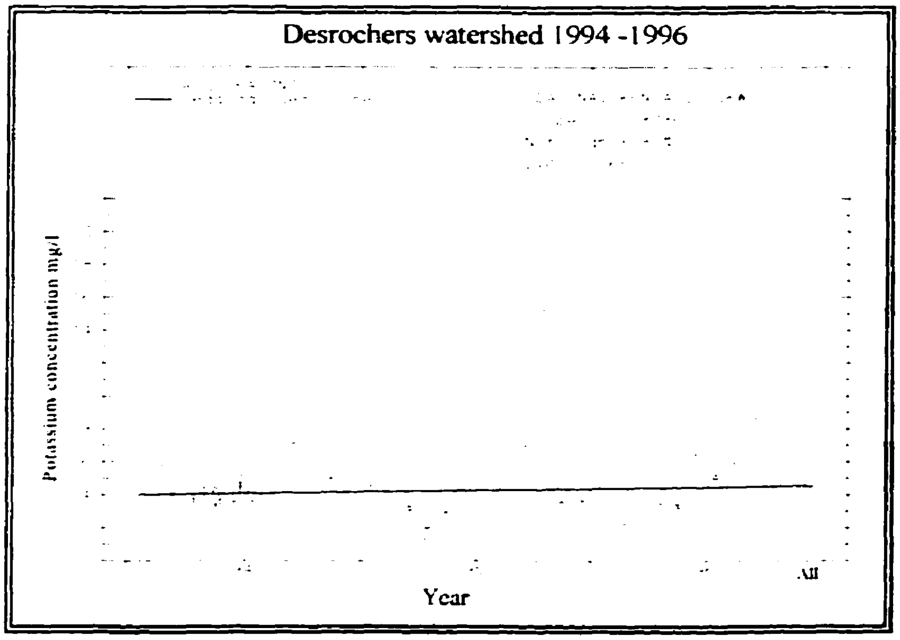

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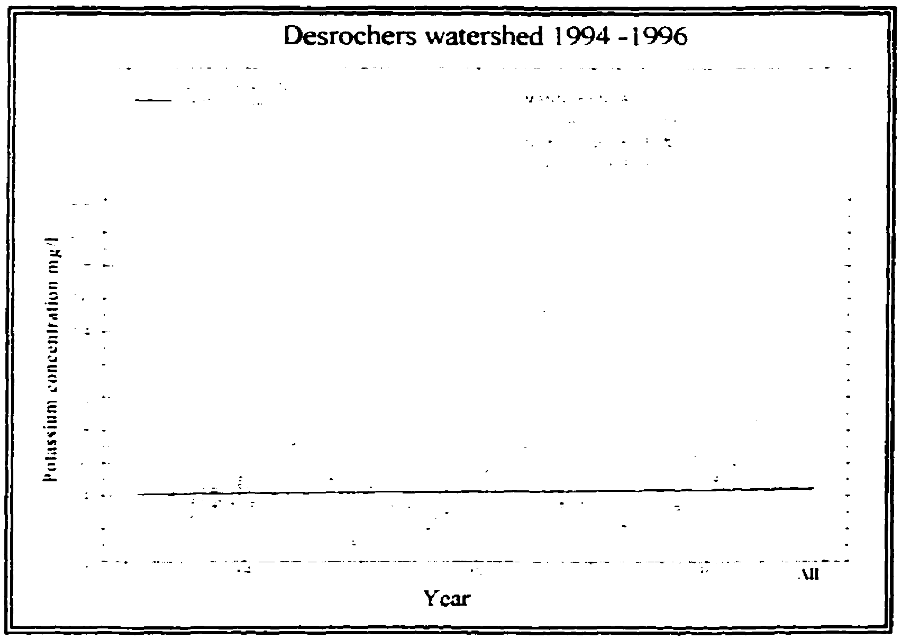

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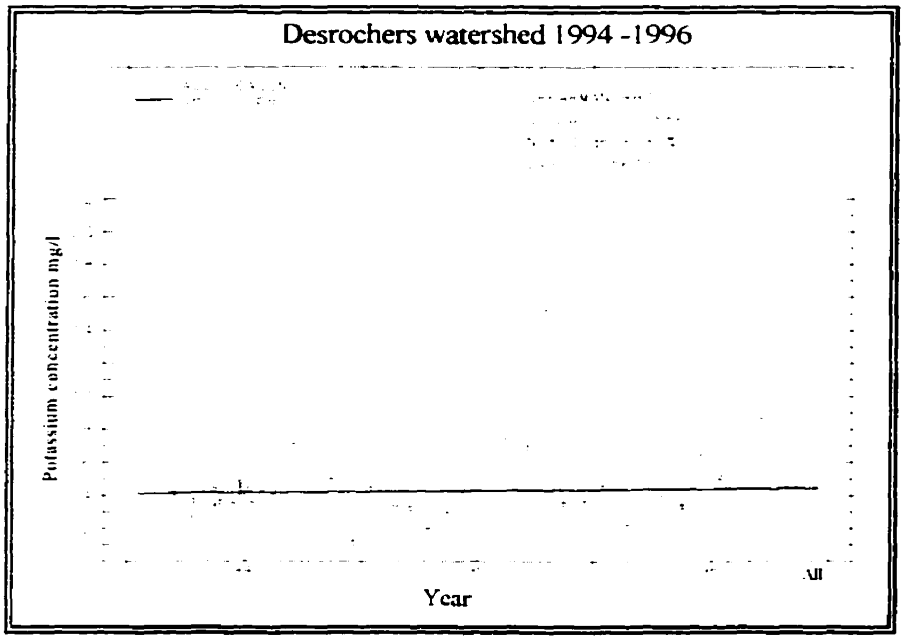

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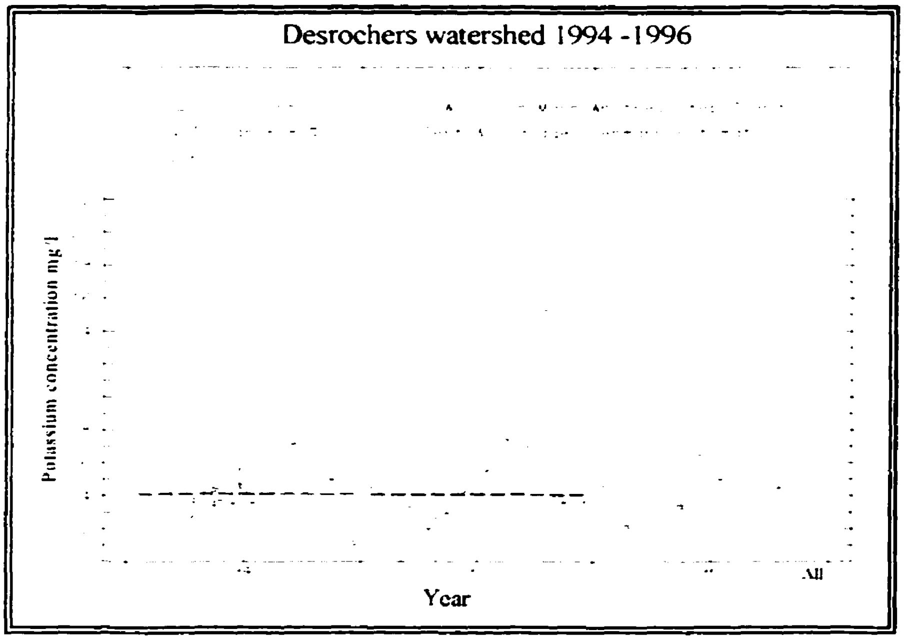

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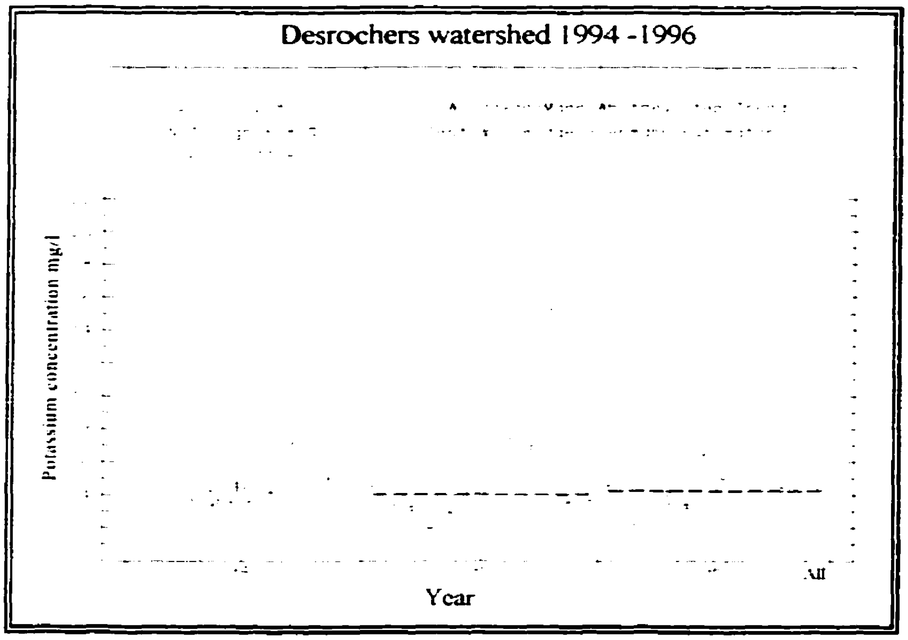

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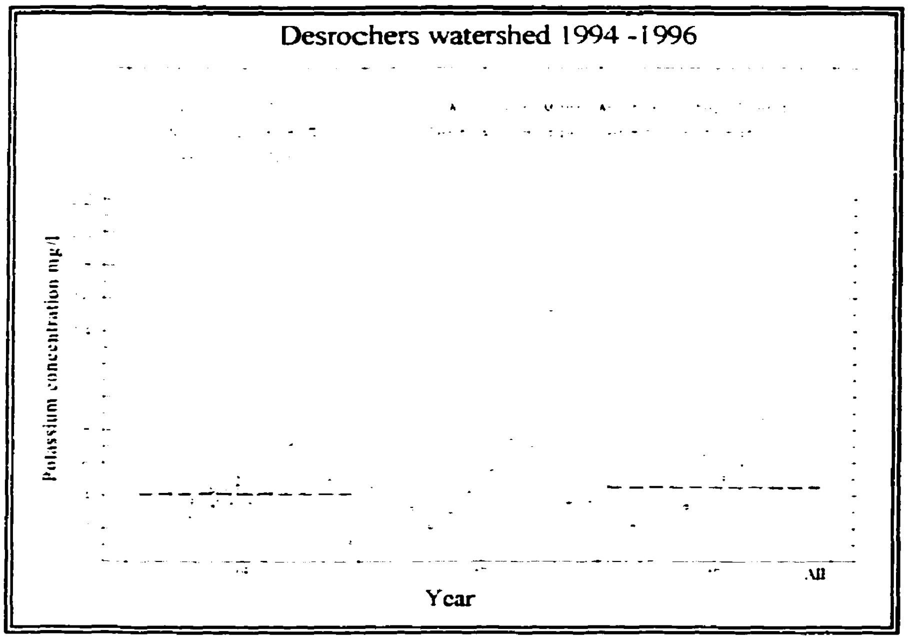

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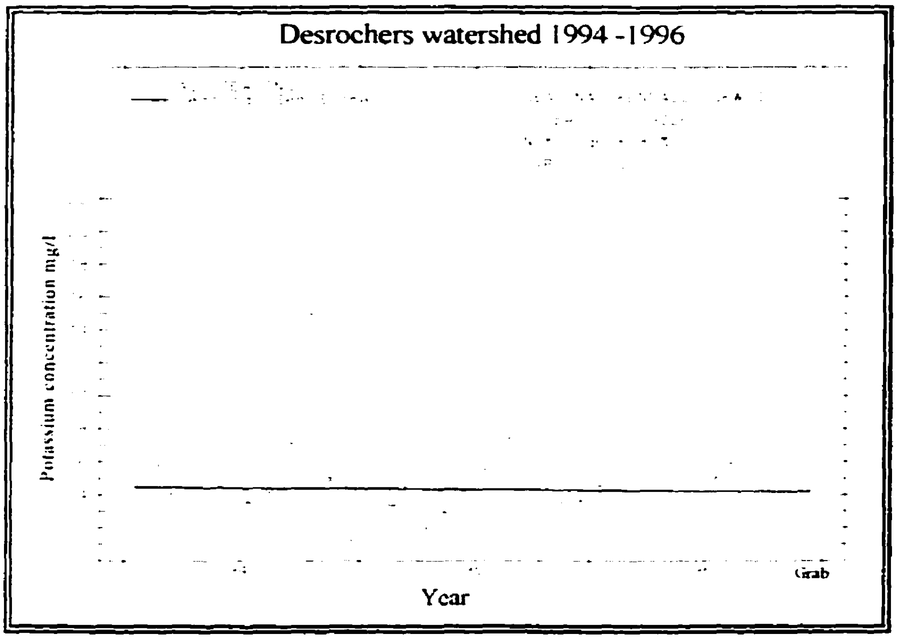

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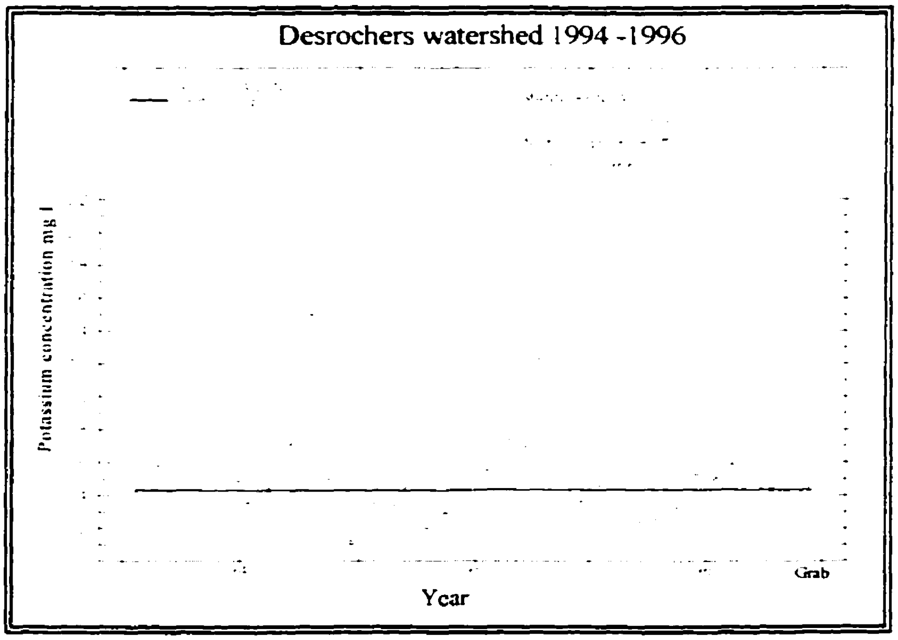

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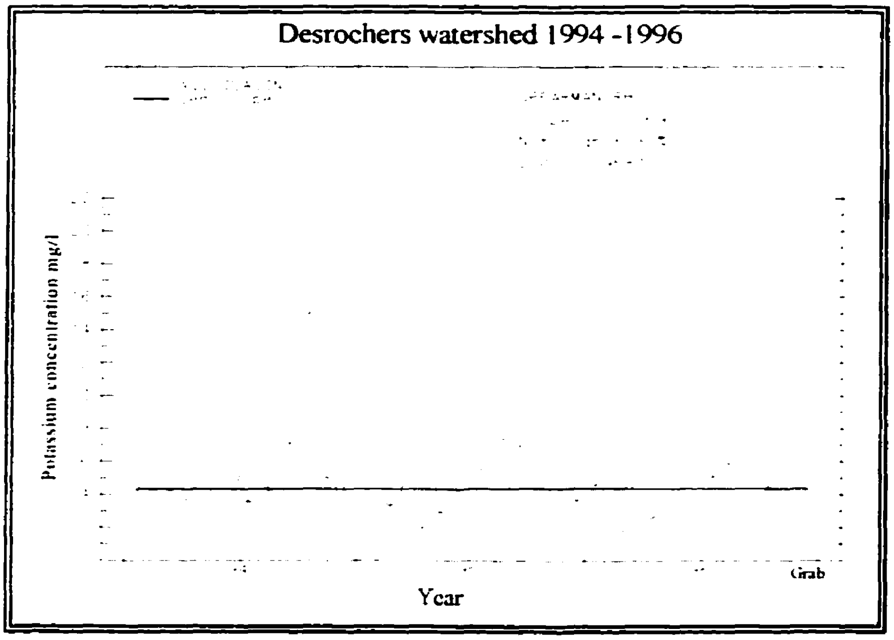

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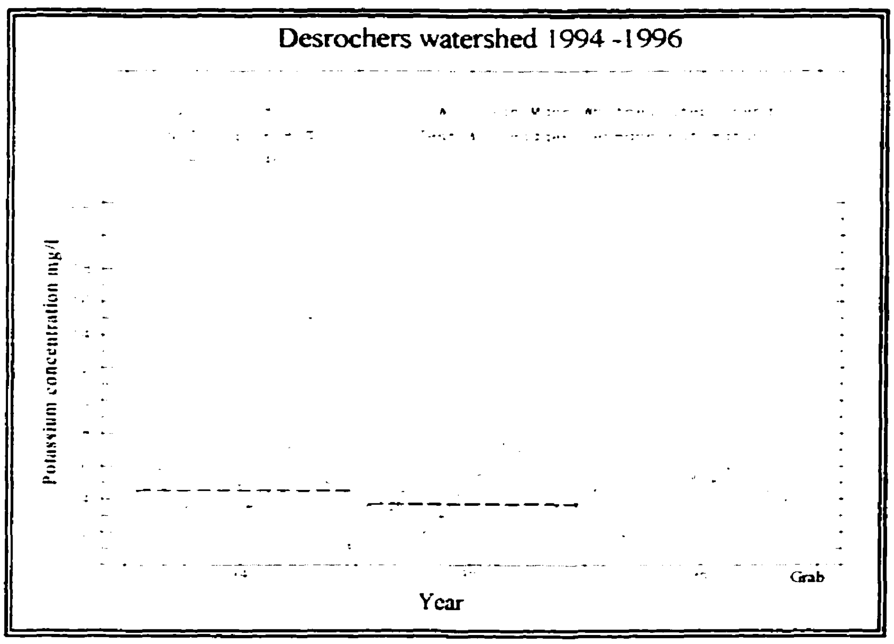

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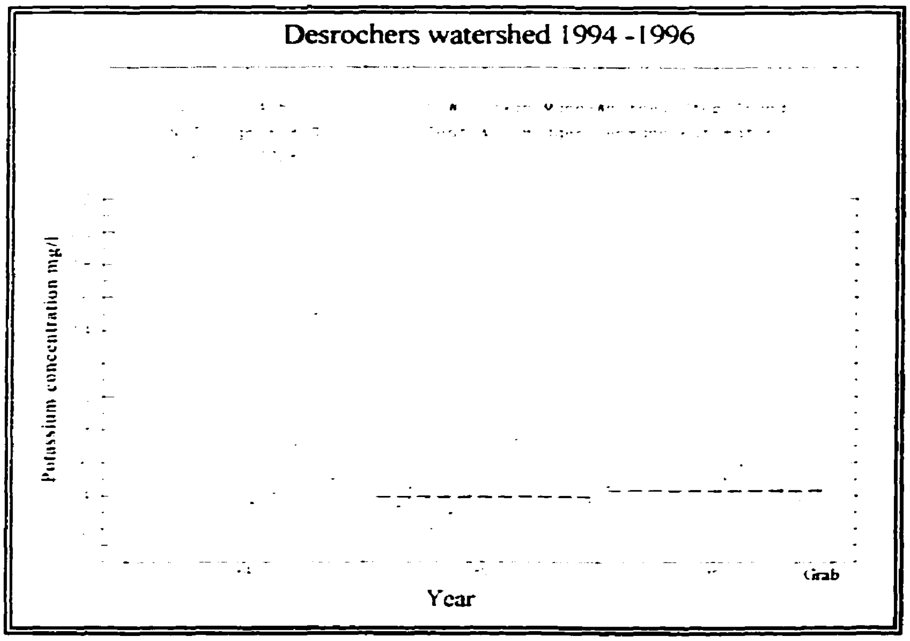

