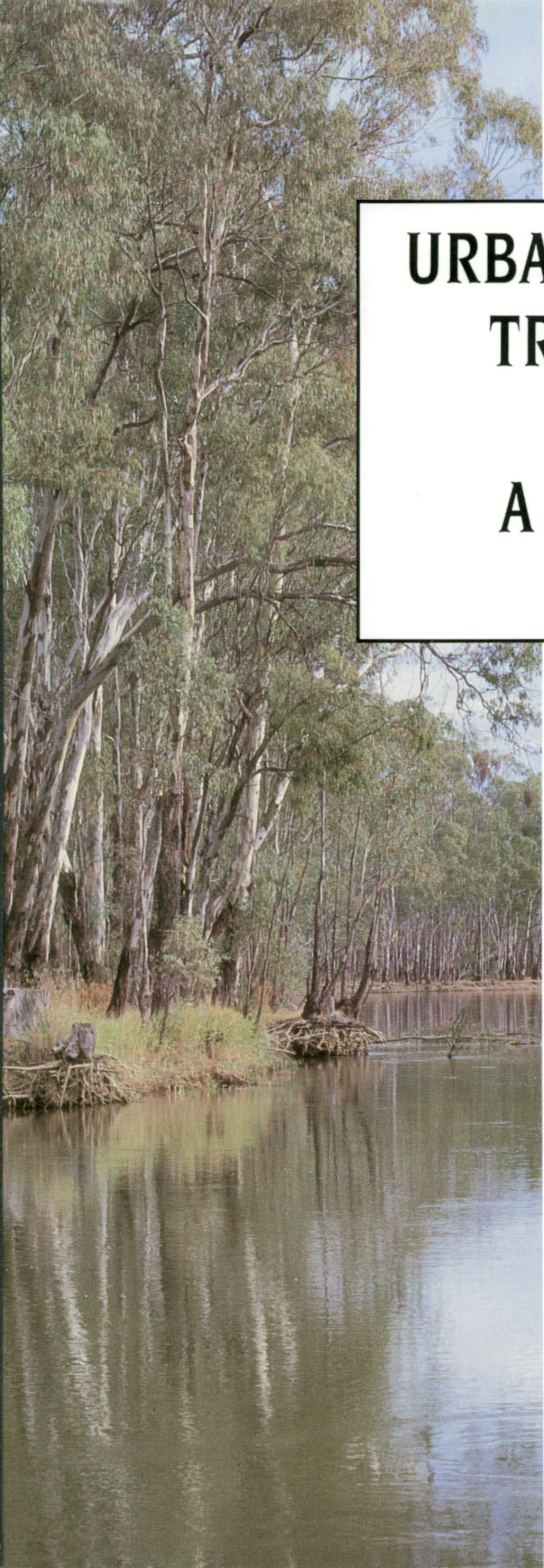

URBAN STORMWATER TREATMENT BY STORAGE: A STATISTICAL OVERVIEW

H. P. Duncan

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COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

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PREFACE

The Cooperative Research Centre for Catchment Hydrology's Urban Hydrology research program comprises two main projects. Project C1 investigates methods for estimating runoff and pollution loads from urban catchments over a range of time and space scales. Project C2 brings together several studies aimed at improving design and management procedures for urban waterways.

This report was prepared for Project C1 by Hugh Duncan, seconded to the CRC for Catchment Hydrology from Melbourne Water, and follows on from a review recently completed by Hugh of urban stormwater quality literature. The main objectives of that review were to assess the current status of urban stormwater quality research, to facilitate access to existing information, and to establish priorities for future work.

Tom McMahon
Program Leader, Urban Hydrology
Cooperative Research Centre for Catchment Hydrology

ABSTRACT

This report presents a statistical overview of urban stormwater treatment by detention in on-stream storage. The study was carried out by comparing and analysing the results of investigations at up to 51 separate locations in four countries reported in the literature.

All water quality concentration data analysed appears to be log-normally distributed. Area ratio is the best measure of basin size tested for predicting water quality change in storage. For some water quality parameters, input concentration is a highly significant explanatory variable, regardless of whether output concentration or percentage change is required. Area ratio and input concentration together can explain up to 89% of the between-study variation in output quality.

