# A Comparison of Chemical Load Estimation Algorithms Using Data Obtained by Sampling Four South African Rivers at Varying Frequencies

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## Abstract

Different algorithms for the calculation of constituent loads in rivers were compared using continuous flow records and discrete constituent concentration records obtained by regular grab sampling. It was concluded that no specific algorithm is superior in all cases. The best algorithm could only be selected by jointly considering the type of constituent (conservative or non-conservative) and the sampling frequency. In general all the load estimation algorithms overestimated conservative constituent (TDS and Cl) loads, underestimated suspended solids loads and showed only slight tendencies of both over- and underestimation of non-conservative constituent ($NO_3$ and $PO_4$) loads. It was also shown that a drastic reduction of the sampling frequency in the dry season had no adverse effect on the accuracy of load estimates.

## Introduction

This paper provides a comparison of some algorithms used for estimating constituent loads in rivers.'

Accurate estimates of salt and suspended sediment loads in rivers are of importance for a number of reasons. Most important among these is the fact that the response of impoundments to man's activities in the catchment depends mainly on the load (and not so much the concentration) of chemicals and suspended solids reaching the impoundment. Therefore most water quality management strategies and the methods used to predict the possible outcome of such strategies are based on the resulting modification alternative strategies would have on the load of pollutants to impoundments. Estimating pollutant loads plays an essential role in assessment and prediction of the level of eutrophication in impoundments (Toerien, 1977; Golterman, 1980a; 1980b; Jones and Lee, 1981; Lee and Jones, 1980; Vollenweider and Kerekes, 1980; Walmsley and Butty, 1980a) and in the assessment and prediction of mineralisation (Guariso, Whittington, Abdel-Samie and Kramer, 1980; Hall and Görgens, 1978; Hutchinson and Midgley, 1978). The importance of making accurate load estimates has been stressed by Lettenmaier and Richey (1979), Scheider, Moss and Dillon (1979), Rodiek (1979); and Reckhow, Beaulac and Simpson (1980).

If continuous flow records and discrete constituent concentration records resulting from regular sampling at a particular point in a river are available, the load of a particular constituent is found by taking the sum of the products of the flow and concentration over short time intervals. However, if the concentration measurements are made with long time intervals in between, various algorithms have been used to estimate the concentration which would have occurred over shorter time intervals in order to calculate constituent loads (Unger, 1970; Cahill, Imperato, Nebel and Verhoff, 1975; National Eutrophication Survey, 1975; Sharpley, Syers and O'Connor, 1976; Osborne and Moss, 1977; Phillips, 1977; Santschi and Schindler, 1977; Smith and Stewart, 1977; Timmons and Holt, 1977; Timmons, Verry, Burwell and Holt, 1977; Grizzard, Randall, Hoehn and Saunders, 1978; Verworn, 1978; Weber, Cluis and Bobee, 1979; Cluis, 1980; Walmsley and Butty, 1980).

This study provides a comparison of some of the algorithms for estimating constituent loads from continuous flow records and discrete records of constituent concentrations, achieved by sampling at different frequencies, on the accuracy of annual load estimates in selected South African rivers.

The study was limited to a comparison of algorithms applicable to continuous flow and discrete concentration records. The performance of the various algorithms, as reflected by the accuracy of the load estimates, was compared as a function of the following factors:

- The type of constituent involved, e.g. conservative versus non-conservative constituents;
- the sampling frequency used to obtain the discrete concentration records; and
- the effect of using data from rivers in different parts of the country representing different catchment sizes and climatic regions.

## Methods and Materials

### Flow and constituent records

In order to compare different algorithms for estimating constituent loads, four rivers were selected on the basis that continuous flow recordings were available as well as constituent concentration records based on regular sampling at one- or two-daily sampling intervals covering a period of at least one year. Information on the catchments of the rivers, namely the Vaal, Balfour, Blinkwater and Orange, and a statement of the constituents for which load calculations were performed are given in Table 1. The daily means and coefficients of variation for

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TABLE 1
GENERAL INFORMATION ON THE RIVERS, CATCHMENTS, CONSTITUENTS AND SAMPLING PROGRAMME FROM WHICH THE DATA USED IN THIS STUDY WERE OBTAINED

| River | Gauging Weir | Catchment Area km$^2$ | MAR* $10^6 m^3$ | Constituents | Daily Means | CV** % | Sampling Frequency | Period Sampled | Notes |
|---|---|---|---|---|---|---|---|---|---|
| Vaal | C2M6 | 79 903 | 1 255 | Flow | 159 $m^3/s$ | 318 | Continuous | 77-10-01 | Part of the catchment urbanised and industrialised |
| | | | | TDS | 399 mg/ℓ | 33 | Daily | to 78-09-30 | |
| | | | | CL | 28,4 mg/ℓ | 54 | Daily | | |
| | | | | $NO_3$ | 0,45 mg/ℓ | 148 | Daily | | |
| | | | | $PO_4$ | 0,18 mg/ℓ | 79 | Daily | | |
| Balfour | Q9M19 | 76 | 18 | Flow | 0,32 $m^3/s$ | 202 | Continuous | 78-01-01 | Rural catchment (Fort Beaufort Area, Cape). |
| | | | | TDS | 131 mg/ℓ | 35 | Daily | to 78-12-31 | |
| Blinkwater | Q9M17 | 218 | 8 | Flow | 0,10 $m^3/s$ | 548 | Continuous | 78-01-01 | Rural catchment (Fort Beaufort Area, Cape). |
| | | | | TDS | 764 mg/ℓ | 23 | Daily | to 78-12-31 | |
| Orange | D1M03 | 37 100 | 4 105 | Flow | 491 $m^3/s$ | 130 | Continuous | 75-10-01 | Rural catchment |
| | | | | Suspended Solids | 1,04 g/ℓ | 164 | 2-Daily | to 76-09-30 | |