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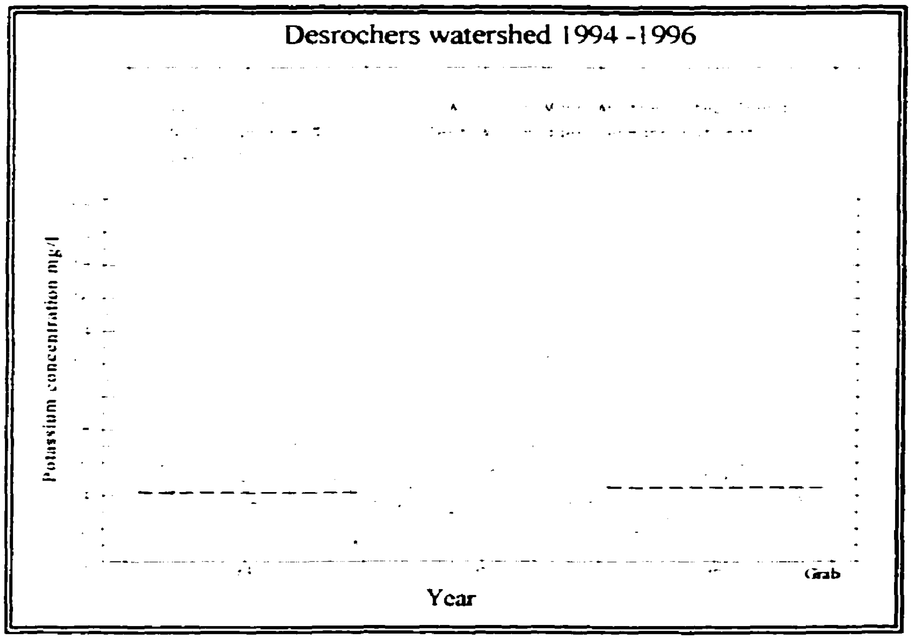

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Appendix H

Graphical Display of the non-parametric test for trend for TKN concentrations at St. Esprit and Desrochers

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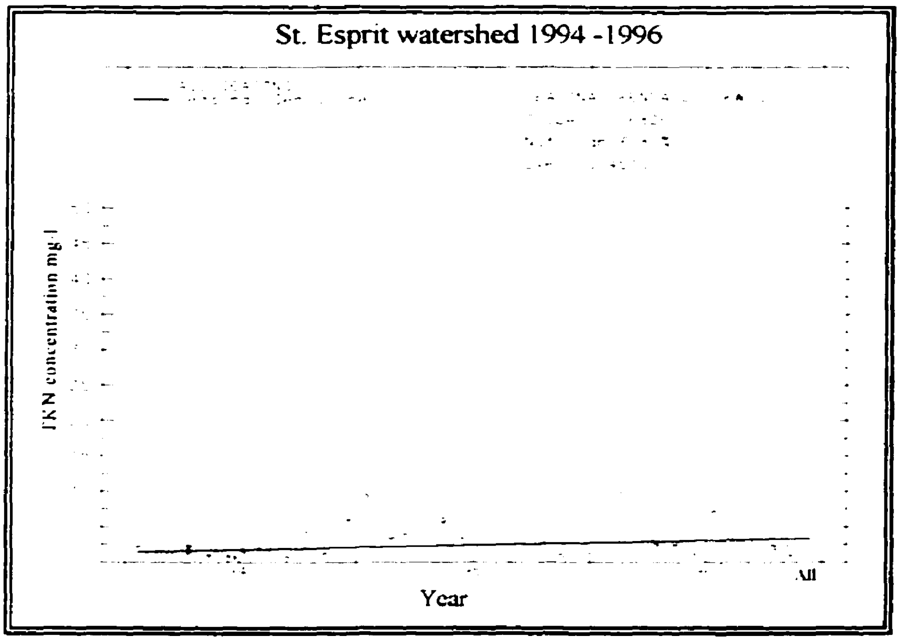

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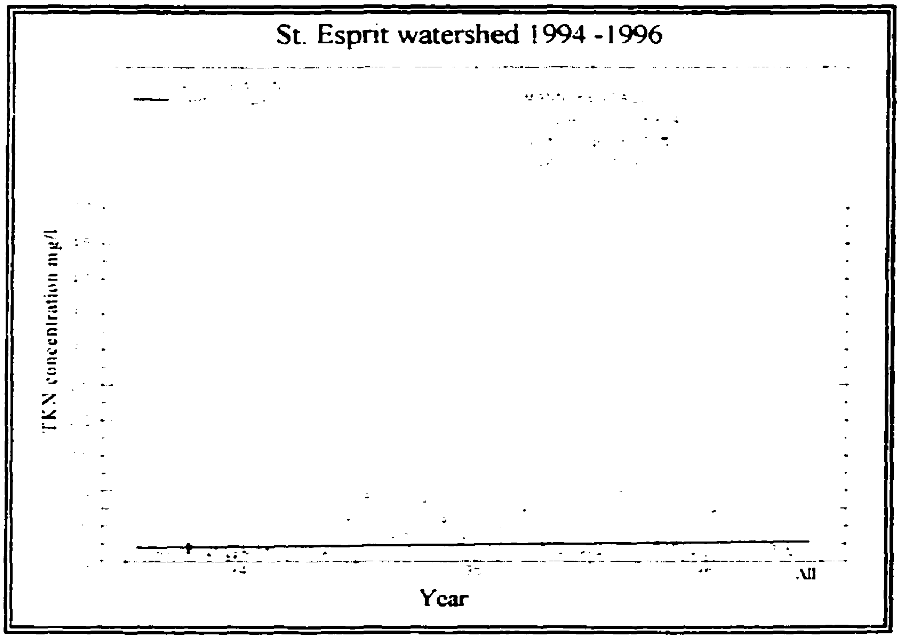

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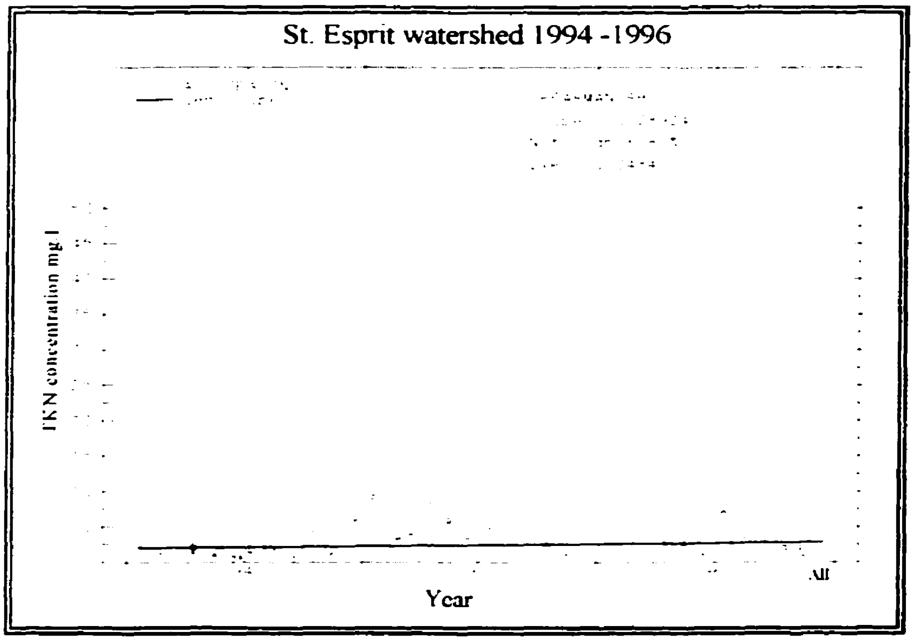

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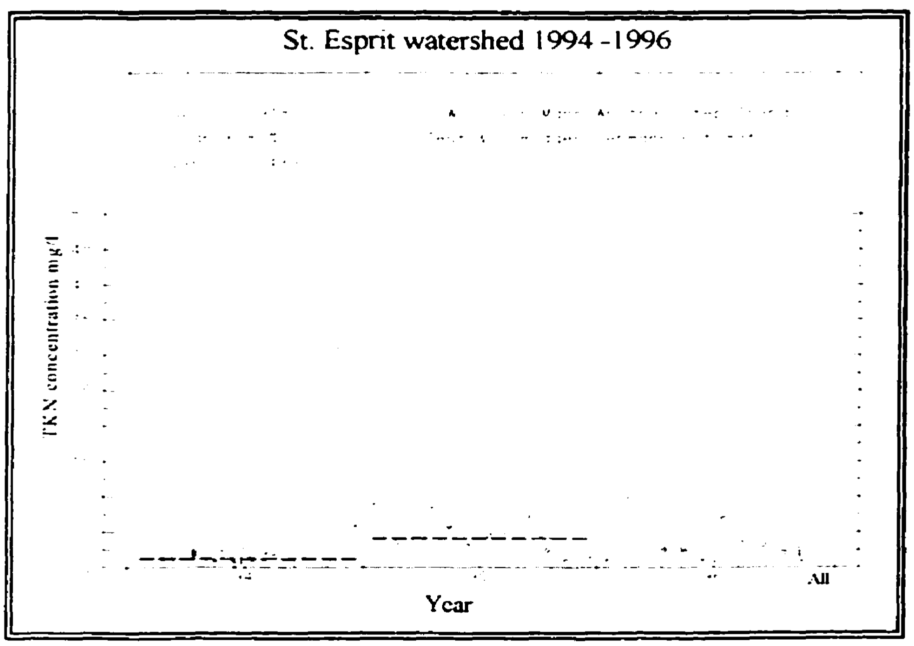

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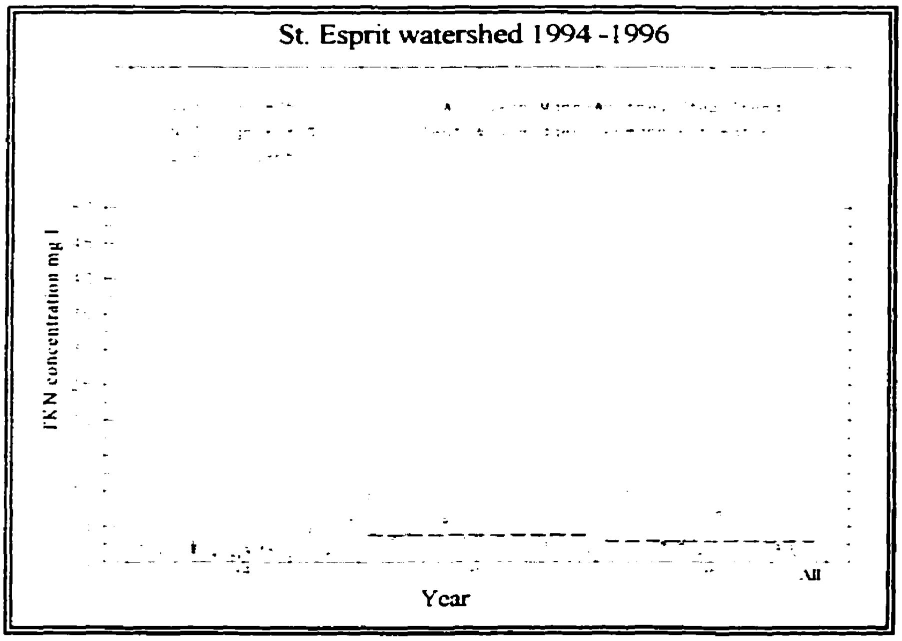

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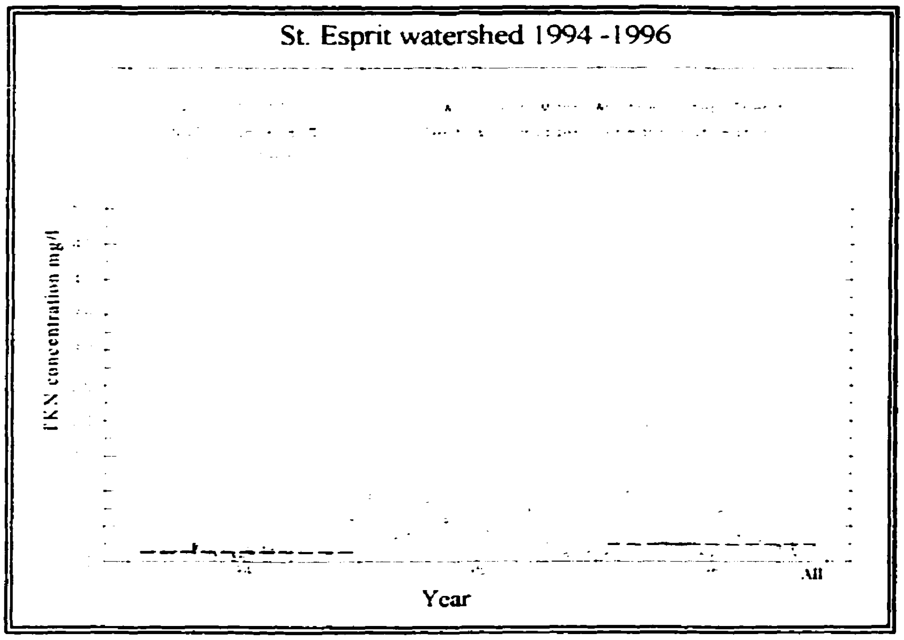

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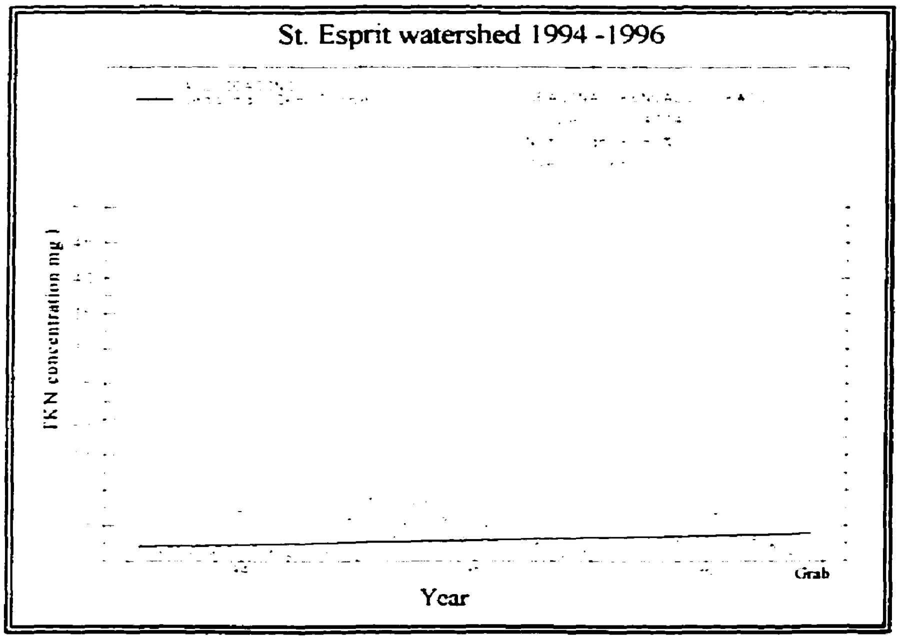

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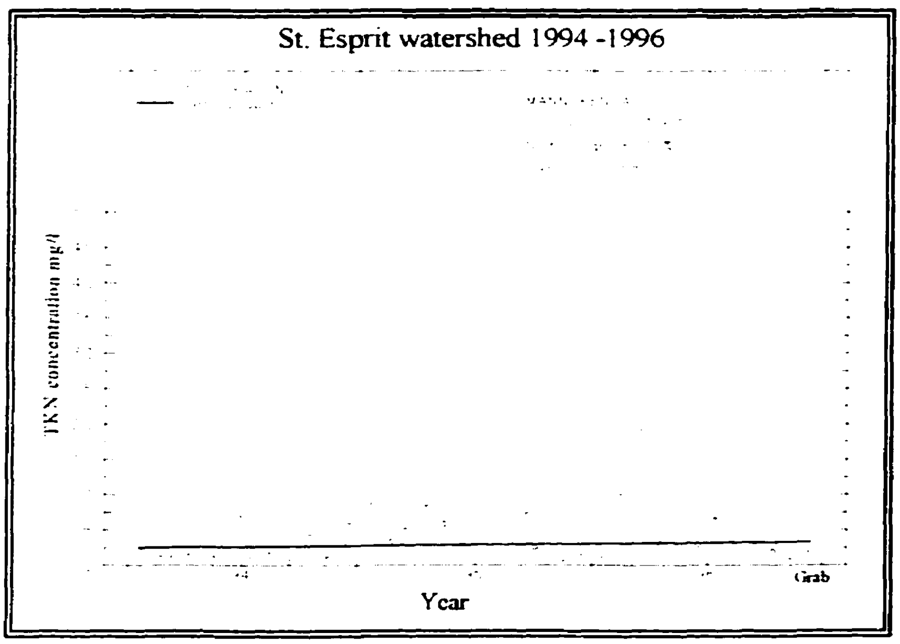

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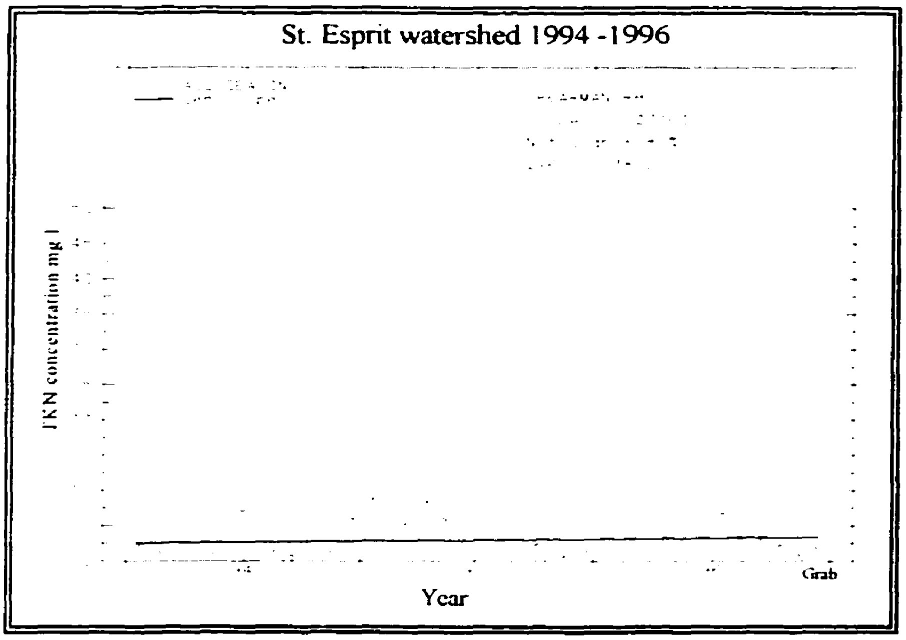