The 11 water quality parameters tested fall into three groups, based on their behaviour in storage -- a settling group, a proportional group, and a rate-limited group. For the settling group, output concentration is roughly proportional to the square root of the input concentration, and inversely proportional to the square root of the area ratio. For the proportional group, output concentration is proportional to input concentration, and decreases very slowly as area ratio increases. For the rate-limited group, output concentration is proportional to input concentration to the power 1.6, and decreases slowly as the area ratio increases.

The derived relationships indicate that two smaller basins in series are more effective than one larger basin with the same total area ratio for all water quality parameters tested. Wetlands are either less effective than ponds of the same area ratio, or not significantly different from ponds, depending on the water quality parameter under consideration.

Average storage performance curves are presented for selected water quality parameters.

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URBAN STORMWATER TREATMENT BY STORAGE:

A STATISTICAL OVERVIEW

1. INTRODUCTION

This report presents a statistical overview of urban stormwater treatment by detention in on-stream storage. The study was carried out by comparing and analysing the results of investigations reported in the literature from 51 separate locations in four countries. The main emphasis is on lakes and ponds, but a comparison between pond and wetland performance is also included. The objective is to identify relationships embedded in the data, rather than to test a pre-existing hypothesis, so initial assumptions about likely processes and relationships have been kept to a minimum. Typically, between one half and three quarters of the between-study variation in output concentration can be accounted for using just two explanatory variables.

Detention has been a recognised component of urban stormwater treatment since at least the early 1970's. At first storage was described mainly in the context of flow control to other treatment facilities (Inaba 1970; Field 1973; Feuerstein & Friedland 1975), but the storage element was soon seen to provide useful water quality improvement in its own right (Guy 1978; Biggers et al. 1980). Detention storage has been classed as a Best Management Practice, which in this context means 'a nonstructural or elementary structural stormwater pollution control measure' (Finnemore 1982). Published studies have typically recorded removal efficiencies of 80%, 70%, 60%, and 50%, for suspended solids, heavy metals, phosphorus, and oxygen demand respectively, although the scatter of results is wide (Duncan 1995).

A substantial body of research on the effectiveness of detention has accumulated over the years, and has generated a range of descriptive and numerical design guidelines to improve output quality. Descriptive guidelines based on physical processes are provided by Randall (1982) and by the NURP project (Torno 1984). Cullen et al. (1988) emphasise the biological aspects of storage ponds, while Yousef et al. (1986a) concentrate on the nutrients nitrogen and phosphorus. Taken together, the guidelines from these studies recommend:

- long, narrow configurations, i.e. length to width ratios of 2:1 to 3:1,
- inlet and outlet structures at extreme ends of the basin,
- use of baffles or flow retarders,
- construction of ponds in series or in two stages, to reduce short-circuiting,
- development of grass cover on the floor of dry basins to reduce erosion,
- use of underground tile drains for outlet discharge, soil type permitting, to provide filtration,
- use of wet basins or dual-purpose basins (dry basins with extended detention time) in preference to conventional dry basins,
- open areas of water for sedimentation,
- 10 to 30% of surface area less than one metre depth, for emergent macrophytes,
- control of normal top water level for management of macrophytes,
- fully drainable pond for ease of maintenance,
- trash and bedload traps upstream to reduce dredging of main pond, and
- depth not exceeding 2 metres for good nutrient removal.

More quantitative design guidelines have also been reported. Heaney (1986) tabulates pollutant removal for a range of pollutants and storage types, using data from the NURP study. Driscoll

(1986a) and Phillips & Goyen (1987) plot suspended solids removal against area ratio (basin surface area/catchment area), while Lawrence (1986) presents graphs of basin performance against hydraulic residence time.

A review of wetlands in the United States is provided by Strecker et al. (1992), who discuss the mechanisms and efficiency of water quality improvement. Wetland size, age, and flow conditions, seasonal changes, level of maintenance, and whether natural or constructed may all influence the contaminant removal efficiency.