* Mean annual runoff
**Coefficient of variation

flow and constituent concentrations are also given in Table 1 to indicate the variability. Only the samples taken in the Vaal River were preserved with $HgCl_2$ (20 mg Hg per litre sample). Total dissolved solids (TDS) were estimated from electrical conductivity (EC) readings using relationships between TDS and EC established for each sampling point. Sampling was done at gauging weirs at which flow was recorded continuously. The flow records were digitised and the results expressed as mean daily flows in $m^3/s$. A few missing values in either the flow or constituent records were replaced by the mean of the values preceding and following a missing value. Because this study was mainly concerned with a comparison of algorithms of load estimation and not with the absolute loads as such, an informal treatment of missing values was regarded as acceptable.

In order to assess the influence of the sampling frequency used in obtaining the concentration records, the two-daily or daily concentration records available for the rivers mentioned in Table 1 were sub-sampled. Sub-sampling was done at sampling frequencies ranging between once every three days and once every thirty days. For example, the original record of daily concentrations of the dissolved constituents in the Vaal River was broken up into additional records by three-daily, weekly, two-weekly and monthly sub-sampling of the original records. The original two-daily sediment concentration record was broken up into additional records by four-daily, eight-daily, two-weekly and monthly sub-sampling of the original record. More than one additional concentration record could be obtained for any particular sampling frequency. For example, if a record is obtained by weekly sub-sampling out of an original daily concentration record, the first record can be obtained by sampling on the first day of each week in the original record. A second record of concentrations at weekly intervals can be obtained by sampling the second day of each week in the original record and so on. Therefore seven additional concentration records achieved by weekly sub-sampling could be obtained from the original daily record. Using the seven additional weekly records, seven different load estimates by a particular load estimation algorithm could be made. In the same way three load estimates based on three-daily sub-sampling, fourteen load estimates based on two-weekly sub-sampling and thirty load estimates based on monthly sub-sampling could be made. In calculating suspended sediment loads in the Orange River (on the basis of an original concentration record obtained from two-daily sampling) two load estimates based on four-daily, four load estimates based on eight-daily, seven load estimates based on two-weekly and fifteen load estimates based on monthly sub-sampling could be made. These results were plotted as dots opposite each sampling frequency for each method in Figures 1 to 7.

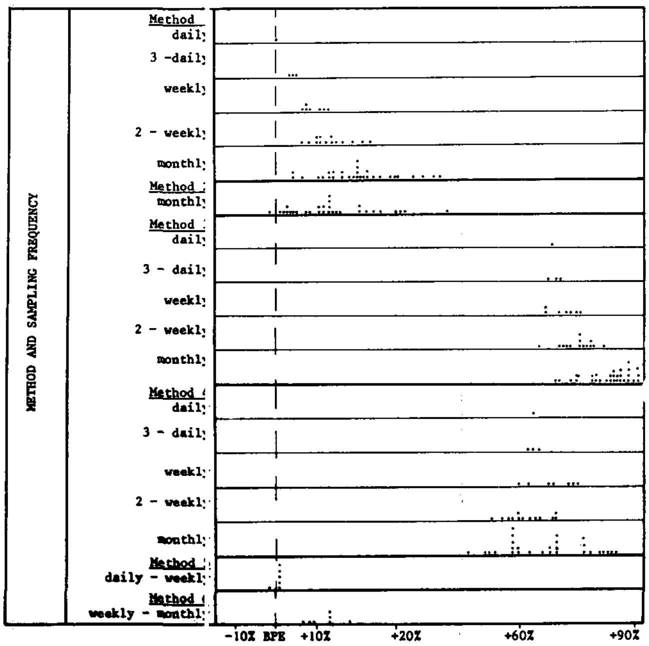


*Figure 1*
*Percentage deviation from the best possible estimate (BPE) of annual total dissolved solids loads in the Vaal River as derived from different methods of load calculation. The dots, opposite each sampling frequency, represent different load estimates which could be obtained from the same record*