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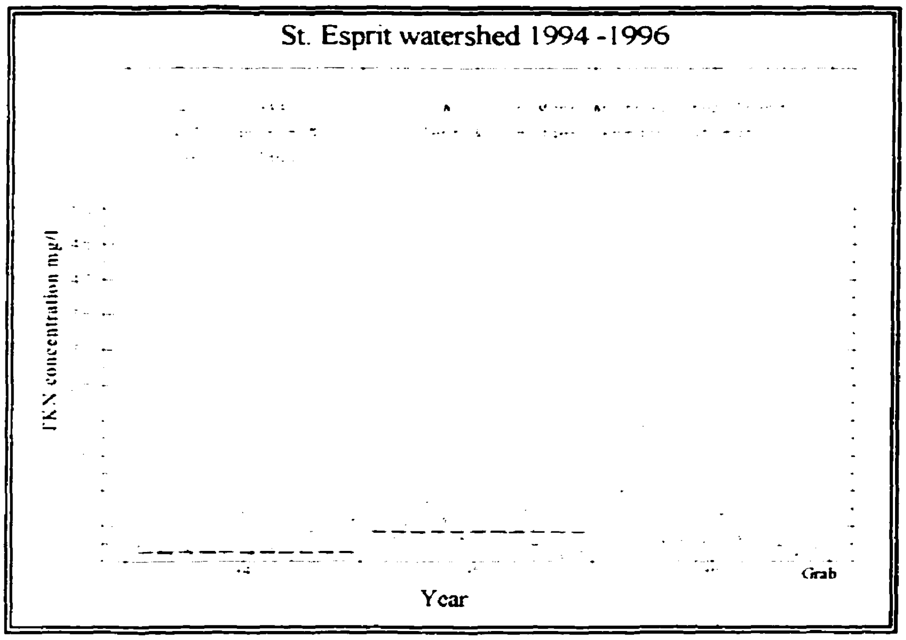

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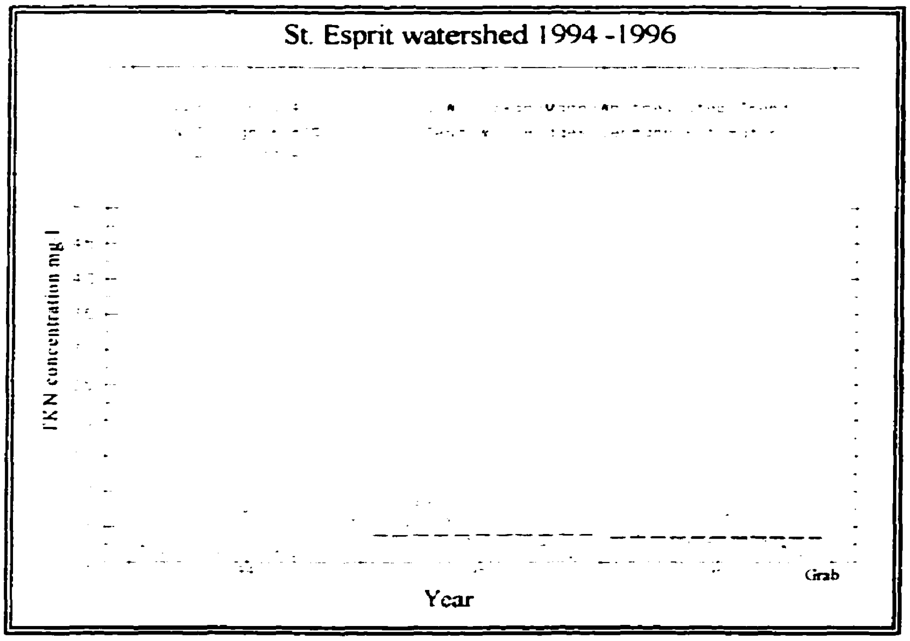

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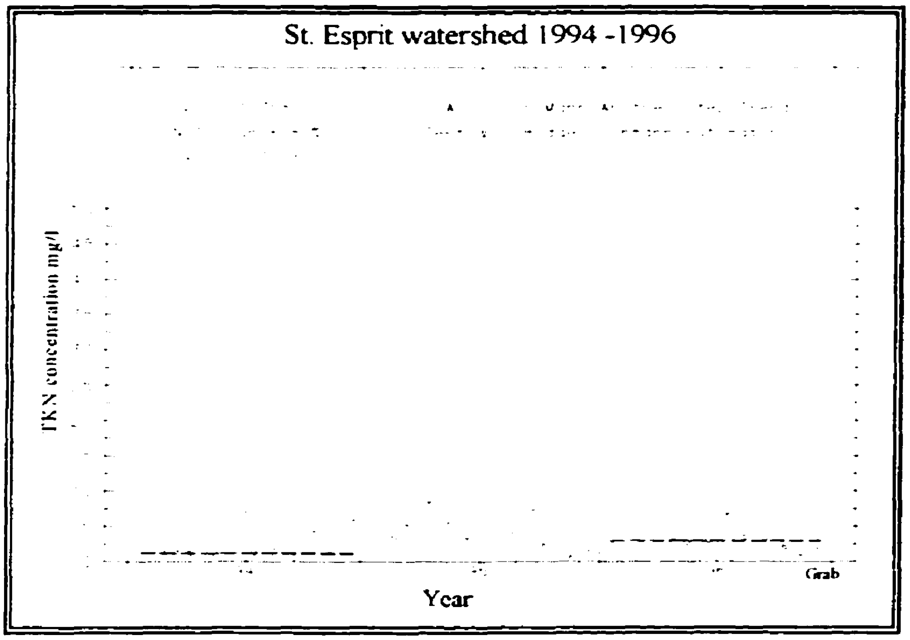

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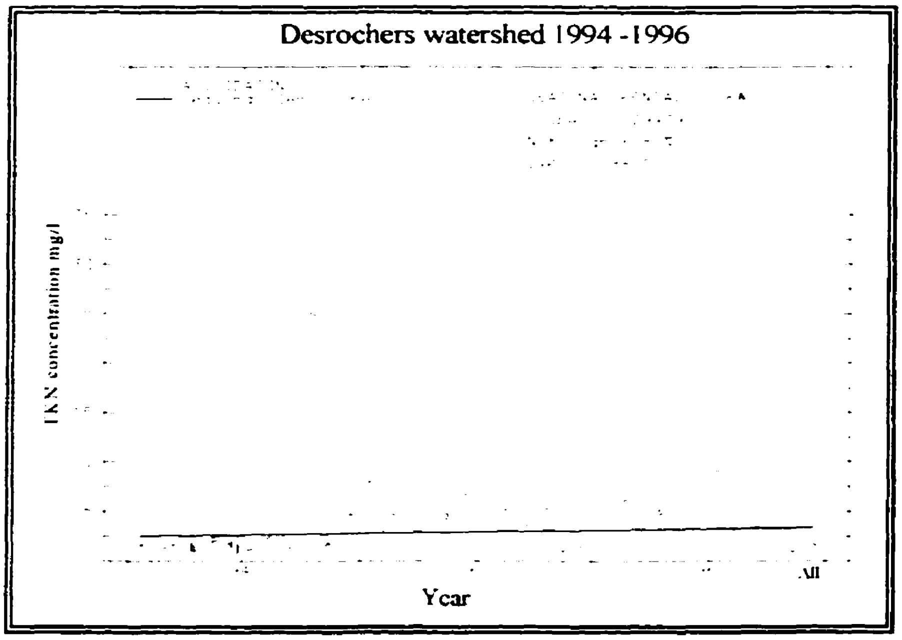

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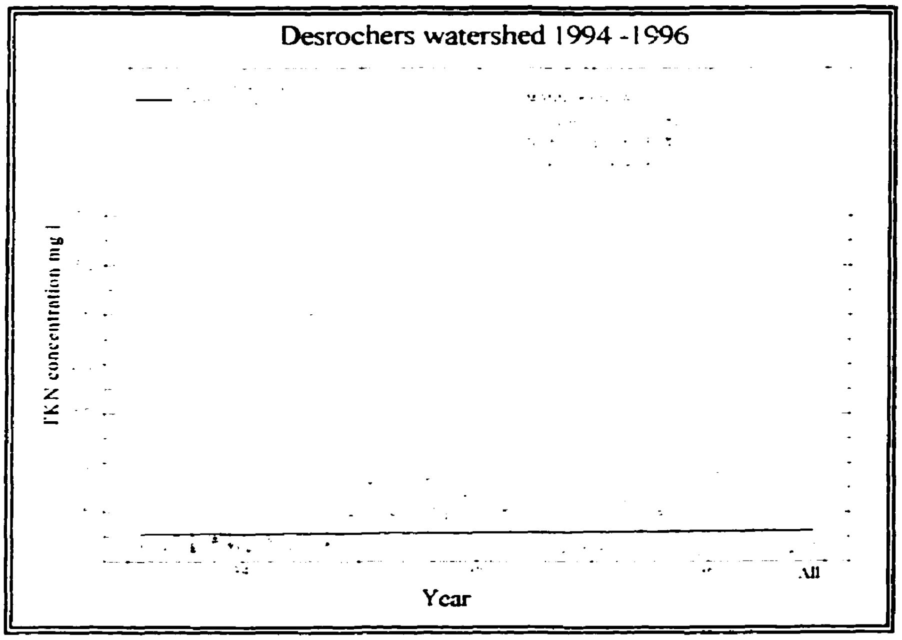

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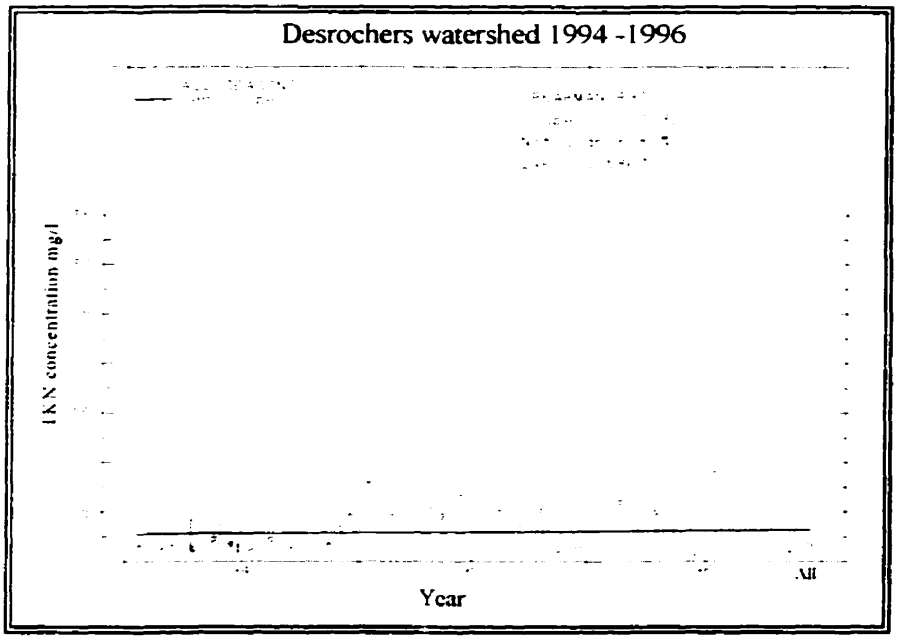

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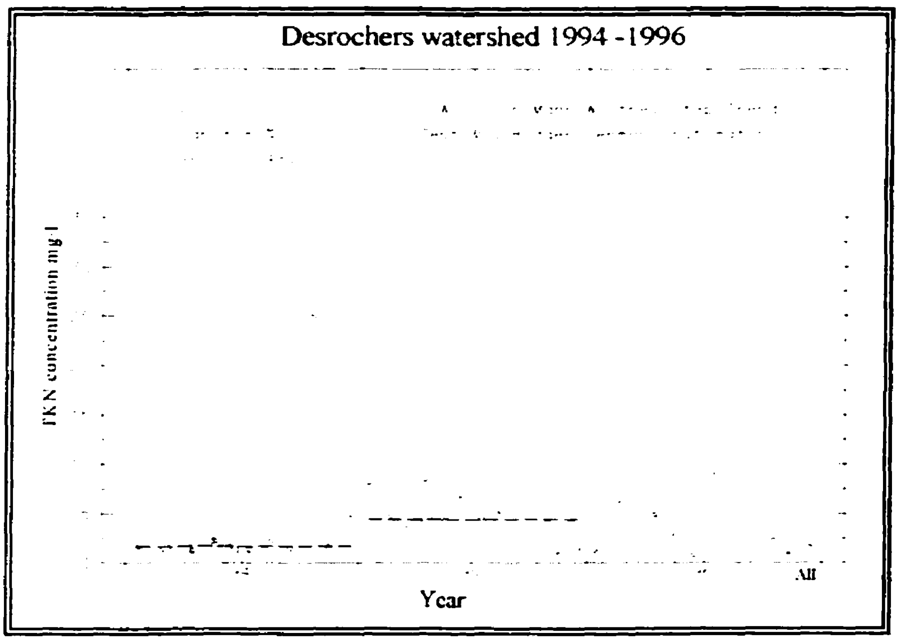

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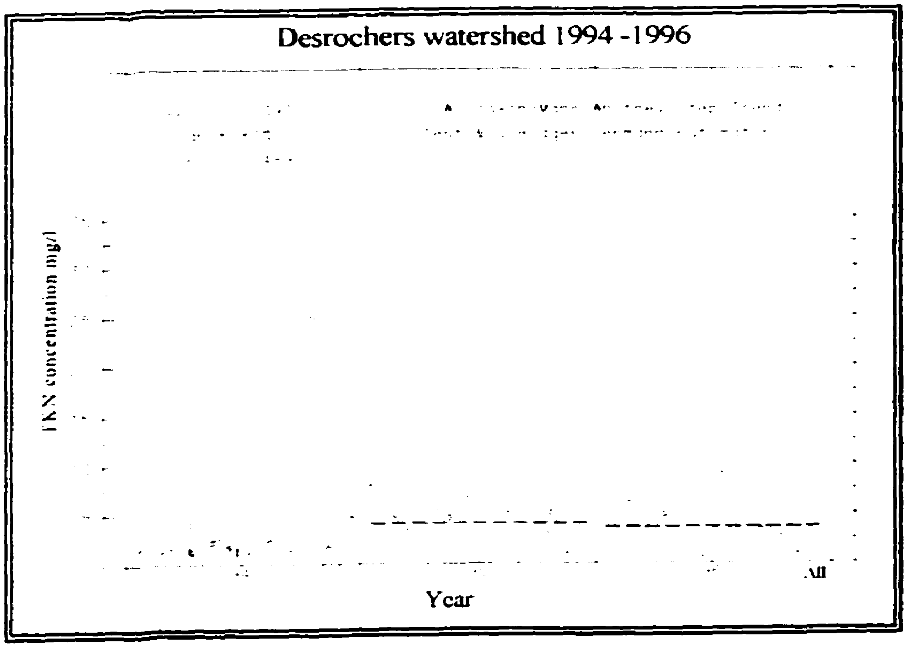

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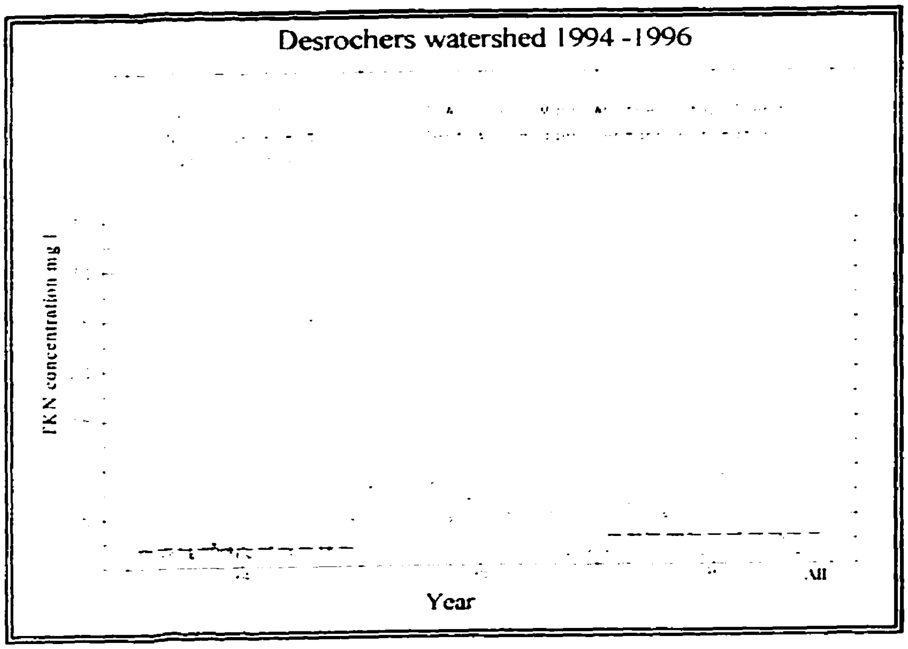

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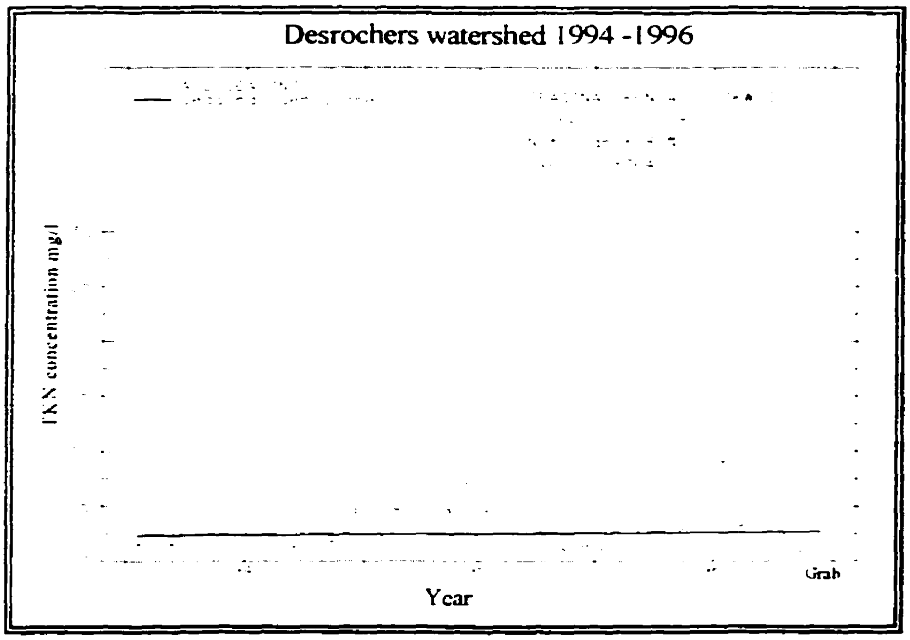