This report concentrates mainly on the variation *between* studies reported in the published literature, a source of information which, apart from the NURP program (Athayde et al. 1983), has rarely been exploited. Thus a significant result here does constitute largely new information, and it is encouraging to see how closely it agrees with the more conventional *within* study results. On the other hand, a negative or non-significant result here does not in any way detract from the conclusions of studies set up to examine a particular aspect of treatment by storage in more detail.

2. DATA MANAGEMENT

The data as initially collated for this study is listed in Appendix A. It has been retabulated into a spreadsheet format more suitable for analysis, based on an initial review of the amount and type of data available. One record in the analysis format is the average behaviour of one experimental condition at one site in the source document. Thus, for example, the four nested sites of Wu et al. (1988) at Charlotte in North Carolina form four records, and the separately tabulated results for summer and autumn storms at Viborg in Denmark (Hvitved-Jacobsen et al. 1987) form two records. This means that separate records are not always fully independent.

Data has been prepared for a multiple regression approach, using output concentration in milligrams per litre as the dependent variable. Percent removal (or removal efficiency) has frequently been used in published studies as the measure of basin performance, but it is not a suitable measure for statistical analysis. It is clearly not normally distributed as it is bounded at +100%, which denotes complete removal. Percent remaining in the outflow is a better measure statistically, but is less than ideal for another reason. The use of percent remaining suppresses the importance of the input concentration - it is too easy to assume that dividing by input concentration has standardised the data against this parameter and so 'removed' its effect. The analysis which follows shows that this is not at all the case for some water quality parameters.

Output concentrations in this data set can be described by the log-normal distribution. The observed data points and fitted probability distributions are plotted for each contaminant in Appendix B, together with results of the Shapiro-Wilk test for normality (applied in the log domain). The hypothesis of log-normality can not be rejected at the 99% confidence level for any of the eleven contaminants tested, and ten of the eleven fall within the 95% band. Furthermore, the residuals remaining after the regression analysis described in the following section are all log-normally distributed at the 95% level. This fully supports the almost universal observation of log-normality in urban water quality concentration data (Mance & Harman 1978; Torno 1984; Driscoll 1986b; Marsalek 1991). Accordingly, log-transformed concentration data has been used throughout the analysis.

The explanatory variables used are input concentration, area ratio, basin storage, and average depth. Input concentration is measured in milligrams per litre. Area ratio is the surface area of the storage divided by the total catchment area, and is dimensionless. Basin storage is the storage volume divided by the total catchment area, and has units of millimetres. It represents the depth of rainfall which could be held in the storage given 100% runoff from the catchment.

Average depth is calculated as the storage volume divided by the surface area, and is measured in metres.

Mean annual rainfall in millimetres was also tested as an explanatory variable. Although occasionally significant, it was found to be less valuable than input concentration or basin size. Due to limitations imposed by sample size, it was not used in detailed analysis.

These explanatory variables were chosen for their simplicity, their relevance to existing descriptive and quantitative design guidelines and, for the size measures at least, their general availability. A consequence of using these measures is that only on-stream storages can be included - the concepts of area ratio and storage cannot be directly applied to off-stream storages. Descriptors which incorporate runoff information (such as mean overflow rate or mean residence time) are intuitively appealing, but are less readily available for many sites.

The use of input concentration as an explanatory variable for output concentration tends to produce high correlation coefficients, particularly when the basin has little effect on concentration. In one sense this is correct - if the input concentration is known and the basin has no effect, the output concentration is indeed known accurately - but it seems to overstate the practical utility of the relationship. The standard error about the regression line is not influenced by such effects, and is therefore a better measure of practical value. It is reported here, along with the correlation coefficient, for every relationship calculated.

Input concentration is frequently not quoted in published reports, particularly when performance is expressed as a percentage change in concentration. But prior studies (Ferrara & Witkowski 1983; Grizzard et al. 1986) and initial review of this data show that it cannot be ignored, even when output is expressed as a percentage of input. As a result, a considerable amount of otherwise valuable data has necessarily been excluded from the analysis.