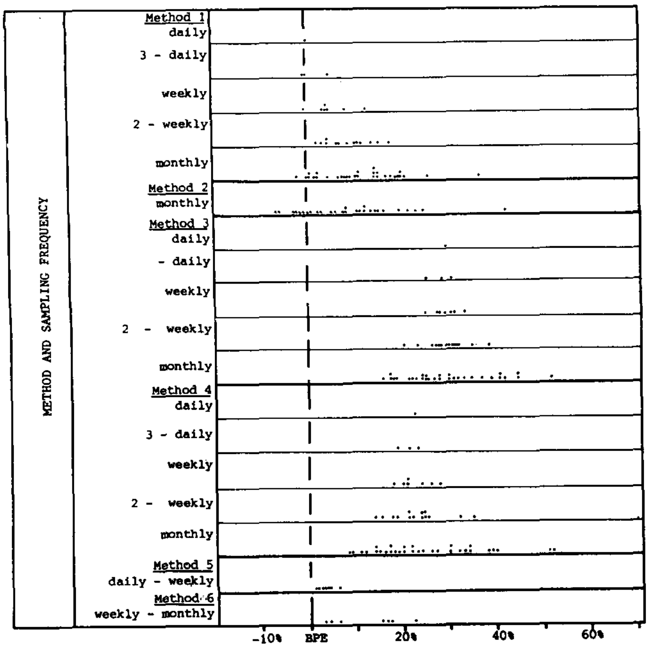


*Figure 2*
*Percentage deviation from the best possible estimate (BPE) of annual total dissolved solids loads in the Balfour River as derived from different methods of load calculation. The dots, opposite each sampling frequency, represent different load estimates which could be obtained from the same record*

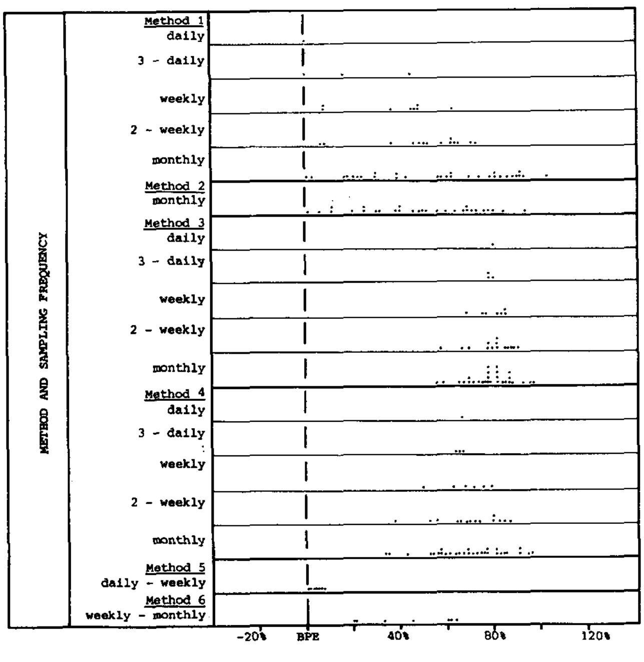


*Figure 3*
*Percentage deviation from the best possible estimate (BPE) of annual total dissolved solids loads in the Blinkwater River as derived from different methods of load calculation. The dots, opposite each sampling frequency, represent different load estimates which could be obtained from the same record*

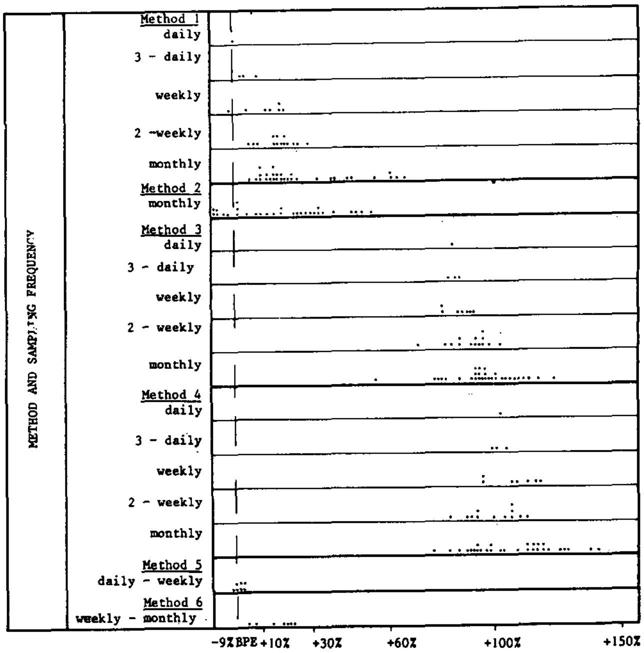


*Figure 4*
*Percentage deviation from the best possible estimate (BPE) of annual chloride loads in the Vaal River as derived from different methods of load calculation. The dots, opposite each sampling frequency, represent different load estimates which could be obtained from the same record*