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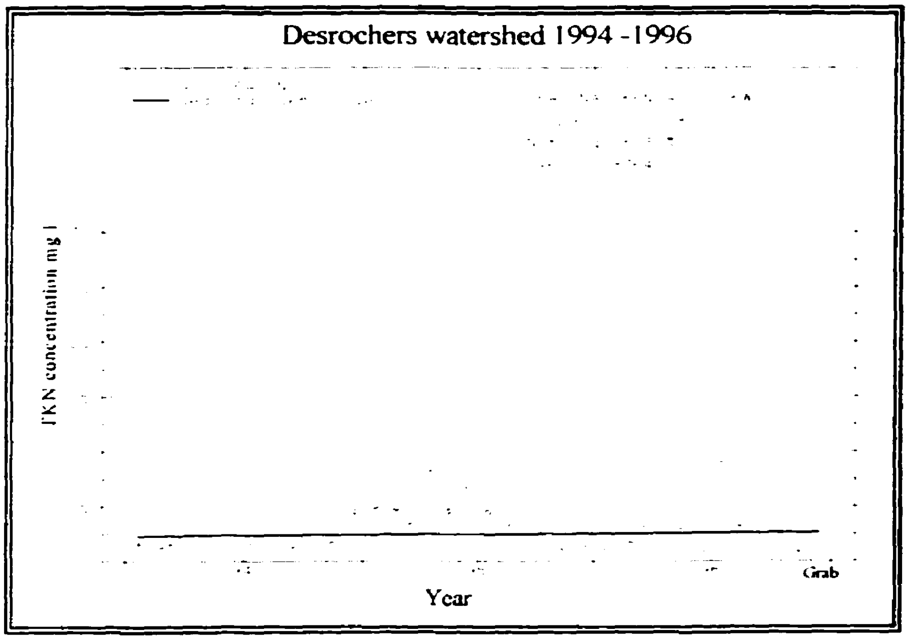

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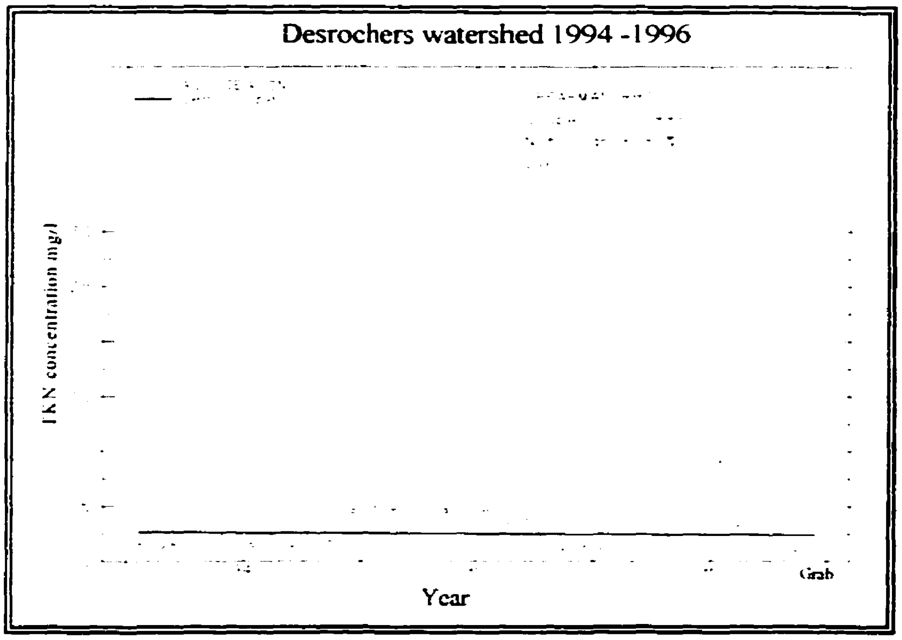

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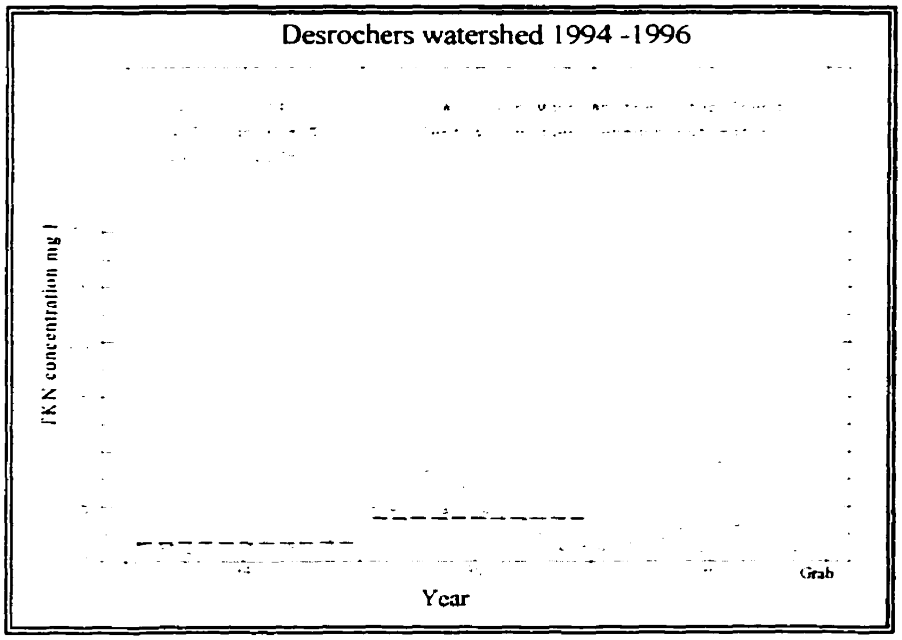

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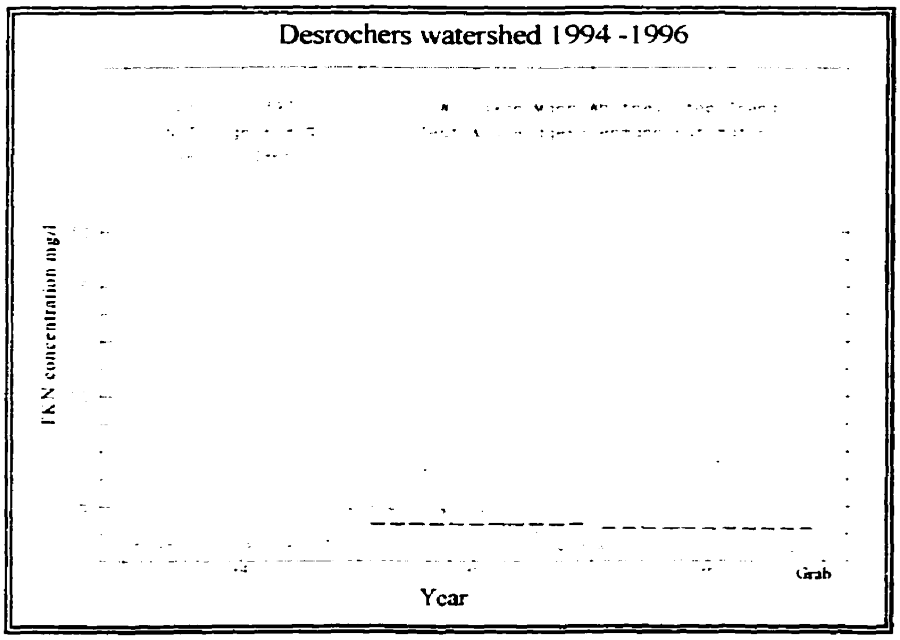

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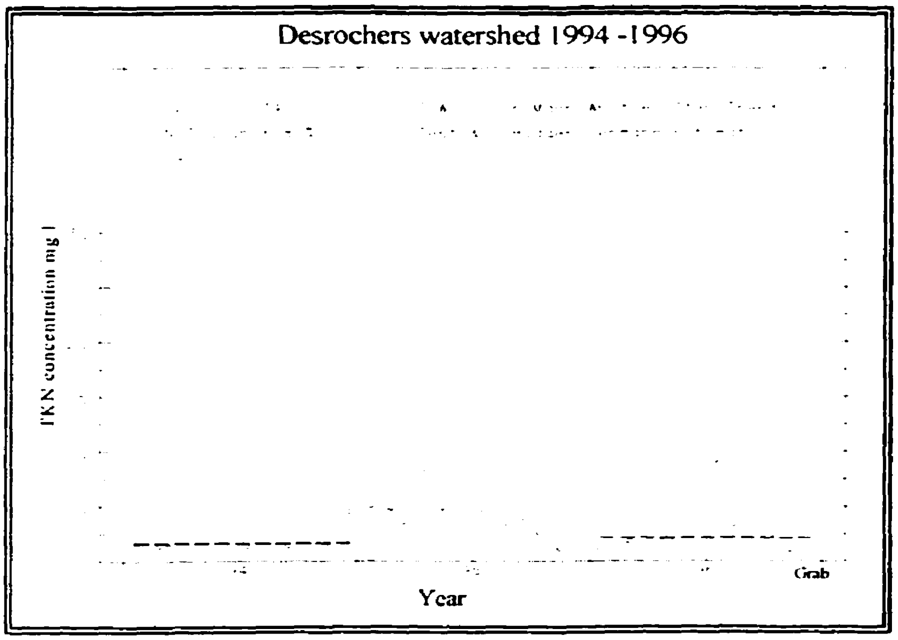

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Appendix I

Graphical Display of the non-parametric test for trend for total phosphorus concentrations at St. Esprit and Desrochers

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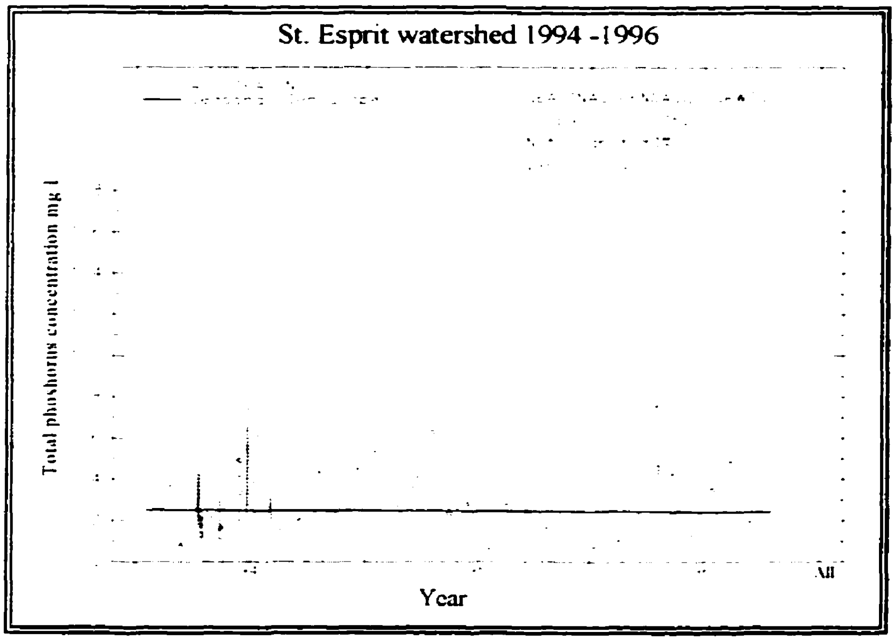

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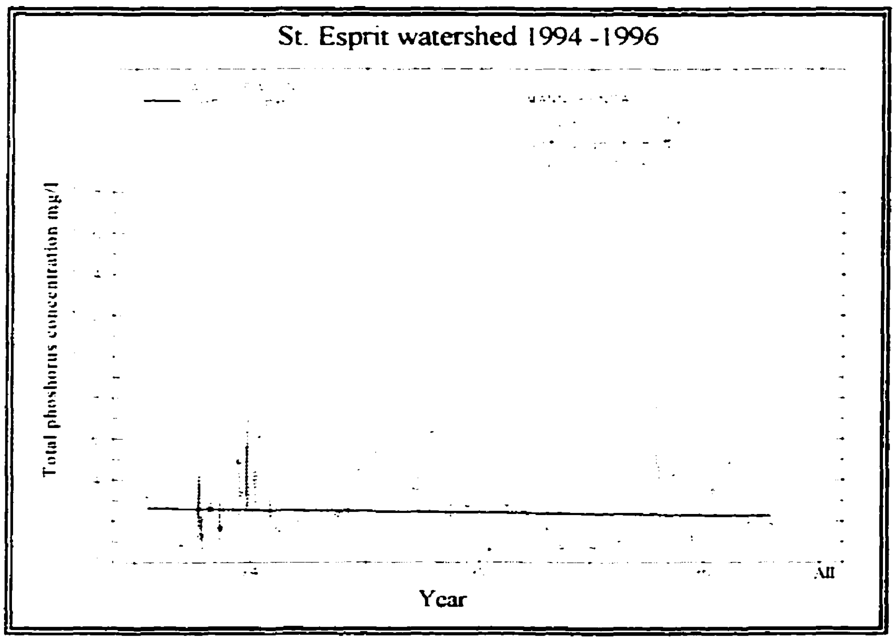

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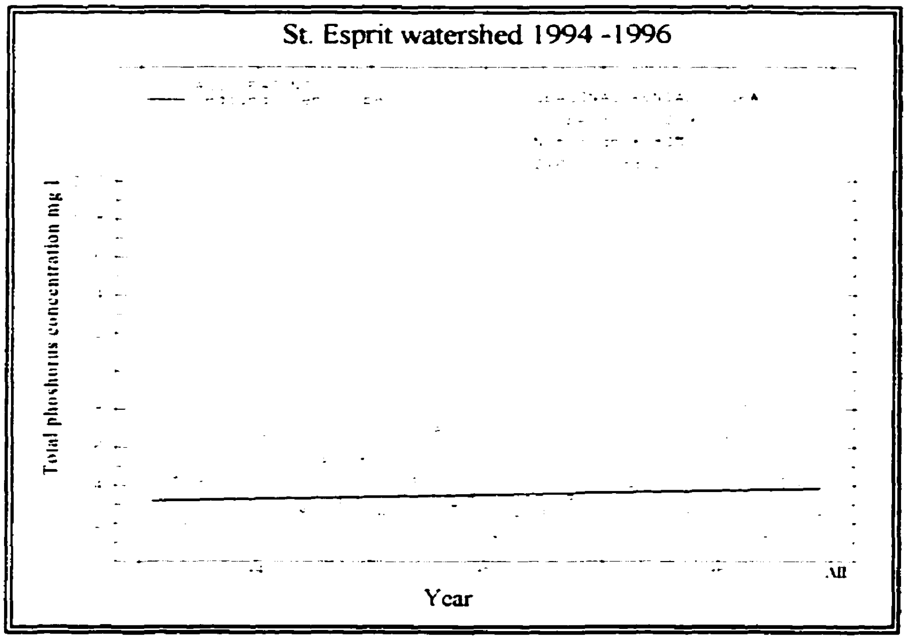

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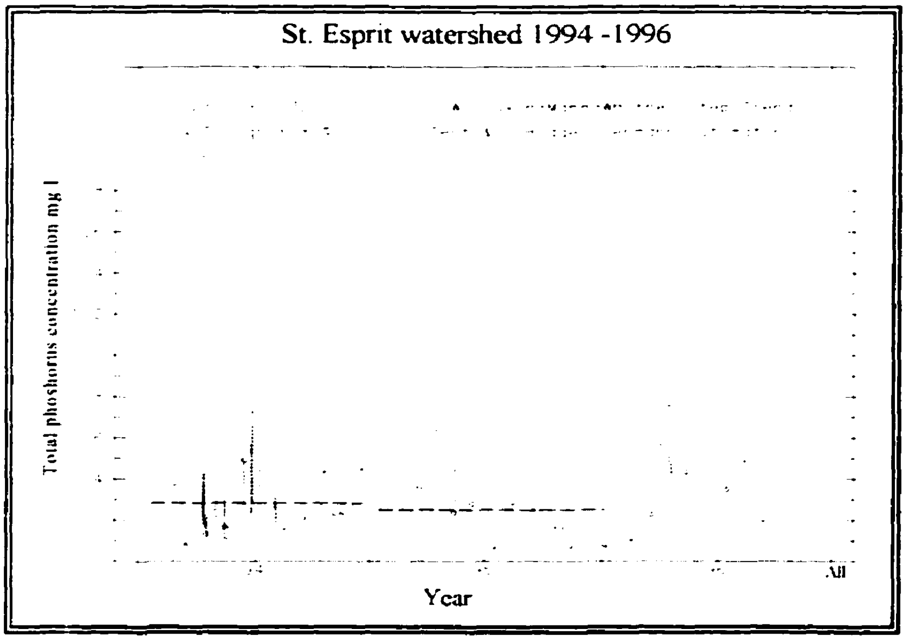

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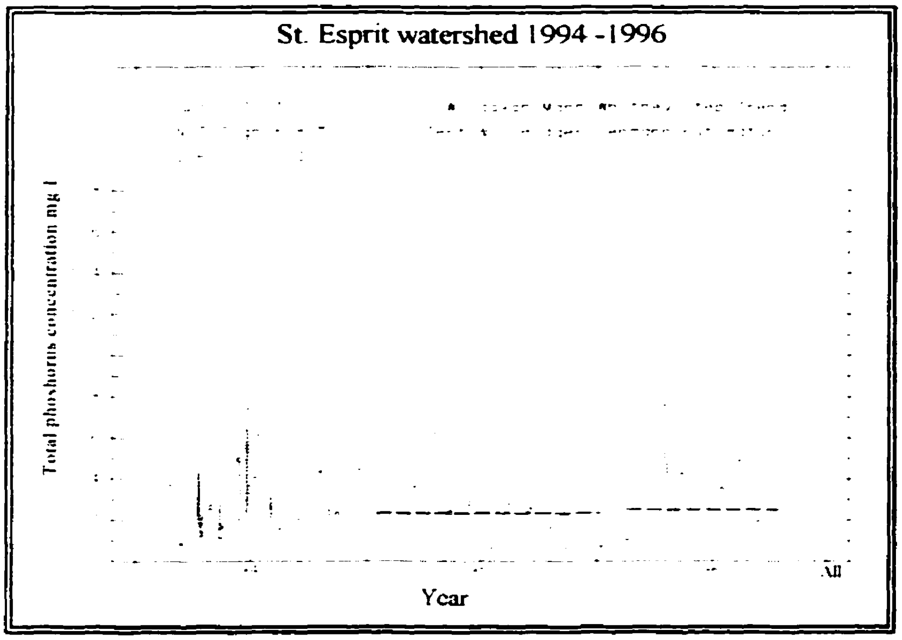

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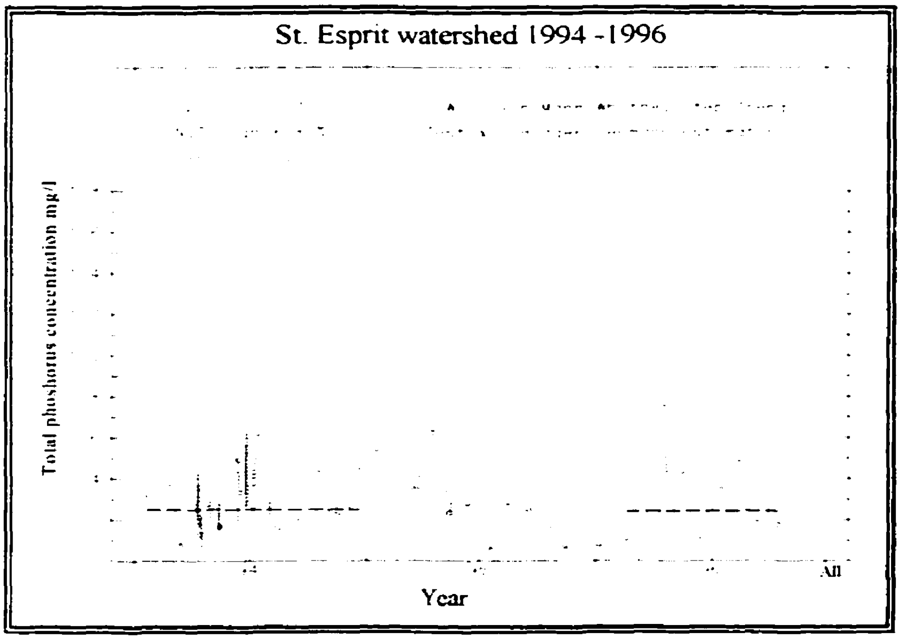