To obtain sufficient data for analysis, it has been necessary to combine different conditions which would ideally be treated separately. Firstly, all types of on-stream storage have been considered together. Most records are for wet ponds or lakes, but dry ponds, oversized pipes, and wetlands are also included. Oversized pipes are small underground storages formed by the use of a much enlarged pipe diameter for a short length of drain. Secondly, the time over which results are averaged covers a wide range, from isolated storm events to total flow over a study year. Most records are the average of several storm events at a site, and at most of these sites the flow is negligible except during storms. Thirdly, the quality data quoted may be based on arithmetic means, geometric means, or medians of individual readings or events. The validity of grouping these diverse conditions together is checked in a later section.

In most cases the three basin size measures can be taken directly from the published sources, but occasionally one or more of the measures cannot be obtained from information supplied. To make at least partial use of this data, the missing size measures have been estimated by correlation with the available measures. In five cases, all part of the NURP study, area ratio and storage have been estimated from the overflow rate (mean runoff rate/basin surface area), and in seven cases storage has been estimated from area ratio or vice versa. Altogether, 38 data records have been obtained from 27 different locations.

It can be seen that a statistically rigorous treatment of data has not been achieved - there are just too many possible conditions, and not enough data to distinguish between them. Even so, the similarities and differences which emerge from the analysis which follows seem to be both useful and informative.

3. MAJOR EXPLANATORY VARIABLES

Assessment of the major explanatory variables has been carried out using multiple regression on log-transformed data. Eleven water quality parameters had sufficient data to permit analysis. They are suspended solids, total lead, total zinc, dissolved phosphorus, total phosphorus, organic nitrogen, ammonia nitrogen, total Kjeldahl nitrogen, oxidised nitrogen, total nitrogen, and chemical oxygen demand.

Data from the pond at Maitland Interchange, Florida, reported by Hvitved-Jacobsen et al. (1984) and Yousef et al. (1986a), shows such high contaminant removal that the record appears to be a statistical outlier for several quality parameters. The Maitland pond is unusual in that surface outflow rarely occurs, and pond water quality has been taken as an estimate of output quality. The authors note the unusually high contaminant removal, and discuss the likely causes. Such high removal appears to be unlikely elsewhere unless a number of conditions are met. The record has therefore been deleted from the current analysis whenever it is a probable outlier, which is the conservative approach from a treatment efficiency point of view. Results from other studies at the same site (Yousef et al. 1984; Yousef et al. 1985; Yousef et al. 1986b) have not been deleted.

It should be noted in this context that the data used here represents actual practice, not necessarily best management practice. This is particularly true of the older basins, some of which were not designed with water quality improvement in mind at all. Hopefully, new basins specifically designed for quality management would perform more like the best of those described here.

For each water quality parameter, the output concentration has been regressed against the input concentration and each measure of basin size in turn. The size measures are all strongly correlated with each other, so they have not been used together. Besides, sample sizes are not large enough to permit reliable analysis using more than two explanatory variables. The best regression using two explanatory variables is tabulated below for each water quality parameter. In almost all cases area ratio is the best size measure, but where it is not, the relationship using area ratio is also included, to allow direct comparison between quality parameters. Units are milligrams per litre for input and output concentration and millimetres for storage, while area ratio is dimensionless. The numbers in brackets are the 95% confidence limits on the coefficients and intercepts.

Suspended Solids:

$$\text{Log}(\text{SS}_{\text{out}}) = \log(\text{SS}_{\text{in}}) \times 0.60(\pm 0.23) - \log(\text{Area Ratio}) \times 0.31(\pm 0.16) - 0.34(\pm 0.48)$$

$$r^2 = 0.65,\ \text{Standard Error} = 0.28,\ \text{Observations} = 31$$

Total Lead:

$$\text{Log}(\text{Lead}_{\text{out}}) = \log(\text{Lead}_{\text{in}}) \times 0.45(\pm 0.44) - \log(\text{Area Ratio}) \times 0.38(\pm 0.36) - 1.91(\pm 0.67)$$

$$r^2 = 0.35,\ \text{Standard Error} = 0.30,\ \text{Observations} = 16$$

Total Zinc:

$$\text{Log}(\text{Zinc}_{\text{out}}) = \log(\text{Zinc}_{\text{in}}) \times 0.30(\pm 0.62) - \log(\text{Area Ratio}) \times 0.73(\pm 0.41) - 2.38(\pm 1.10)$$

$$r^2 = 0.57,\ \text{Standard Error} = 0.38,\ \text{Observations} = 20$$

Dissolved Phosphorus:

$$\text{Log}(\text{DisP}_{\text{out}}) = \log(\text{DisP}_{\text{in}}) \times 1.00(\pm 0.43) - \log(\text{Storage}) \times 0.11(\pm 0.15) - 0.09(\pm 0.61)$$

$$r^2 = 0.73,\ \text{Standard Error} = 0.22,\ \text{Observations} = 13$$

or using area ratio:

$$\text{Log}(\text{DisP}_{\text{out}}) = \log(\text{DisP}_{\text{in}}) \times 0.96(\pm 0.42) - \log(\text{Area Ratio}) \times 0.13(\pm 0.18) - 0.50(\pm 0.60)$$

$r^2 = 0.72$, Standard Error = 0.23, Observations = 13

Total Phosphorus:

$$\text{Log}(\text{TotP}_{\text{out}}) = \log(\text{TotP}_{\text{in}}) \times 0.91(\pm 0.23) - \log(\text{Area Ratio}) \times 0.13(\pm 0.10) - 0.54(\pm 0.27)$$

$r^2 = 0.71$, Standard Error = 0.19, Observations = 33

Organic Nitrogen:

$$\text{Log}(\text{OrgN}_{\text{out}}) = \log(\text{OrgN}_{\text{in}}) \times 0.72(\pm 0.44) - \log(\text{Area Ratio}) \times 0.03(\pm 0.08) - 0.15(\pm 0.18)$$

$r^2 = 0.74$, Standard Error = 0.11, Observations = 10

Ammonia Nitrogen:

$$\text{Log}(\text{AmmN}_{\text{out}}) = \log(\text{AmmN}_{\text{in}}) \times 0.86(\pm 0.54) - \log(\text{Area Ratio}) \times 0.05(\pm 0.24) - 0.31(\pm 0.60)$$

$r^2 = 0.59$, Standard Error = 0.34, Observations = 12

Total Kjeldahl Nitrogen:

$$\text{Log}(\text{TKN}_{\text{out}}) = \log(\text{TKN}_{\text{in}}) \times 1.00(\pm 0.32) - \log(\text{Area Ratio}) \times 0.02(\pm 0.06) - 0.12(\pm 0.13)$$

$r^2 = 0.68$, Standard Error = 0.12, Observations = 25

Oxidised Nitrogen:

$$\text{Log}(\text{OxidN}_{\text{out}}) = \log(\text{OxidN}_{\text{in}}) \times 1.63(\pm 0.34) - \log(\text{Area Ratio}) \times 0.21(\pm 0.14) - 0.53(\pm 0.31)$$

$r^2 = 0.89$, Standard Error = 0.23, Observations = 20

Total Nitrogen:

$$\text{Log}(\text{TotN}_{\text{out}}) = \log(\text{TotN}_{\text{in}}) \times 1.08(\pm 0.25) - \log(\text{Area Ratio}) \times 0.06(\pm 0.06) - 0.23(\pm 0.13)$$

$r^2 =0.82$, Standard Error = 0.10, Observations = 22

Chemical Oxygen Demand:

$$\text{Log}(\text{COD}_{\text{out}}) = \log(\text{COD}_{\text{in}}) \times 1.08(\pm 0.46) - \log(\text{Storage}) \times 0.18(\pm 0.13) - 0.04(\pm 0.78)$$

$r^2 = 0.76$, Standard Error = 0.13, Observations = 14

or using area ratio:

$$\text{Log}(\text{COD}_{\text{out}}) = \log(\text{COD}_{\text{in}}) \times 1.08(\pm 0.50) - \log(\text{Area Ratio}) \times 0.20(\pm 0.18) - 0.63(\pm 0.91)$$

$r^2 = 0.72$, Standard Error = 0.15, Observations = 14

Some of the coefficients in the above list are not statistically significant, according to conventional interpretation. But the objective here is to screen the data and reveal relationships, rather than to test a predefined hypothesis, so all coefficients (and their associated confidence bands) are retained for the time being.