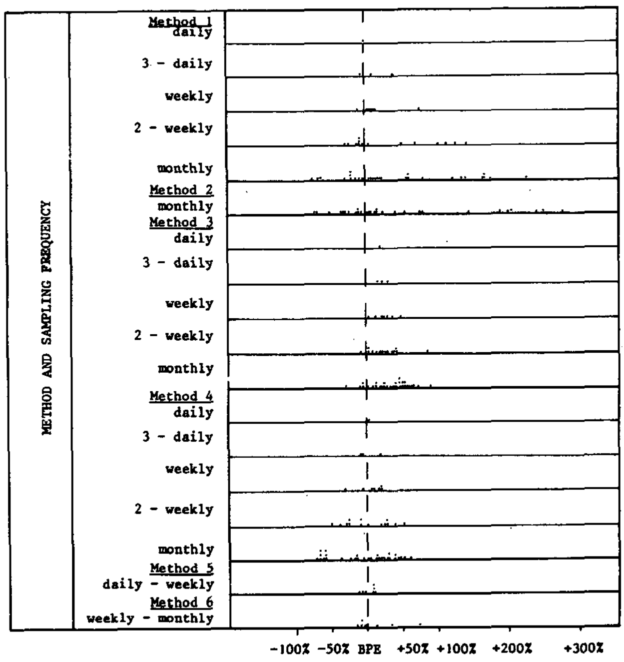


*Figure 5*
*Percentage deviation from the best possible estimate (BPE) of annual nitrate loads in the Vaal River as derived from different methods of load calculation. The dots, opposite each sampling frequency, represent different load estimates which could be obtained from the same record*

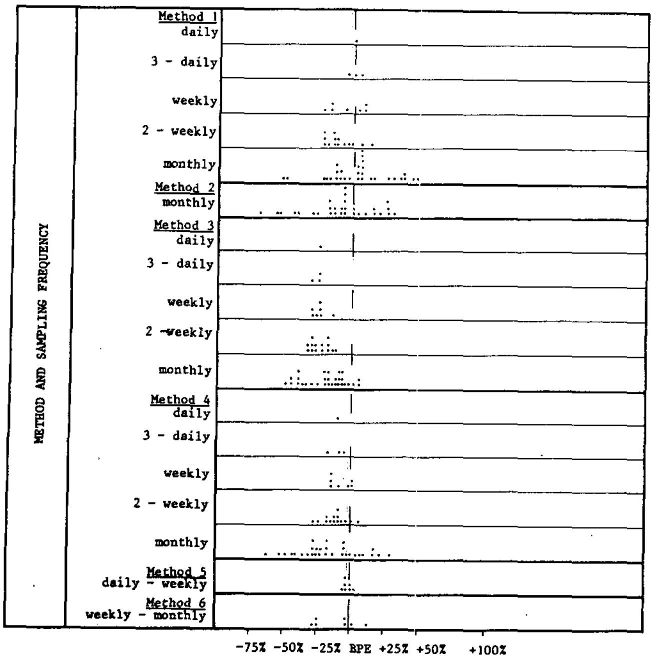


*Figure 6*
*Percentage deviation from the best possible estimate (BPE) of annual ortho-phosphate loads in the Vaal River as derived from different methods of load calculation. The dots, opposite each sampling frequency, represent different load estimates which could be obtained from the same record*

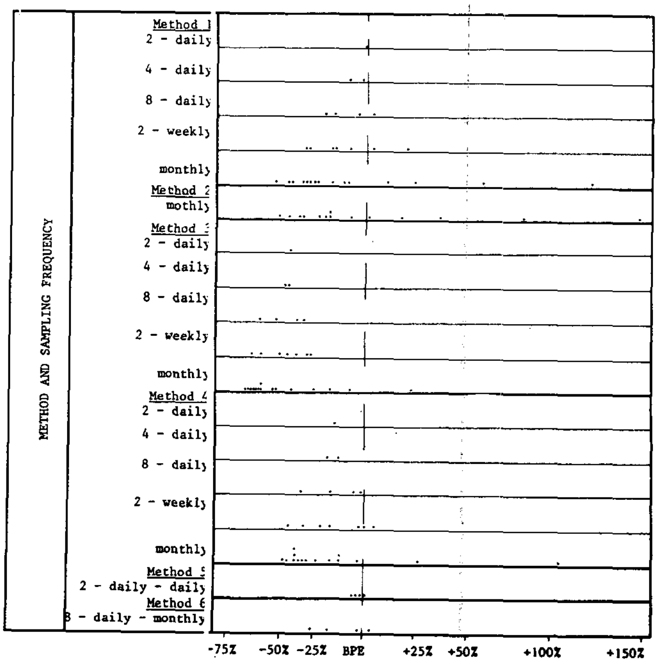


*Figure 7*
*Percentage deviation from the best possible estimate (BPE) of annual suspended sediment loads in the Orange River as derived from different methods of load calculation. The dots, opposite each sampling frequency, represent different load estimates which could be obtained from the same record*

**TABLE 2**
**ALGORITHMS USED FOR ESTIMATING CONSTITUENT LOADS WHICH WERE COMPARED IN THIS STUDY**

| Method No. | Equation | Notes |
|---|---|---|
| 1 | $L = \sum_{i=1}^{n} Q_i \left((C_{t-1} + C_t)/2\right)$ | Considered as best possible estimate with daily sampling |
| 2** | $L = \sum_{i=1}^{n} Q_i C_t$ | Concentrations not averaged. $C_t$ represents a single sample at time t. |
| 3 | $L = \sum_{i=1}^{n} (Q_i)\ ^1/n \sum_{i=1}^{n} (C_t)$ | Computes the product of $C_t$ and total annual discharge. |
| 4 | $L = \sum_{i=1}^{nr} Q_i/nr \sum_{i=1}^{nr} C_t + \sum_{i=1}^{nd} Q_i/nd \sum_{i=1}^{nd} C_t$ | Same as 3 above but products computed separately for dry and wet seasons and then summed. |
| 5 | Same as for 1 above but dry and wet season components used with weekly and daily sampling resp. | |
| 6 | Same as for 5 above with dry and wet season sampling monthly and weekly resp. | |