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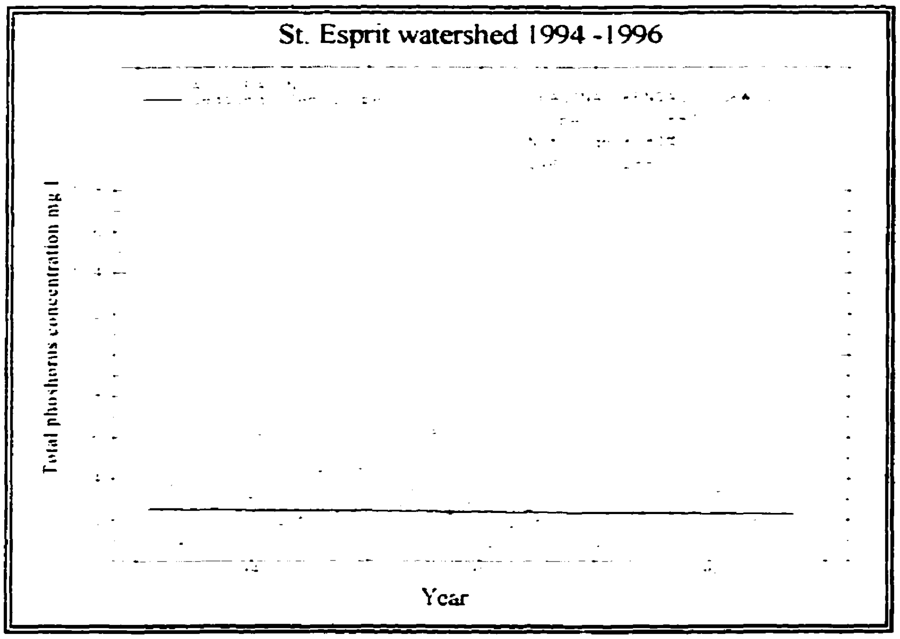

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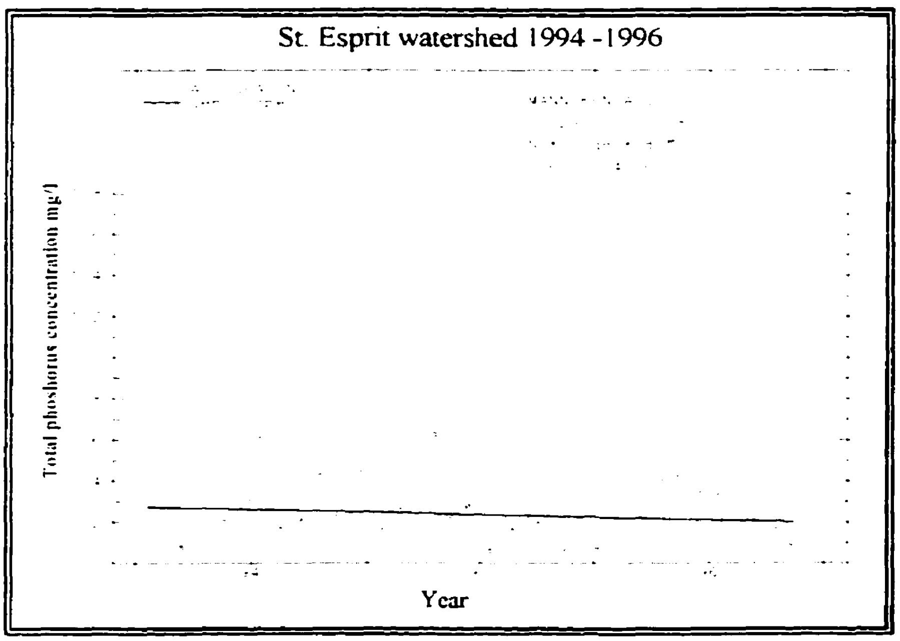

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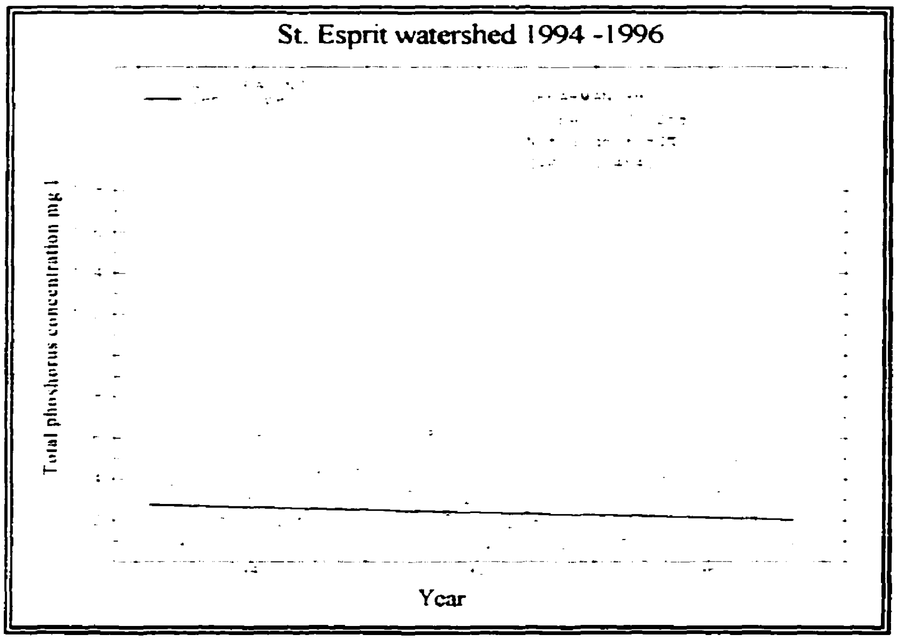

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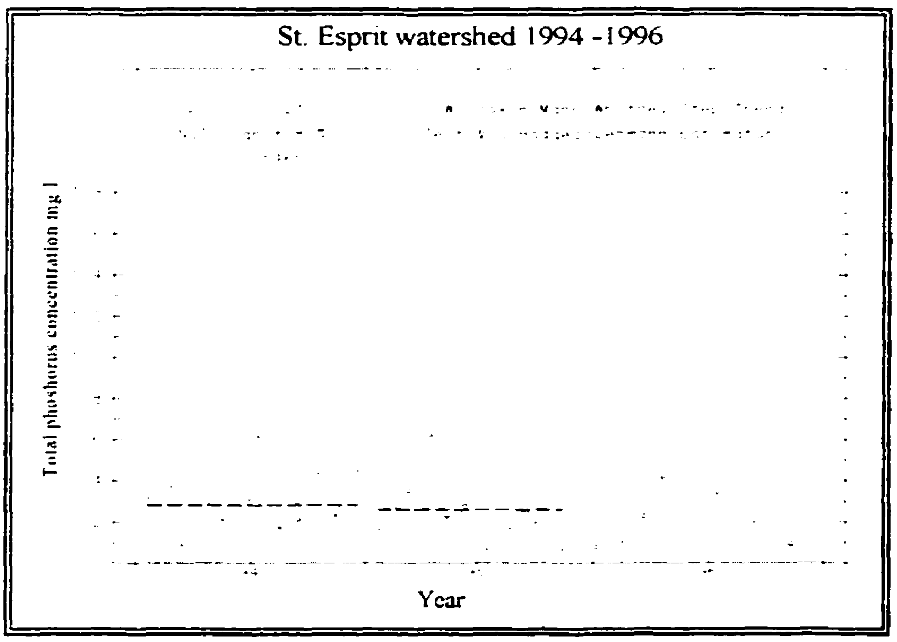

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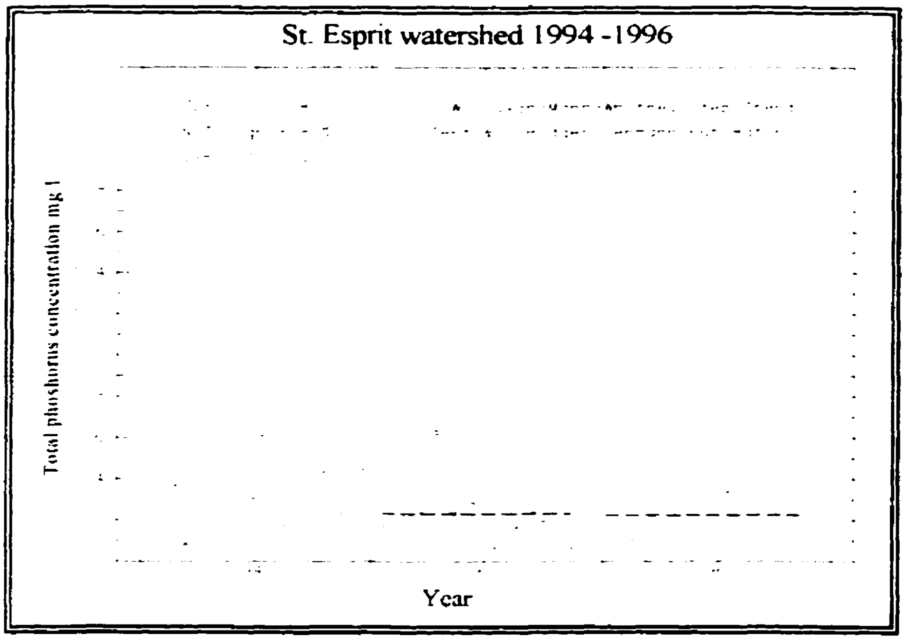

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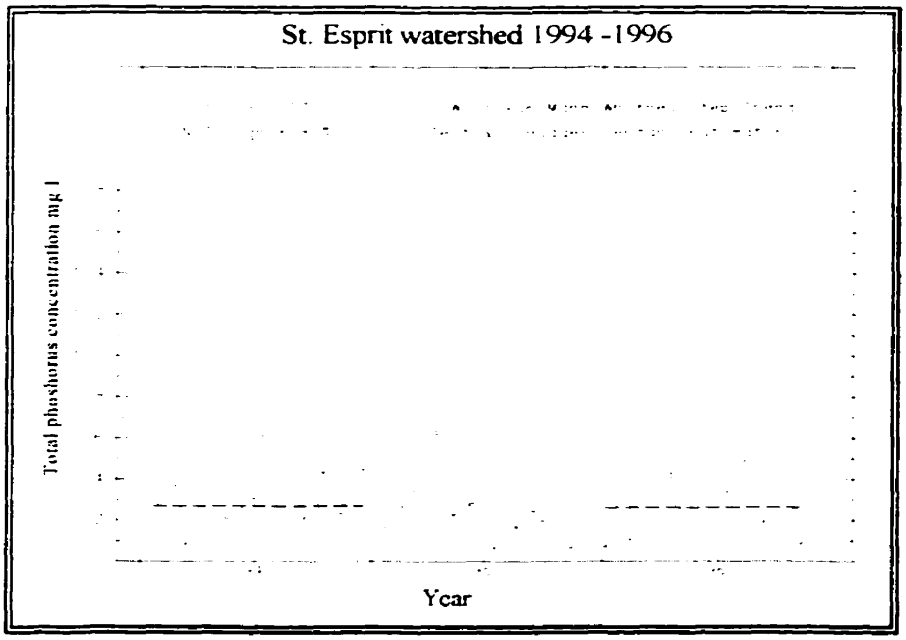

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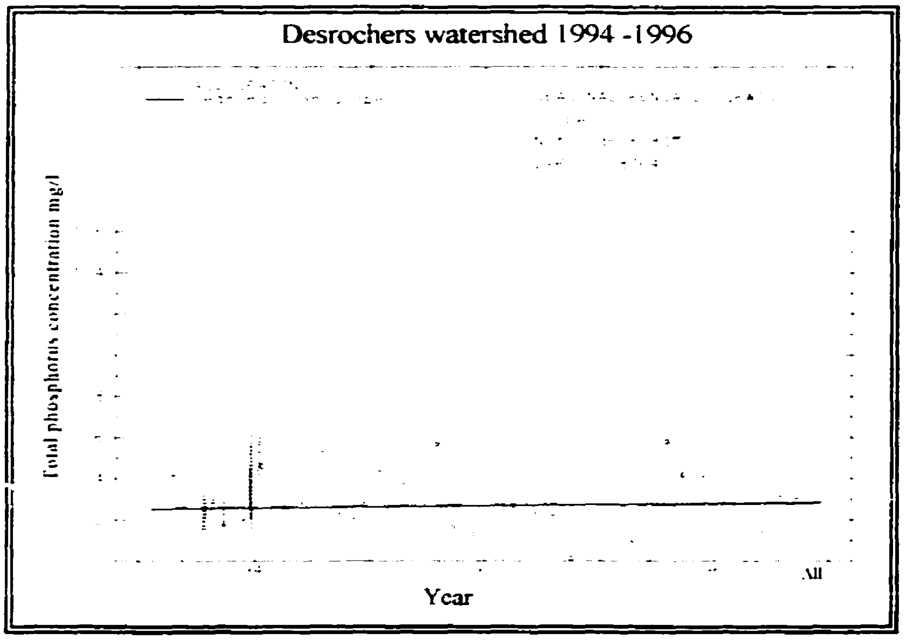

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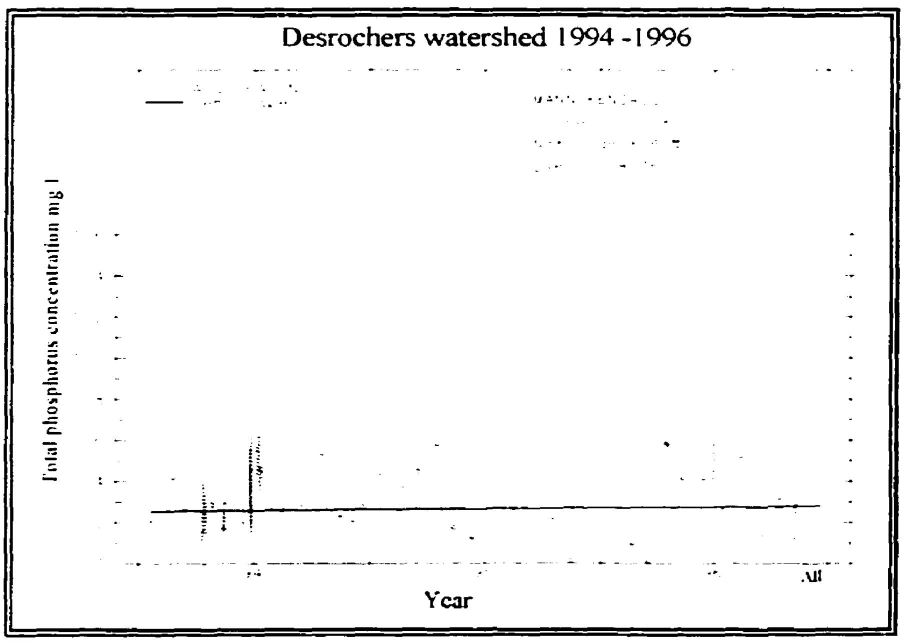

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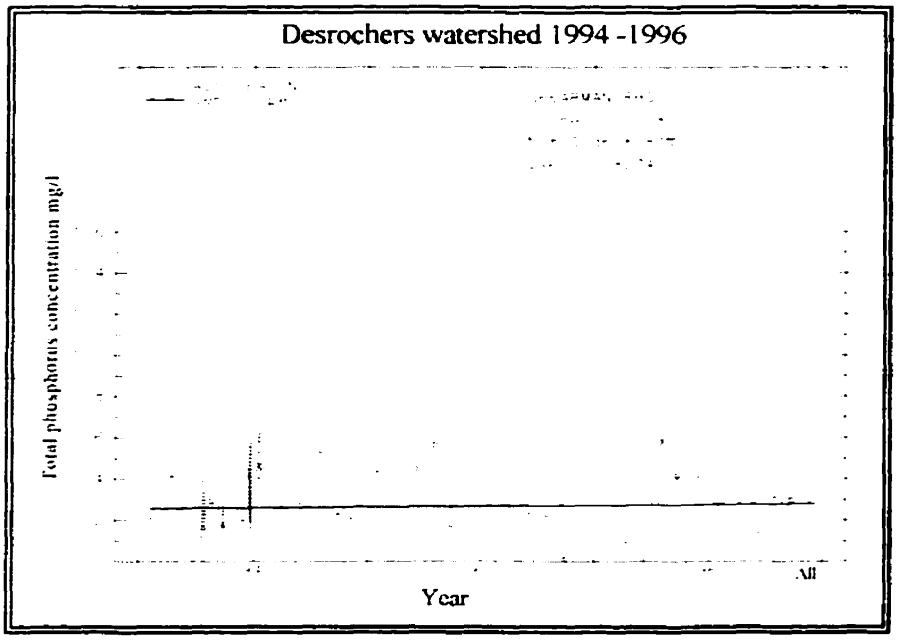

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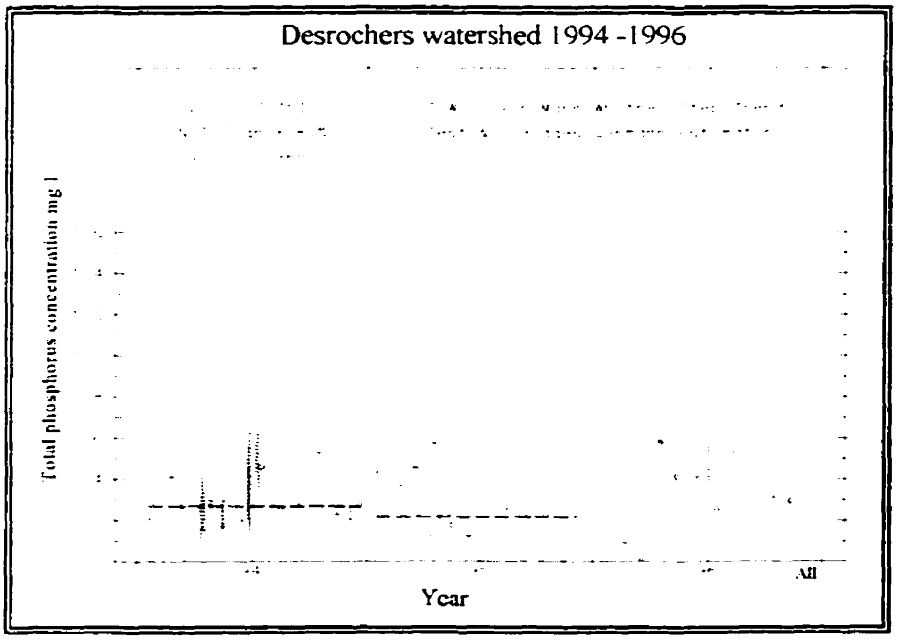