Appendix C tabulates information on the three multiple regressions for output concentration (one for each size measure), a sample regression for output percent, and the mean and standard deviation of input and output data. A graph of observed and predicted output concentration is also shown. Input concentration is plotted on the horizontal axis of the graph. The vertical scatter of the predicted points about the line of best fit is caused by the basin size measure used. The vertical scatter of the observed points includes in addition any remaining variation not explained by the regression.

The best estimates of input concentration and area ratio coefficients, together with their 95% confidence bands, are shown in Figures 1 and 2. It can be seen that the eleven water quality parameters fall into three distinct groups.

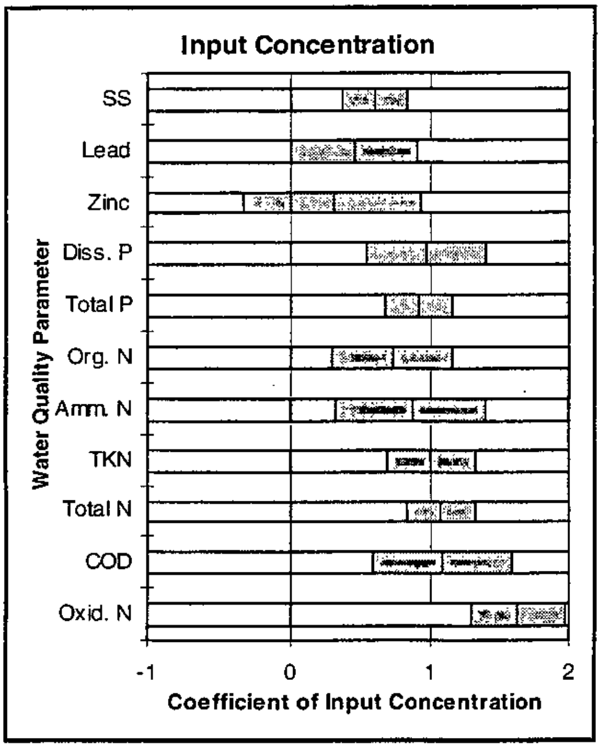

Figure 1: Coefficients of Input Concentration

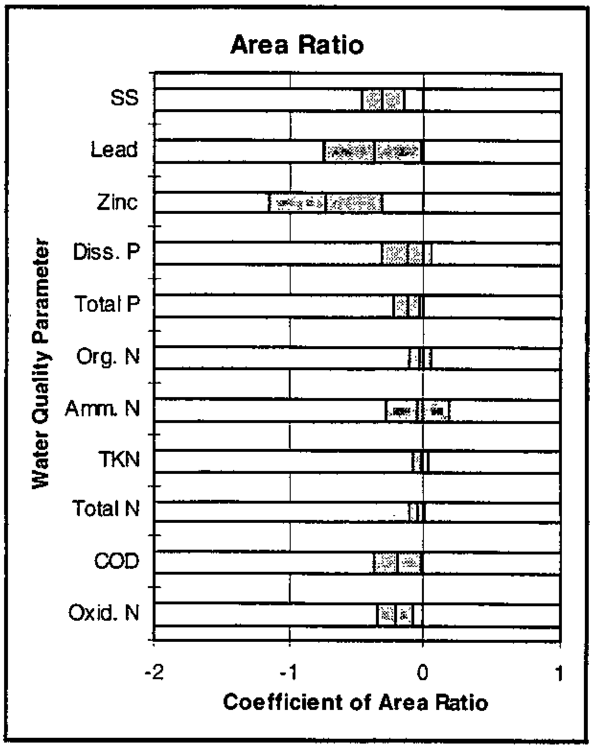

Figure 2: Coefficients of Area Ratio

3.1 The Settling Group

Suspended solids, total lead, and total zinc form one group. Their coefficients of input concentration are significantly (at the 95% confidence level) less than one, and are typically about 0.5, working with log transformed data. In untransformed coordinates, this means that output concentration is roughly proportional to the square root of the input concentration. Increasing the input concentration increases the output concentration, but decreases the percentage of contaminant remaining in the outflow. Behaviour of this form is characteristic of contaminants subject to sedimentation (Ferrara & Witkowski 1983; Grizzard et al. 1986), presumably because higher concentrations tend to include larger particles, leading to faster settling of a portion of the contaminant (Ferrara & Witkowski 1983). Hence this group can be described as the 'settling' group. Under favourable conditions - large area ratio and high input concentration - removal efficiencies of 80% or more can be achieved.