* L = Total annual load, $C_t$ = concentration at time t,
$Q_i$ = discharge volume estimate during sampling interval,
n = total number of samples/year, nr = total number of samples during wet season, nd = total number of samples during dry season.
**Method 2 produced results very similar to method 1 and therefore for the purpose of this study only results of method 2 applying to a monthly sampling frequency are given.

### Load estimation algorithms

The algorithms compared in this study were selected on the basis of the frequency they have been used according to the general literature. Some load estimating algorithms, although frequently used, have been discarded on the basis that they were obviously not applicable under our circumstances. For instance, we failed to establish a meaningful linear relationship (explaining more than 20% of the variance) between flow and concentration for any of the constituents measured in the Vaal and Orange rivers. Therefore we discarded the algorithms based on the assumption of such a linear relationship.

The load estimating algorithms selected for comparison in this study are given in Table 2.

Applying method 7 on records obtained with a daily or two-daily sampling frequency was regarded as the closest approximation to the integrated product of flow and associated concentration. This was regarded as the most accurate and therefore load estimates so obtained were designated as the best possible load estimates (BPE). It is against the BPE that the other load estimates obtained using all the different algorithms, including method 1 for sampling frequencies less than that of the original records, were compared; these comparisons constitute the core of this paper.

The load estimates obtained by using the different methods cited in Table 2 and the constituent concentration records obtained by the different sampling frequencies are given for:

- TDS in the Vaal River, Balfour River and Blinkwater River (Figs 1 to 3);
- chloride (Cl), nitrate ($NO_3$-N), and orthophosphate ($PO_4$-P) in the Vaal River (Figs 4 to 6); and
- suspended sediment in the Orange River (Fig. 7).

### Total dissolved solids loads (Figs 1 to 3)

The general trend is for TDS loads to be increasingly overestimated by method 1 when the sampling frequency is progressively lowered from daily to monthly. The degree of overestimation was of the same order for the Vaal River and the Balfour River ranging from between 5% and 10% of BPE at three-daily sampling intervals to just over 40% at monthly sampling intervals (see Figs. 1 and 2). This is notable given the large difference in their catchment areas (see Table 1). Note also that for these rivers no underestimates occurred. In the Blinkwater River (Fig. 3) the load estimates varied much more and ranged from over 40% of BPE overestimation at a three-daily sampling interval to an overestimation of more than 100% at a monthly sampling frequency. For this river two cases of slight underestimation of the load occurred.

Method 2 was used only on records obtained by monthly sub-sampling of the original records. Very similar results to those for method 1 were obtained when applying method 2 to the same monthly-sampled records for the 3 rivers. However, method 2 did seem to produce slightly reduced overestimates for monthly samples when compared to those obtained using method 1.

TDS loads calculated using method 3 were gross overestimates in comparison with the BPE; method 3 TDS loads using the original daily records overestimated the BPE by a surprising 70% for the Vaal River, 35% for the Balfour River and 83% for the Blinkwater River. These overestimates increased to a maximum of 90% of BPE in the Vaal River, 55% of BPE in the Balfour River and 101% of BPE in the Blinkwater River at monthly sampling intervals. An interesting observation is that although method 3 results were the most biased, the load estimates by method 3 showed a smaller range than load estimates by methods 1 and 2. The clearest case is the Blinkwater River where the range in load estimates using method 1 on the records obtained by monthly sampling was 100% of BPE, whereas the range in load estimates by method 3 on the same records was 46% of BPE.

Also of interest is the relative central tendency in the range of the load estimates obtained when applying method 3 to the records; there is a degree of symmetry about the load estimate based on the original daily record. In contrast, it can be observed that the load estimates obtained by methods 1 and 2 on the same records are skewed to the right. Method 4, in which the original annual records were divided into rainy and dry season records, produced results slightly less biased than those obtained using method 3, as was to be expected since method 4 represents in essence a refinement of method 3. Methods 5 and 6, it will be recalled, are based on the same principle as method 1, although shorter time intervals between sampling are used in the rainy than in the dry season. Method 5, with daily sampling in the rainy season and weekly sampling in the dry season, produced load estimates comparable to BPE which is an important result as will be discussed below. The estimates obtained by method 6 (weekly – monthly sampling) are comparable to the estimates by method 1 based on weekly sampling in both rainy and dry seasons.