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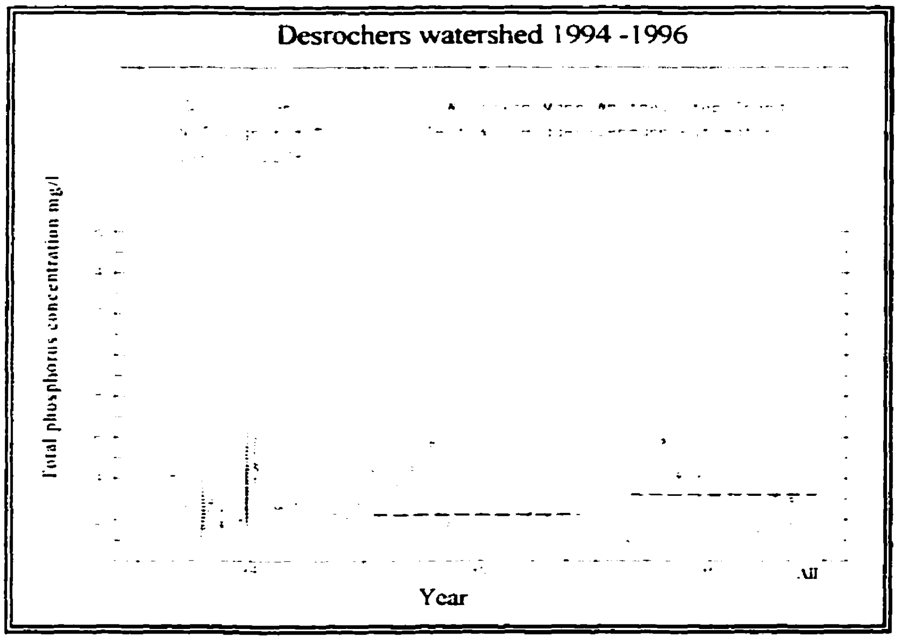

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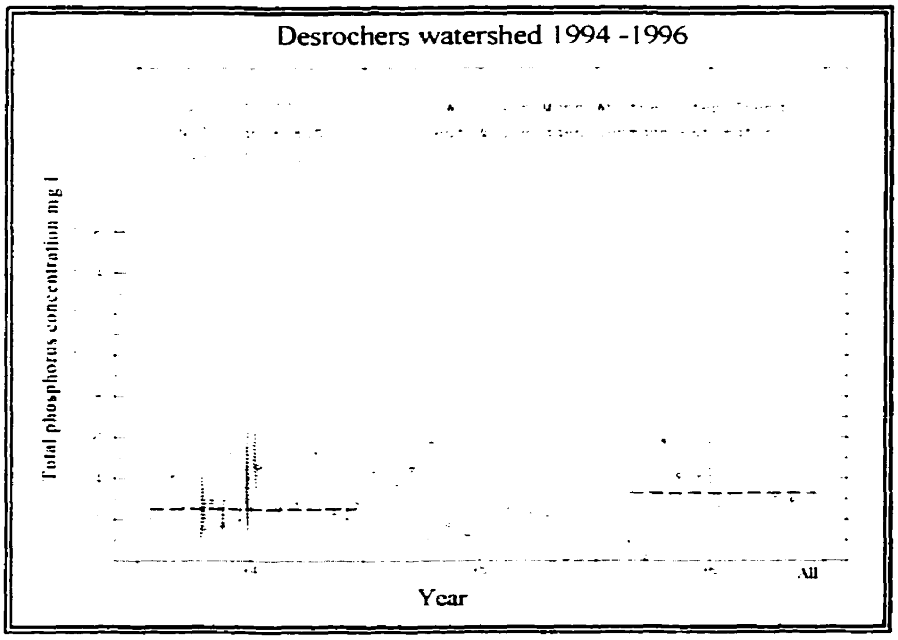

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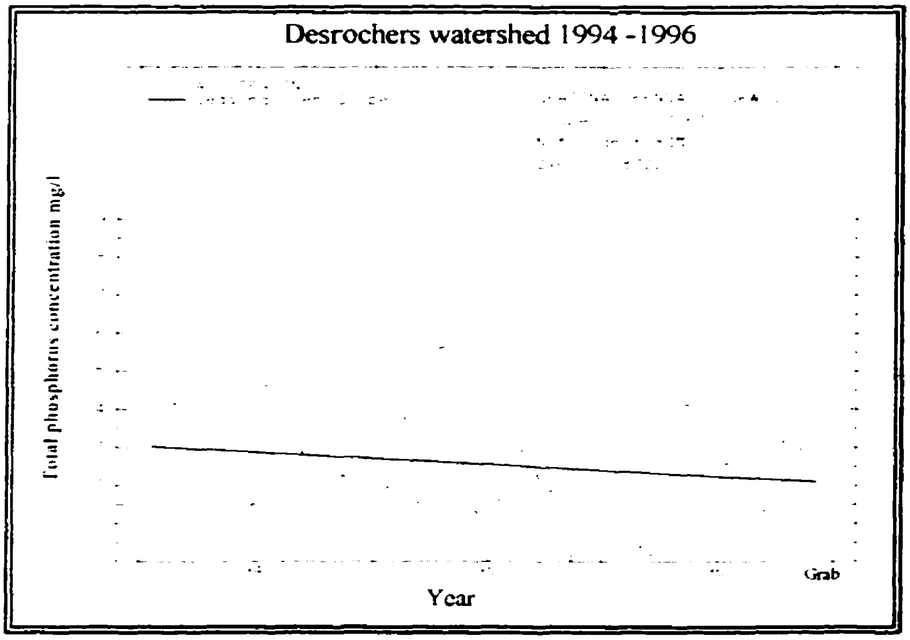

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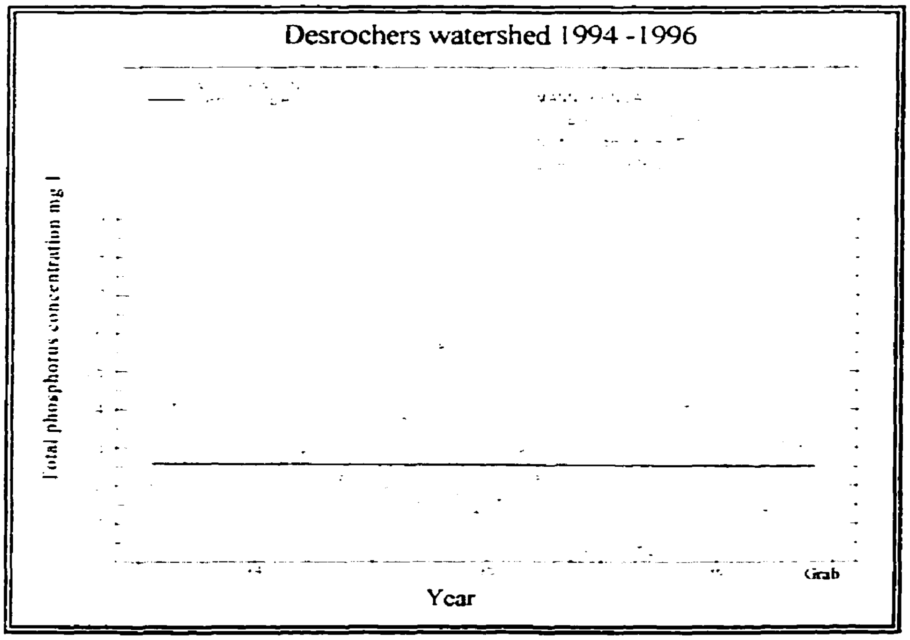

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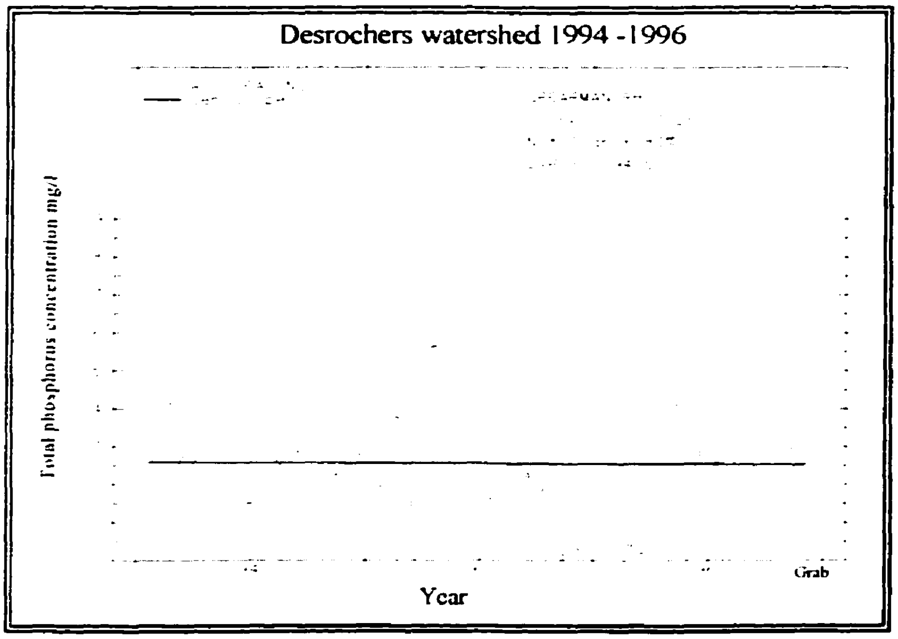

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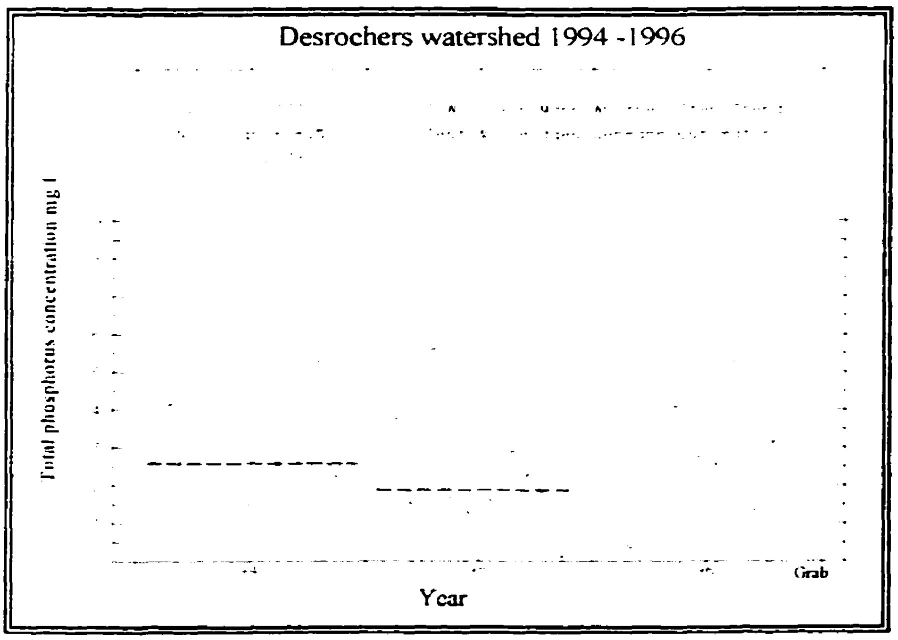

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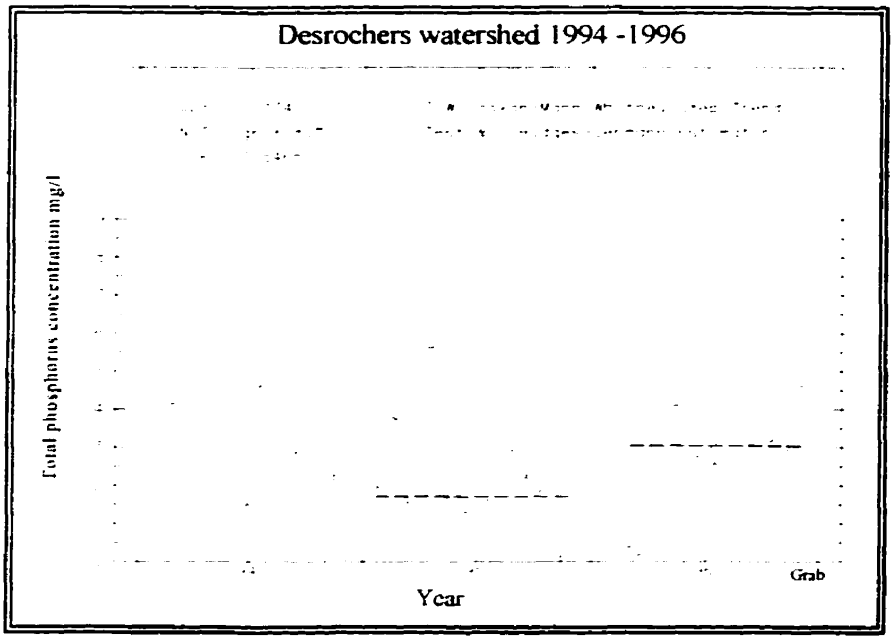

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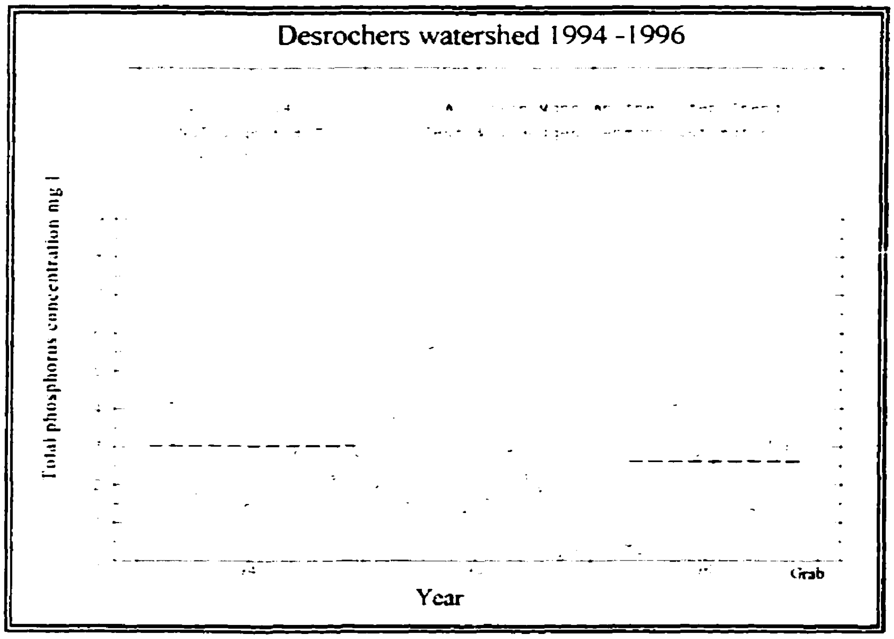

Figure I24

Appendix J

Graphical Display of the non-parametric test for trend for sediment concentrations at St. Esprit and Desrochers

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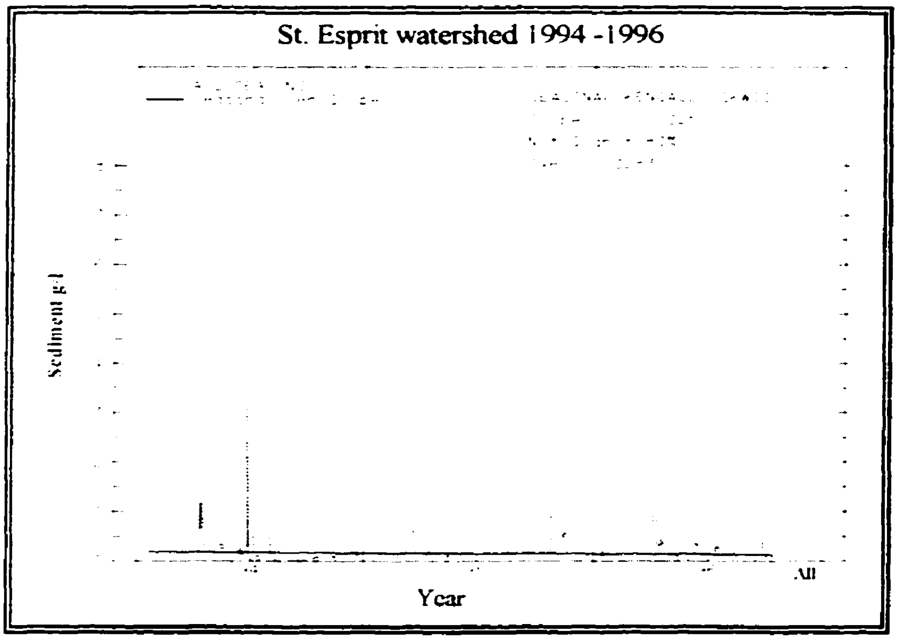

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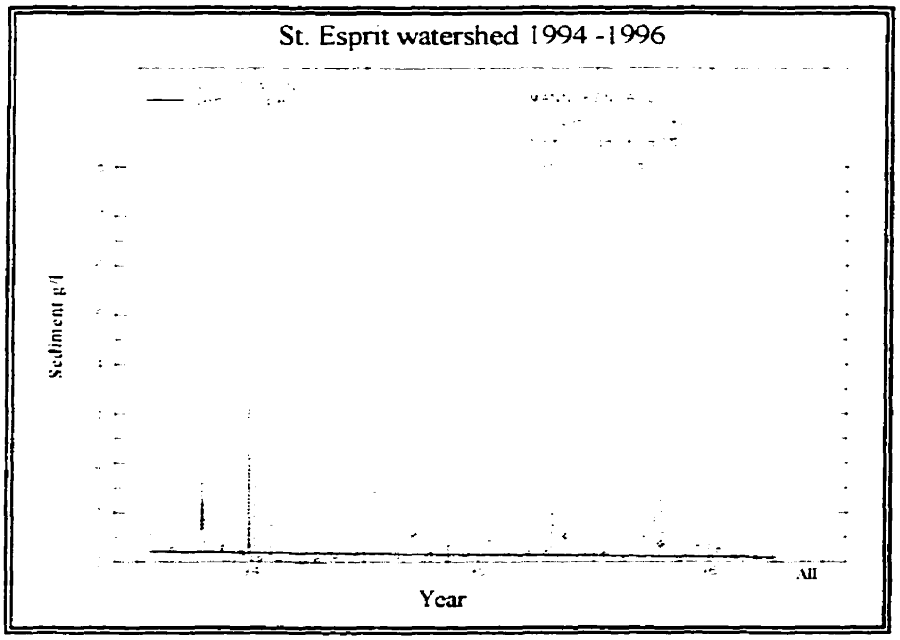

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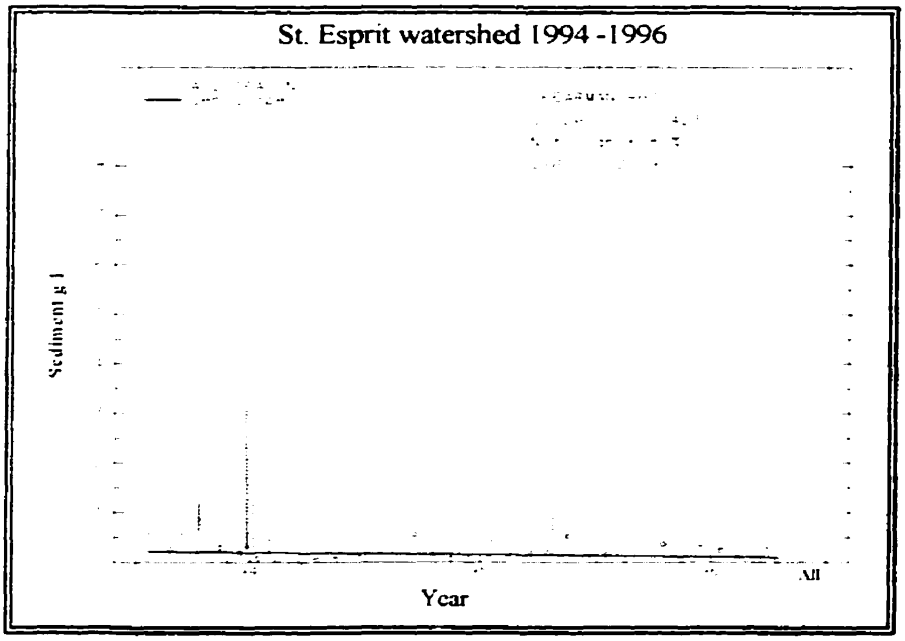