The area ratio coefficients of the settling group are significantly (at 95%) less than zero, and are typically about -0.5. Thus doubling the area ratio would reduce the output concentration by about one third. In each case area ratio is the best measure of basin size, followed by storage volume. Average depth is a very poor measure, which is to be expected. Increasing the pond depth increases the retention time, but also increases the settling time required to remove a given particle from the flow.

3.2 The Proportional Group

Chemical oxygen demand, dissolved and total phosphorus, and all forms of nitrogen except oxidised nitrogen form a second group. Their coefficients of input concentration are never significantly different from one, and the group mean is indeed very close to 1.0. This means that output concentration is proportional to input concentration for these quality parameters or, equivalently, that the percentage of contaminant remaining in the outflow is not affected by the inflow concentration. The overall removal efficiency is typically about 20 to 40%.

For this group of quality parameters, the common assumption of proportional behaviour in storage appears to be justified. An implication of this behaviour is that settling is not a dominant removal process. This is not surprising for the parameters with a large dissolved component, but the presence of total phosphorus in the group is interesting. Perhaps we should say that even if settling does occur, the contaminant apparently is not chemically immobilised by the physical settling.

The area ratio coefficients for the proportional group are typically about -0.1, which is very close to zero. But due to quite narrow error bands, the difference from zero is significant (at 95%) for two of the quality parameters (COD, Total P) and marginal for a third (Total N). Since these are the most global or inclusive parameters in the group (of which the others are subsets), it is probably fair to say that the effect of area ratio on the group as a whole is significant. So increasing the basin size does decrease the output concentration of this group of parameters, but the effect is very small. Doubling the area ratio would decrease the output concentration by less than one tenth.

Area ratio is the best measure of basin size for total phosphorus and total nitrogen, but storage is a little better for chemical oxygen demand. No measure of basin size is significant for the remaining parameters in this group. Either basin size really is not important for these parameters, or the measures used here fail to capture the essential features. Or perhaps the chemical and biological interactions between the various dissolved nutrients are just too complex to resolve using this type of approach on the amount of data available.

Literature review has shown that most nitrogen in urban runoff comes from rainfall and dustfall, rather than from the urban environment (Duncan 1995). This may help to explain the narrower observed range of inflow concentrations for the forms of nitrogen (since they are less affected by local variation), the generally poor removal by storage, and the very small effect of basin size (since the runoff water may already be approaching equilibrium with the atmosphere with respect to the various forms of nitrogen).

3.3 The Rate-Limited Group

Oxidised nitrogen (nitrite plus nitrate) stands in a group of its own, as its coefficient of input concentration (about 1.6) is significantly (at 95%) greater than one. In other words, the lower the inflow concentration, the more completely it is removed. This implies a removal process that can handle a given rate of contaminant removal, but is relatively insensitive to the concentration present. At higher input concentrations, where quality improvement is most needed, the removal efficiency is poor.

Area ratio is the best measure of basin size, while depth is not significant. The area ratio coefficient is about -0.2, and is significantly (at 95%) different from zero. Thus doubling the area ratio would reduce the outflow concentration by about one eighth.

Oxidised nitrogen can be produced in urban stormwater by nitrification of ammonia in aerobic sediments, and can be removed by denitrification in anaerobic sediments (Hvitved-Jacobsen et al. 1984). The role of bottom sediments in this process helps to explain why area ratio is the preferred size measure, and the role of bacteria and diffusion processes make a rate-limited removal process at least plausible.