### Chloride loads (Fig. 4)

Chloride data were used in the case of the Vaal River only. Chloride load estimates by means of methods 1 and 2 followed the same pattern as the TDS loads for the Vaal River. The maximum overestimation by means of method 1 at monthly sampling intervals was 66%. Method 2 overestimated to a lesser degree than method 1, as was the case with TDS. Both methods 3 and 4 grossly overestimated the chloride loads at all sampling intervals, but exhibited a similar symmetry in the range of their estimates to that of TDS loads. The maximum single overestimation (140% of BPE) was obtained using method 4 applied to records obtained by using monthly sampling intervals. Similarly to the results obtained with TDS, method 5 produced load estimates comparable to BPE and method 6 produced load estimates comparable to method 1 at a weekly time interval.

### Nitrate loads (Fig. 5)

Nitrate data were available for the Vaal River only. Estimates of nitrate loads by method 1 differed in two important aspects from load estimates for chloride and TDS. Firstly the range over which the load estimates varied for records obtained from a given sampling frequency was much wider, e.g. between −73% and +230% of BPE for monthly sampling intervals as compared to a range of less than 40% of BPE for TDS and less than 65% of BPE for chloride in the Vaal River. Secondly, there was much less of a tendency to produce biased load estimates of nitrate compared to TDS and chloride loads by the same methods. This is indicated by a relatively large number of load estimates smaller than the BPE.

As in the previous case there was not much difference between results obtained using methods 2 and 1 at a monthly sampling interval. The most marked difference between load estimates for conservative constituents (TDS and chloride) and non-conservative constituents, as represented by nitrate, is apparent in methods 3 and 4. Previously these methods led to gross overestimates of loads whereas for nitrate both methods 3 and 4 resulted in markedly better load estimates (closer to BPE) than method 1 for records obtained at the same sampling intervals. Method 3 differed from 4 in that it tended to overestimate the load in virtually all cases whereas method 4 seemed to overestimate and underestimate in an equal number of cases. Methods 5 and 6 resulted in load estimates comparable to those obtained when applying method 1 to records obtained by sampling the whole year round at the frequency used for the rainy season in methods 5 and 6; this, again, is an important result and will be discussed below.

### Orthophosphate loads (Fig. 6)

Orthophosphate data were available for the Vaal River only. Orthophosphate is also considered to be a non-conservative constituent and the load estimates showed the same tendencies (although not as prominent) as found for nitrate loads. Load estimates using method 1 fell within the range −50% to +50% of BPE, which is larger than that found for TDS and chloride loads, but much less than the range of 300% of BPE found for nitrate loads. Method 2 still gave much the same results as method 1 although it tended to underestimate the load more often in this case.

Method 3 consistently underestimated the orthophosphate loads. The same was true for method 4 but the underestimation was not as marked as in method 3. The estimates by methods 5 and 6 were comparable to the estimates by method 1, as found for TDS, chloride and nitrate loads.

### Suspended sediment loads (Fig. 7)

Suspended sediment data were selected from the Orange River only. In general the results for method 1 shown in Fig. 7 show much the same pattern as those for orthophosphate loads. A peculiar aspect of the load estimates for suspended sediment is that, although underestimates occurred most frequently, some very large overestimates (up to 120% of BPE) of the loads did occur. Method 2, in contrast to its performance in all the previous applications related to chemical constituents, produced load estimates with a slightly larger range than method 1. Methods 3 and 4 consistently underestimated suspended sediment loads. The range over which the load estimates varied was also smaller than that in the case of methods 1 and 2.

Methods 5 and 6 again resulted in load estimates comparable to those obtained using method 1.

## Discussion

The results obtained in this study demonstrate the importance of sampling at an appropriate frequency and the importance of using an appropriate integration algorithm for concentrations in order to estimate loads for the different types of constituents (e.g. conservative or non-conservative or suspended sediment).

### The effect of constituent type on load estimates

A comparison of the load estimates obtained using methods 3 and 4 in relation to those obtained using the other methods for the conservative constituents TDS and chloride (Figs. 1 to 4), the non-conservative constituents nitrate and orthophosphate (Figs. 5 and 6) as well as for suspended sediment (Fig. 7), confirms the above. Methods 3 and 4 gave poorer estimates of conservative constituent loads (TDS and chloride, Figs. 1 to 4) but better estimates of the non-conservative constituents (nitrate and orthophosphate, Figs. 5 to 6) and suspended sediment (Fig. 7). The type of constituent should also be considered when interpreting or applying results from load estimates by any of the methods because of the general tendency for all methods to overestimate conservative constituent loads and underestimate non-conservative and suspended sediment loads. Estimates of non-conservative loads deviated from the BPE by up to 300% of BPE for nitrate (Fig. 5) whereas the maximum deviation observed for conservative constituent loads was *ca.* 150% of BPE for chloride (Fig. 4).

### The effect of sampling frequency on load estimates

The role of sampling frequency in limiting the accuracy of load estimates is clearly demonstrated by the widening of the range when the sampling frequency decreased from once daily to once monthly. An important observation, furthermore, is that for some methods and constituents, lowering the sampling frequency resulted in increasing the possibility of overestimating loads, e.g. method 1 applied to TDS and chloride (Figs. 1 to 4). For the non-conservative constituent orthophosphate (Fig. 6) and suspended sediment (Fig. 7), lowering the sampling frequency and using method 1 resulted in increasing the chance of underestimating the loads. However, when using method 3 on the non-conservative constituents nitrate and orthophosphate (Figs. 5 to 6) and suspended sediment (Fig. 7), lowering the sampling frequency resulted only in the widening of the range with no marked change in the chance of over- or underestimating the loads.