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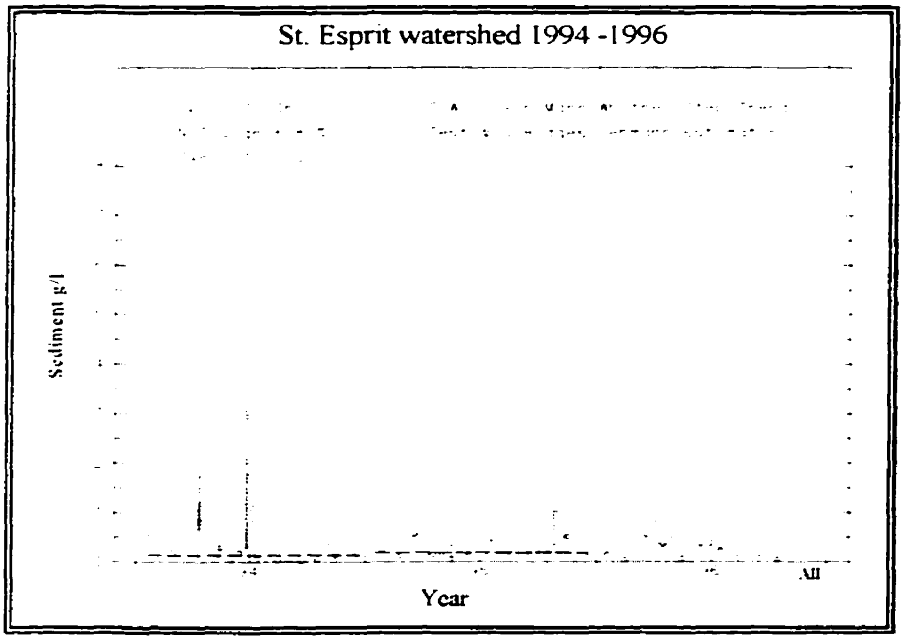

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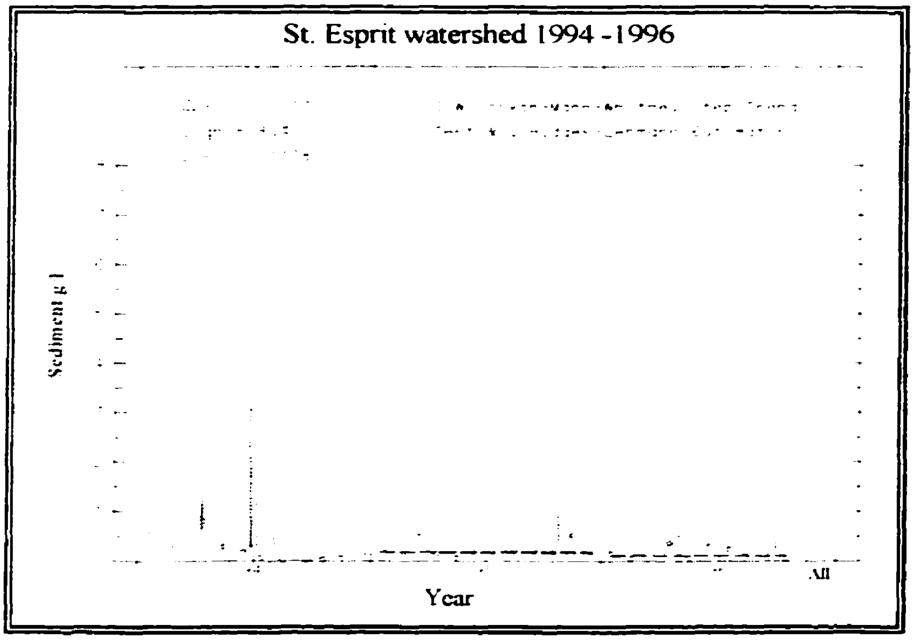

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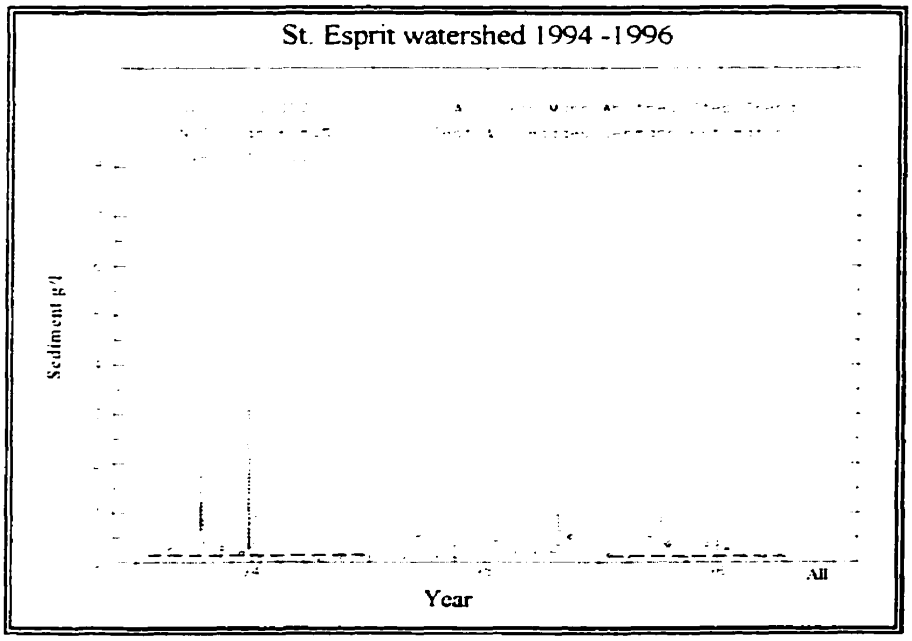

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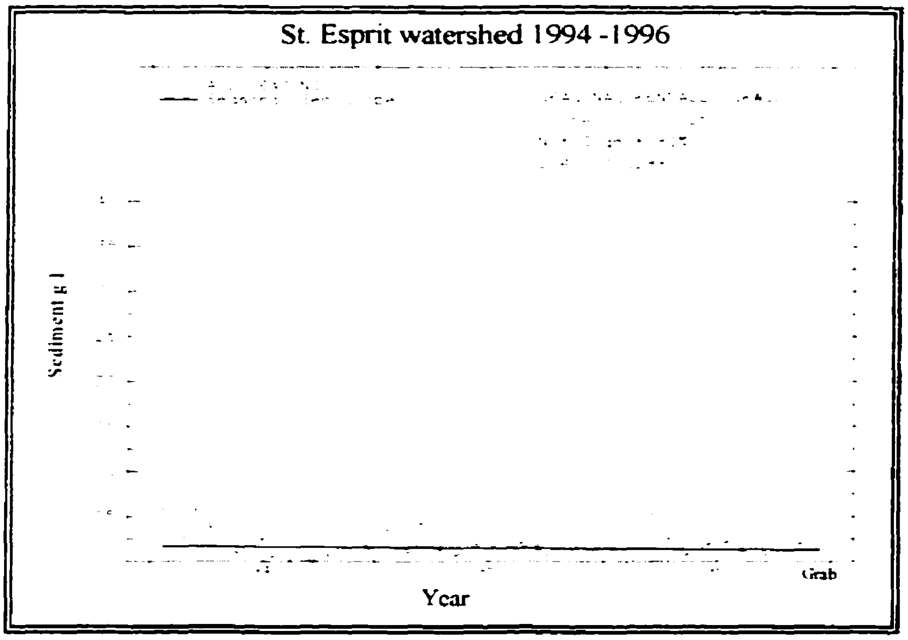

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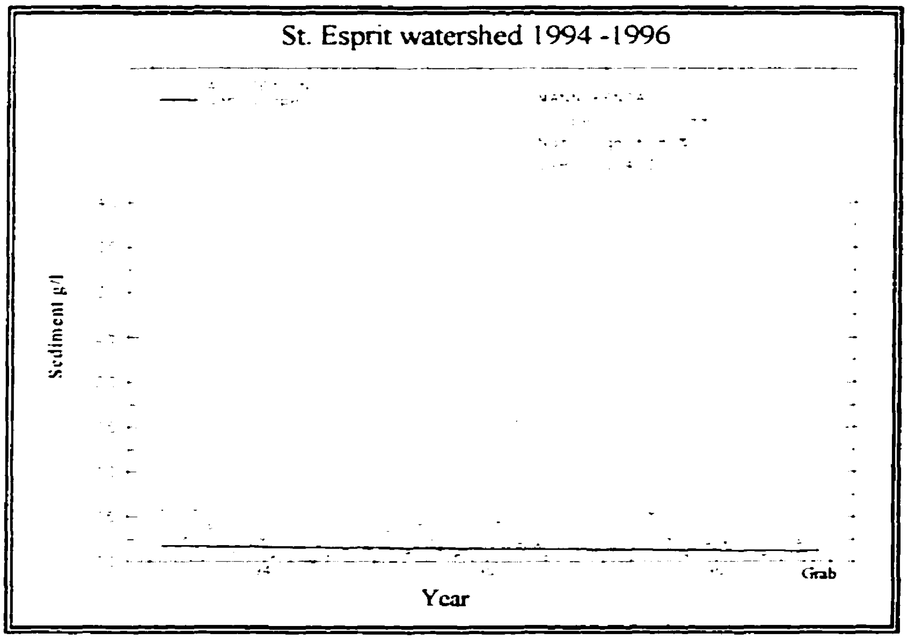

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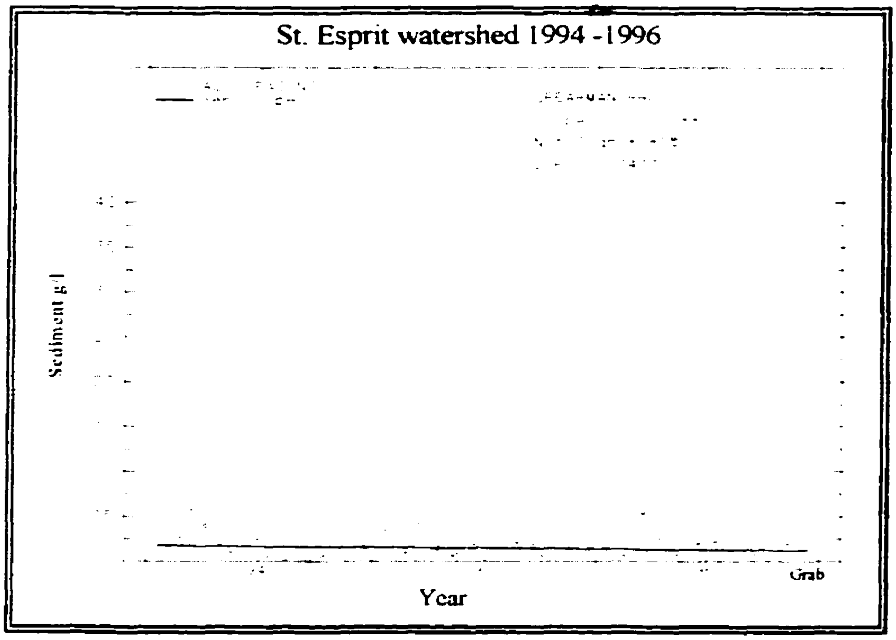

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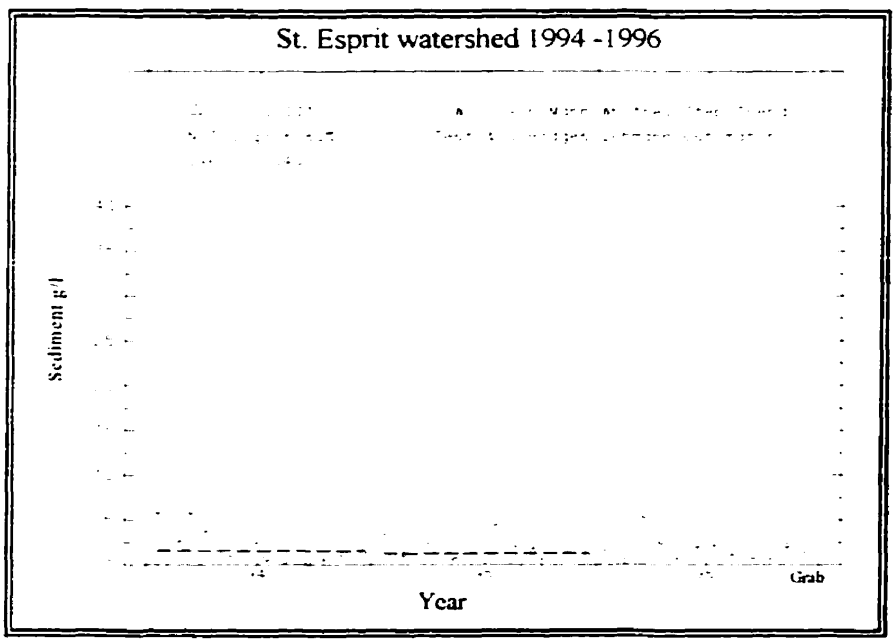

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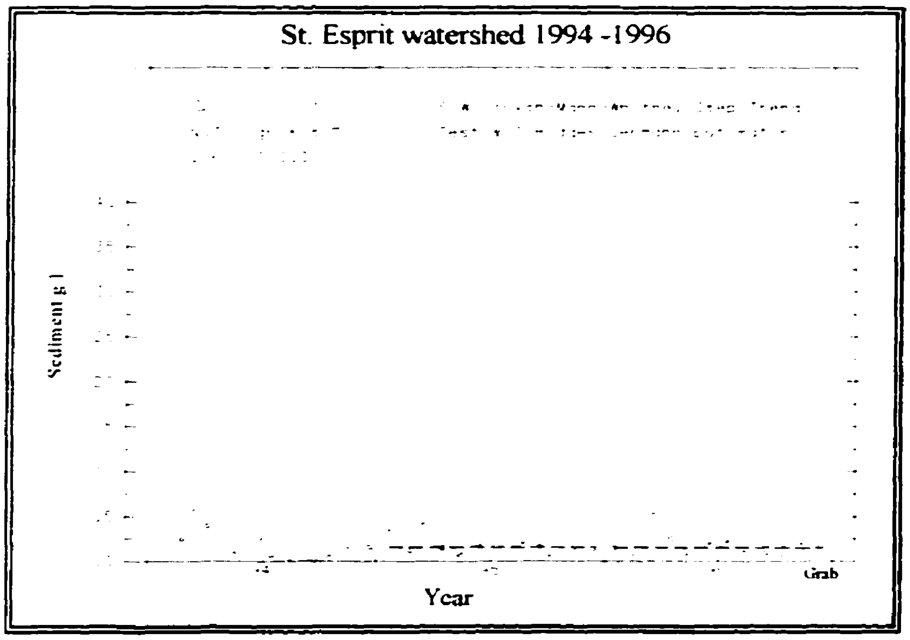

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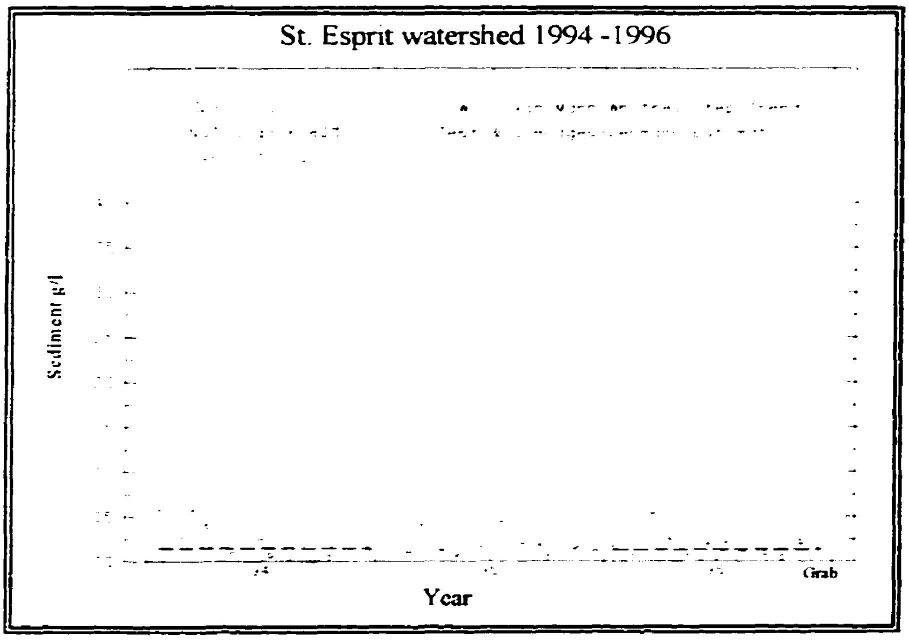

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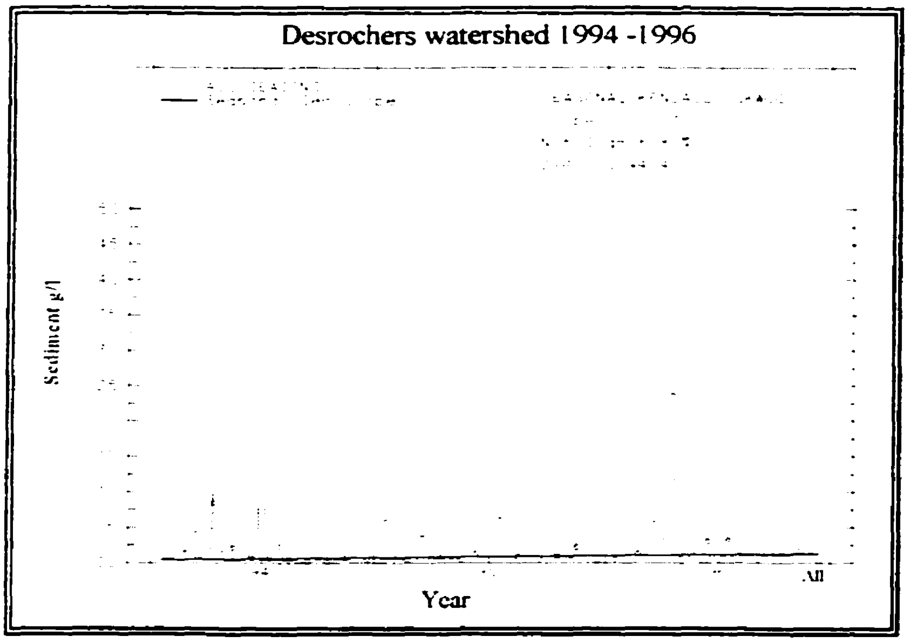