All the rivers considered in this study are situated in the summer rainfall area of South Africa. The rainfall in this area has a very pronounced seasonal character where about 80 per cent of the rainfall occurs in the summer (Braune and Wessels, 1981). This in turn results in highly variable river flows with most of the variation occurring in summer. The adoption of a suitable high sampling frequency in summer, which is the rainy season for all the rivers considered, is shown to be of great importance. In all cases a drastic lowering of the sampling frequency in the winter months or dry season (when very little variation in flow compared to the wet season occurs) did not noticeably increase the deviation of load estimates from the BPE, when compared to year round sampling at the higher frequency used in summer. This observation should be important for agencies involved in the monitoring of water quality because the reduction of the frequency of sampling for, say, six months of the year could result in large savings.

### The effects of the discharge and concentration regimes of rivers on load estimates

The general tendency for certain methods to overestimate conservative and underestimate non-conservative loads can probably be related to some kind of concentration flow relationship in these rivers. This relationship is probably highly complex and the findings of Rooseboom (1981) that sediment loads in rivers are yield controlled and not transport controlled may also apply to salt loads. If this is the case then it will be unlikely that any relationship useful for estimating loads from flow data will be established.

In Fig. 8 frequency distributions for orthophosphate and TDS concentrations in the Vaal River, suspended solids in the Orange River and flow in the Vaal River are given. It is common for South African rivers to have the few low TDS concentrations associated with the few high flows during flood events. At the same time the few high suspended sediment concentrations are associated with the few high runoff events. These few high flow events make up a major portion of the annual runoff although they occur for a relatively short time (Fig. 8). Sampling at regular intervals therefore results in a large proportion of samples being taken during low flow conditions at which the more frequent high TDS and low suspended sediment concentrations occur (Fig. 8). A data set obtained in this way would result in a disproportionately (reflecting volumes) large number of samples having high TDS and low suspended sediment concentrations. This outcome would explain the overestimation of TDS loads (Figs. 1 to 3) and the underestimation of suspended sediment loads (Fig. 7). The observation that nitrate and phosphate loads show only slight tendencies towards overestimation or underestimation (Figs. 5 and 6) can probably be related to the fact that no definite relationships between flow and concentration exist for these constituents in the Vaal River. Also the frequency distribution for orthophosphate given in Fig. 8 falls somewhere between that of TDS (which results in overestimates) and suspended solids (which results in underestimates). This may partly explain the fact that the load estimates of the non-conservatives in the Vaal River are centred around the BPE. This may not be the case for less polluted rivers and the findings of this study with regard to nitrate and phosphate loads should only be extrapolated with great care.