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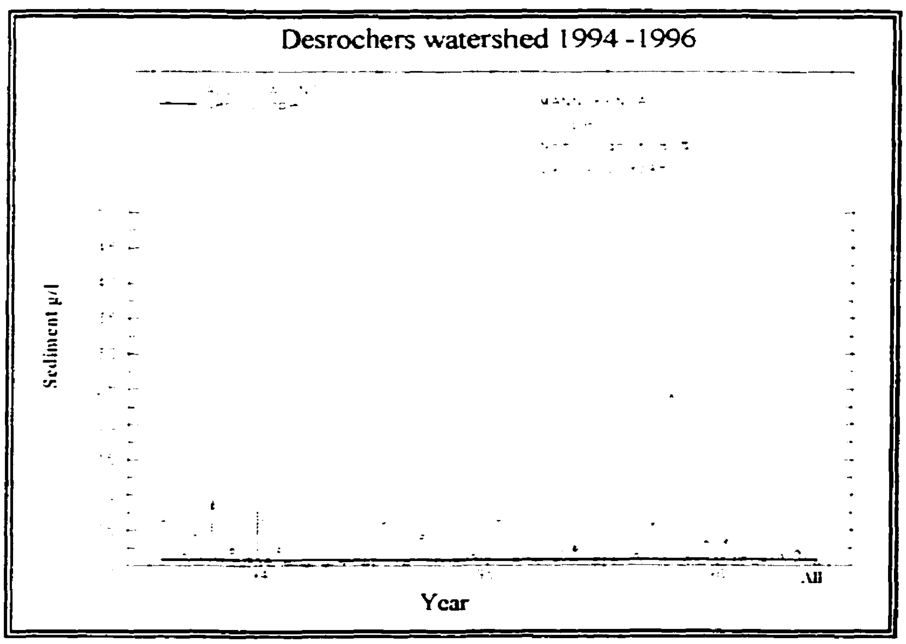

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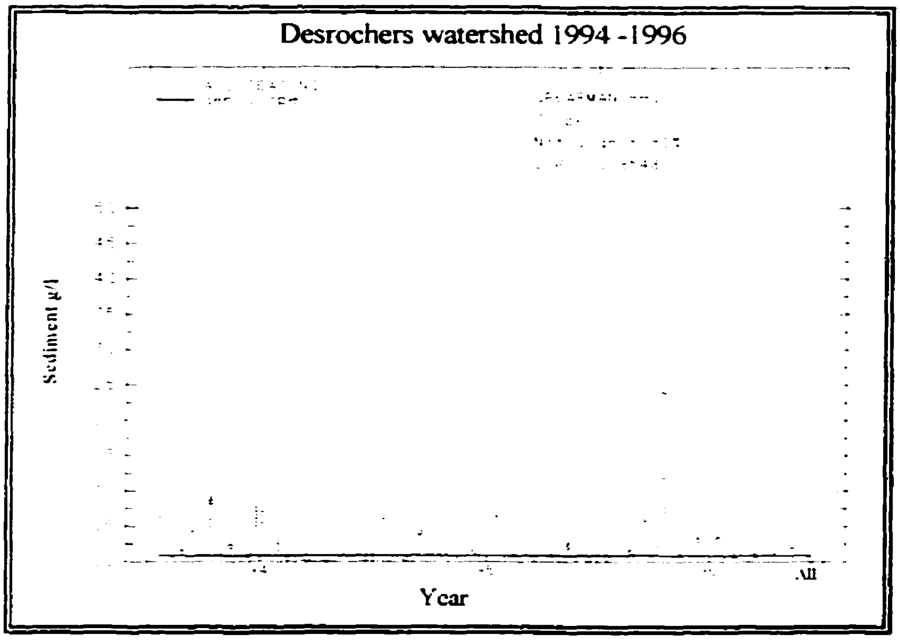

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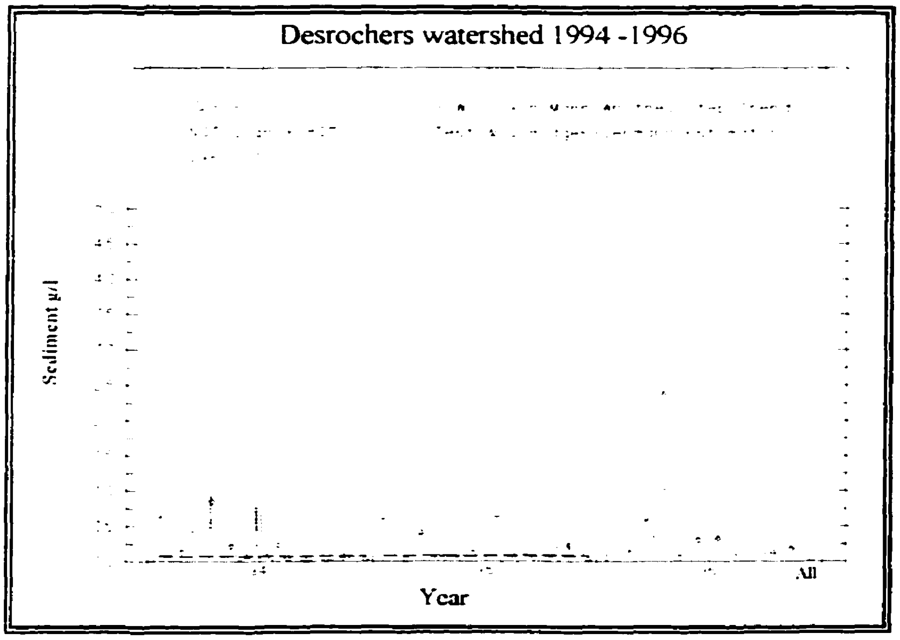

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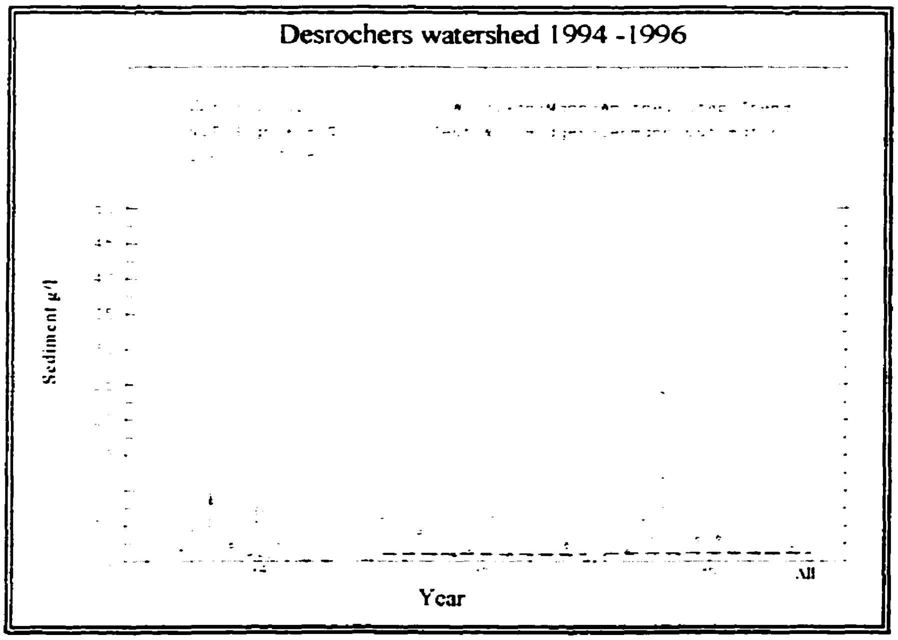

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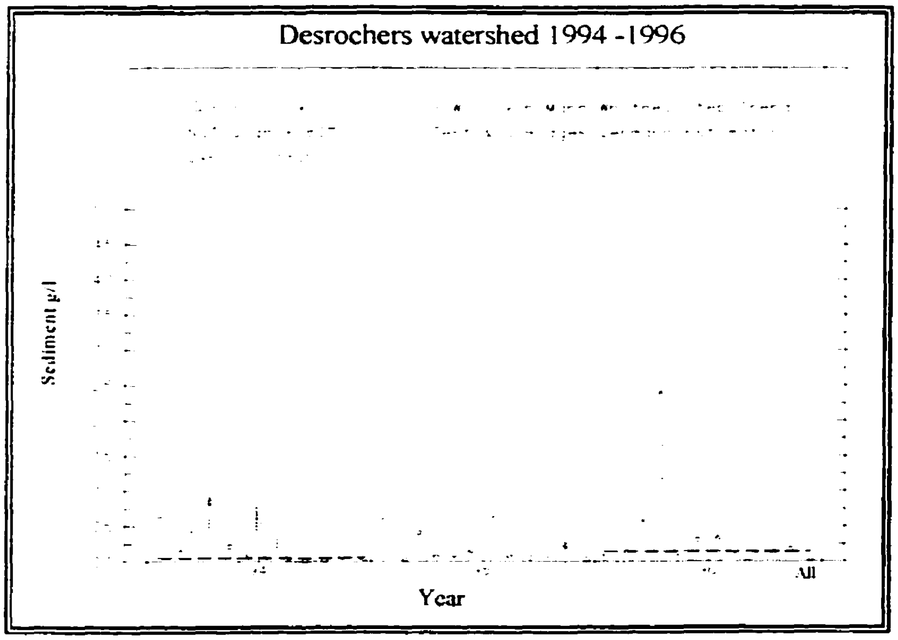

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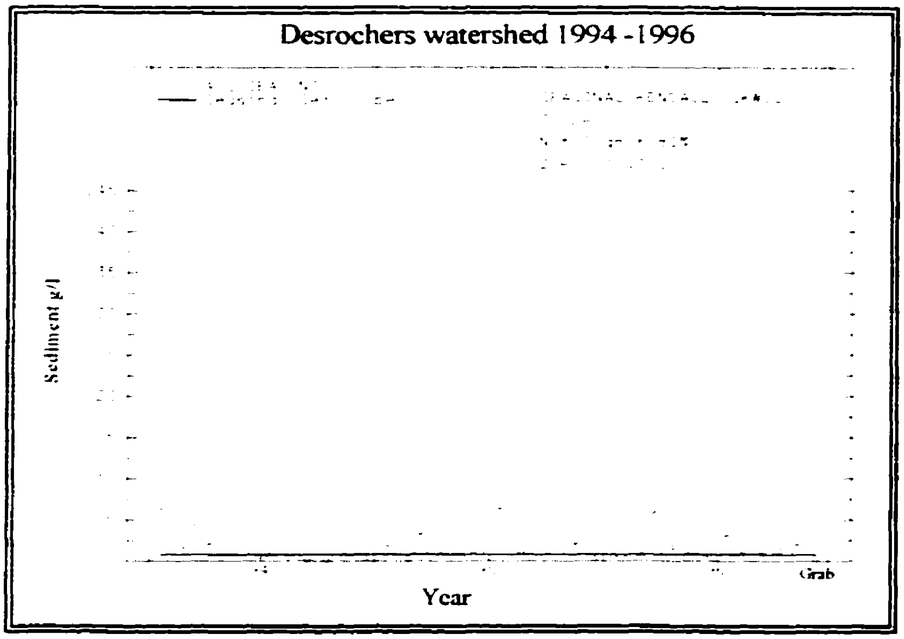

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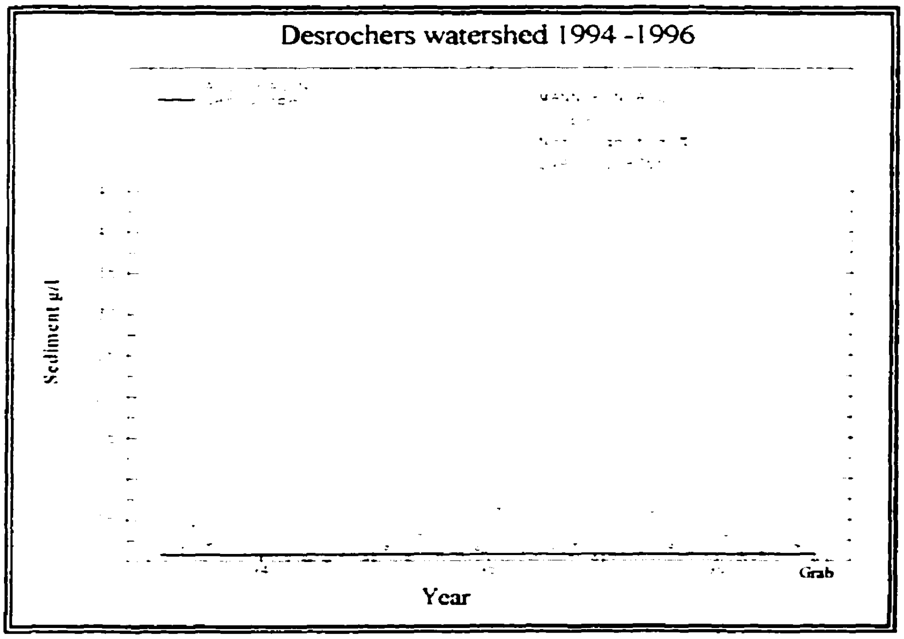

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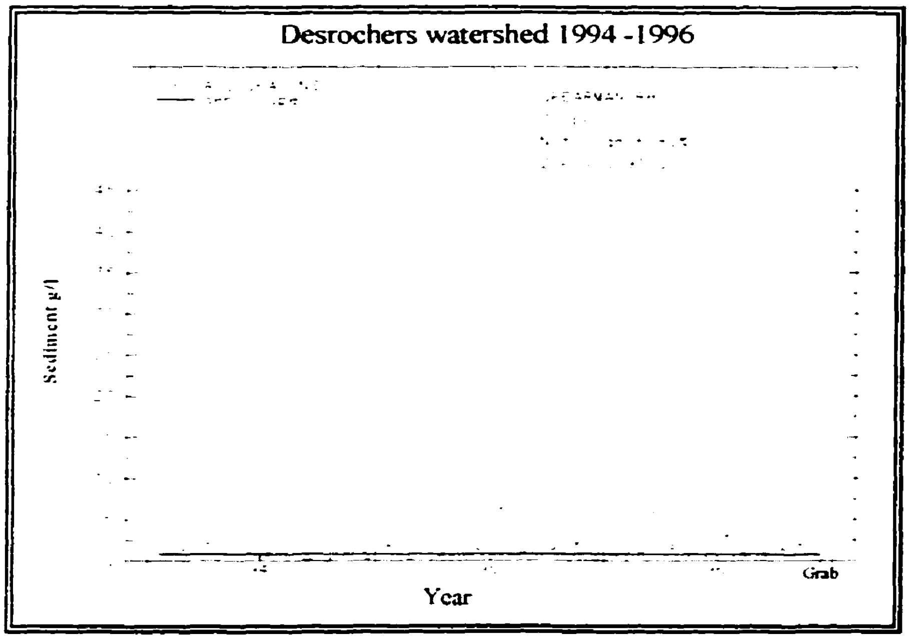

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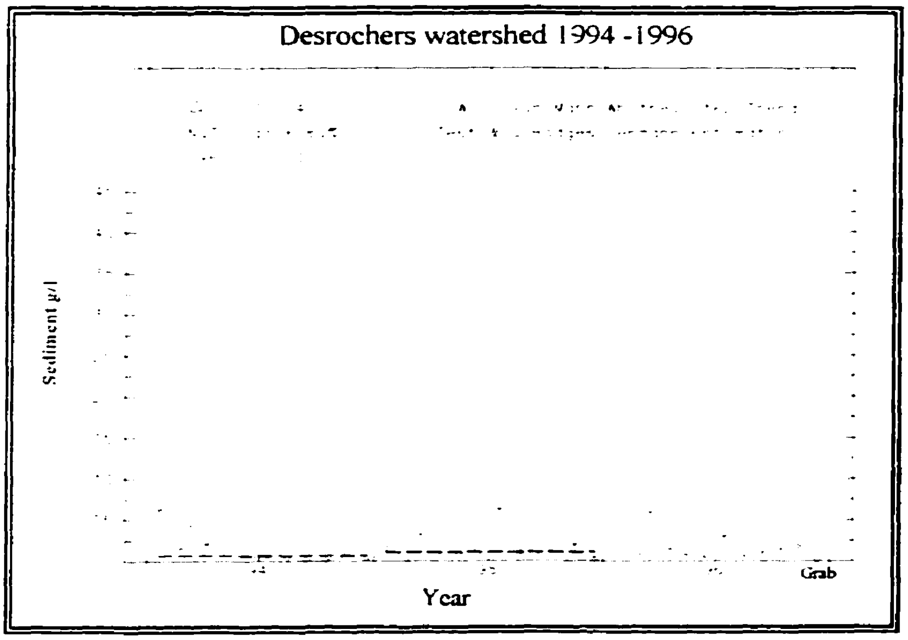

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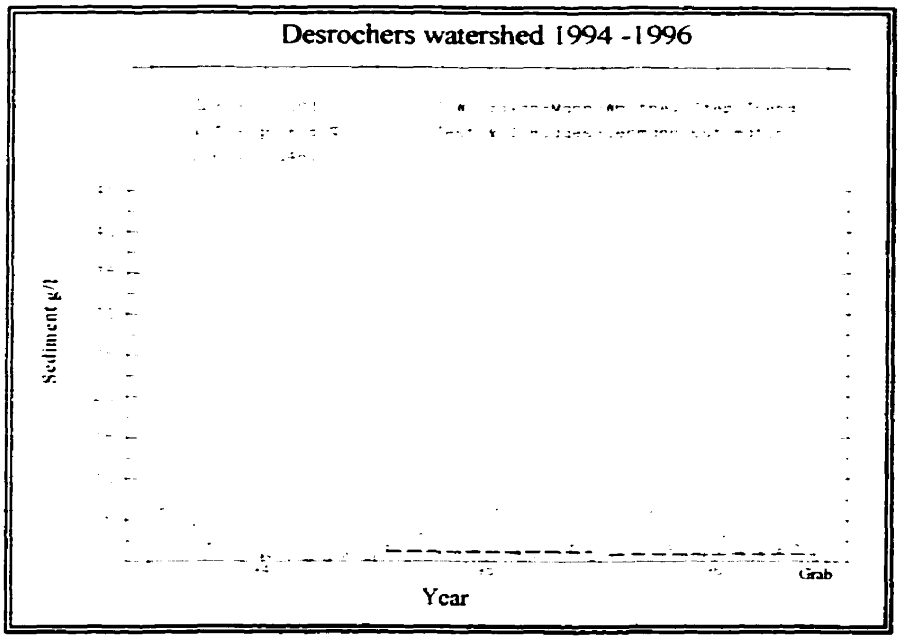

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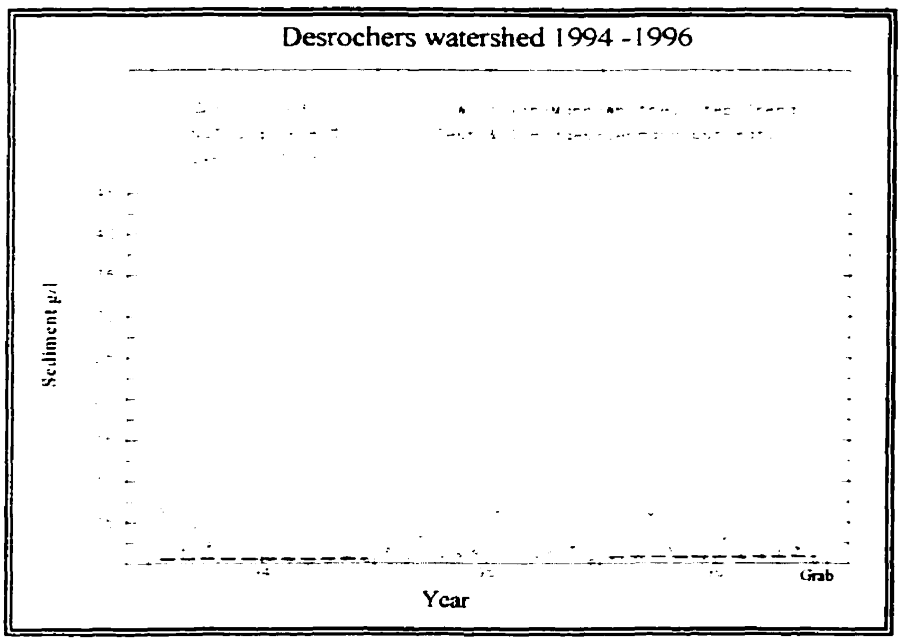

Figure J24