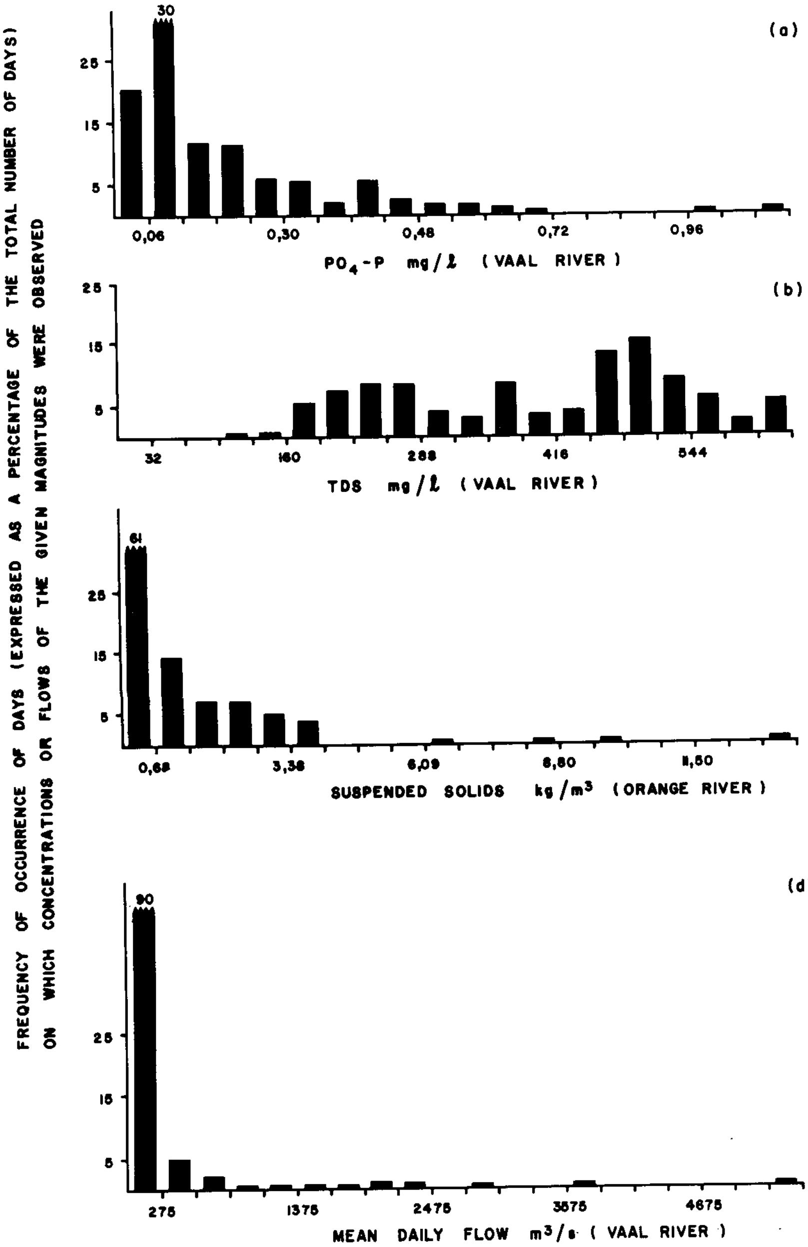


*Figure 8*

*The frequency of occurrence of days (expressed as a percentage of the total number of days) on which constituent concentrations or flows of the given magnitudes were observed (a) ortho-phosphate ($PO_4$-P) in the Vaal River (b) total dissolved solids (TDS) in the Vaal River (c) suspended solids in the Orange River (d) flow in the Vaal River*

### The effect of catchment size and climatic zone on load estimates

Comparison of the accuracy of TDS load estimates in the Vaal, Balfour and Blinkwater Rivers is most interesting. Although the Vaal River is located in a different climatic zone to the other two rivers (which are both tributaries of the Kat River in the Eastern Cape) and although the Vaal River catchment is very much larger than that of the other two rivers (see Table 1), the results obtained for all three of these rivers are remarkably similar. One of the authors, (Kemp, unpublished data) made a similar set of TDS load estimates on the Suikerbosrand River on the Witwatersrand for two different years (1977/78 and 1978/79) using the same methods. The Suikerbosrand River is highly polluted since it drains a heavily urbanized and industrialized catchment. Kemp's Suikerbosrand River results were very similar to the results reported in this study, confirming our observation that, at least as far as TDS is concerned, the findings of this study can be generalised and would probably apply to most South African rivers which derive their runoff from highly seasonal rainfall.

### The effect of the load estimation method

The particular algorithm selected to calculate loads is important as shown by the results. Probably the most important observation is that no single algorithm can be selected as being universally superior for estimating loads. The accuracy with which loads can be estimated is so dependent on the type of constituent, sampling frequency, and the choice of an algorithm that the best approach for a particular situation can only be selected by simultaneously taking these three factors into account. For example when the nitrate load is to be estimated, based on the results shown in Fig. 5, the best estimate would be obtained using method 1 or 4 if daily samples are taken. However, if sampling is executed two-weekly or once monthly, method 3 would give the best estimates. It is only with the conservative constituents TDS and chloride (Figs. 3 to 6) that the use of two of the methods namely, methods 3 and 4, should be avoided regardless of the sampling frequency since they produce results which are invariably high.

## Conclusions

1. There is no algorithm for integrating constituent concentrations in order to estimate constituent loads which is superior in all cases, i.e. involving all constituents and all sampling frequencies. The best algorithm for calculating constituent loads in rivers must be selected by jointly considering the type of constituent (conservative, non-conservative or suspended sediment) and the sampling frequency.

2. It appears as if the findings of this study, at least as far as conservative constituents are concerned, are generally applicable to South African rivers in regions with highly seasonal rainfall and can therefore be used beneficially for the selection of a suitable method for any particular situation in these regions.

3. The sampling of river water at a suitable frequency is essential to permit the estimation of constituent loads with a desired accuracy. For most river quality management purposes which involve estimating loads (e.g. with an accuracy of ± 10%), sampling at high frequencies may be necessary only during the rainy season. Cutting down sampling from a high frequency all year round to low frequencies in the dry season when the variance of both flow and constituent concentration are minimised, can clearly result in large financial savings.

4. When making load estimates by any of the methods compared in this study it should be appreciated that concerning conservative substances the estimates will more likely than not be too large; concerning suspended sediment, the estimates will more likely be too small. Estimates of non-conservative constituent loads show tendencies in each direction with nitrate loads showing a slight tendency towards overestimation and phosphate loads a slight tendency towards underestimation.

5. Clearly this study only touches on some of the important issues at stake and completely ignores some of the others. For example, the fact that constituent loadings are biased suggests some sort of flow-concentration relationship which does not seem to be linear. Further investigation of the existence of (possibly non-linear) flow-concentration relationships is receiving attention now. Another important aspect is to quantify the sensitivity of load accuracy in relation to variance in flow and variance in concentration. What is also important is to get some indication of how accurate the BPE, as defined in this study, is in relation to the actual constituent load passing a point in a river. Data presently accumulated by using continuous electrical conductivity measurements in conjunction with continuous flow measurement should throw some light on this question.

## Acknowledgements

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