3.4 Behaviour

In every case where basin size is found to be significant, area ratio is a good measure of basin size, and with only one exception (COD) it is the best measure. This is a useful result, since the area ratio is perhaps the most commonly available size measure in published literature, and it can be readily obtained from topographic maps for both existing and planned developments. The effect of area ratio is greatest for the settling group of parameters, and least for the proportional group.

The dominance of area ratio as the best measure of basin size was revealed by the statistical analysis. But in hindsight, the result should not be surprising. Of the various processes which may contribute to contaminant removal, settling (see Section 3.1), biological action in bottom sediments, solar radiation input to plants, and movement of atmospheric oxygen into the water all depend on surface area more strongly than on depth. Only in the case of slow chemical reactions in solution is volume (and hence residence time) likely to be more important. The better correlation of COD with volume is consistent with this view.

The common practice of expressing treatment efficiency in terms of percentage change, regardless of input concentration, is valid only for the proportional group of water quality parameters. For the settling group and the rate-limited group, input concentration is a highly significant explanatory variable, even when percentage change is the quantity required. Allocation into groups is based on fairly limited data for the eleven parameters considered here, and has not been done at all for other parameters. It is therefore most important that input concentration is included in all reports which present storage effectiveness data. Tabulation of percentage change alone is not sufficient.

Storage shape and layout have not been directly input in any way, so it is interesting to find a shape effect in the output. For every quality parameter tested, the predicted removal of two smaller storages in series is better than that of a single larger storage of the same total area ratio. The two smaller storages can be thought of as a single basin in which short circuiting has been eliminated. While detailed output should not be taken too literally outside the range of conditions analysed (e.g. for a cascade of very small storages), it appears that a measure of physical reality has been achieved.

Input concentration and area ratio in most cases explain a substantial proportion of the variation in treatment efficiency in storage. The variation explained ranges from 35% for lead to 89% for oxidised nitrogen when expressed as an output concentration directly, and from negligible for total Kjeldahl nitrogen to 65% for oxidised nitrogen when expressed as a percentage of input concentration. The standard error about the regression line ranges from ±0.10 (× or ÷ a factor of 1.3 in untransformed coordinates) for total nitrogen to ±0.37 (× or ÷ a factor of 2.3 in untransformed coordinates) for total zinc.

4. DESCRIPTIVE FACTORS

In addition to the major explanatory variables discussed above, a number of more descriptive factors can also be assessed. These include the storage type (wetland, dry basin, or pond), the location, the types of events measured, and the measure of central tendency used in the source documents. The various factors were lumped together for the analysis of major explanatory variables, and the objective here is to check whether it was statistically valid to do so. Since small sample sizes make formal statistical tests impractical, the effects are assessed visually (for the quality parameters with sufficient data) on the residual graphs in Appendix D. The residuals are the differences between observed values of output concentration and values estimated using the equations derived above. A positive residual indicates a higher output concentration (i.e. lower contaminant removal) than could be explained by the input concentration and area ratio.

Although some minor effects can be noted, none of the subsets identified in Appendix D appear to differ markedly from the bulk of the data. Hence there seems to be no reason to reject any subset from the combined analysis above. It appears that combining the data from the various locations and conditions was an acceptable simplification.

There is perhaps a tendency for the Australian sites to show above average suspended solids input concentrations and below average total nitrogen, which is reasonable in a dry climate far from the largest northern hemisphere industrial areas. Removal of suspended solids, total phosphorus, and total nitrogen at the Australian sites tends to be better than predicted.

The measure of central tendency used to report concentrations seems to have little effect. We would not expect it to for the proportional group, since the input concentration does not matter anyway, but even for suspended solids and oxidised nitrogen any effect appears to be relatively small.

Sites for which low flows or long term mass balances have been measured perform at least as well as those which measured storm events only. So the measured improvement in quality cannot be attributed just to averaging out of peak concentrations in storage.

Finally, the two wetland sites both show poor removal of total phosphorus, compared with ponds having comparable areas and input concentrations. But sample sizes in all cases are so small that any apparent effects can only be suggestive, not statistically significant.

5. PONDS VS. WETLANDS

The distinction between pond and wetland performance can be analysed further for the proportional group of water quality parameters (for which change in water quality in storage does not depend on input concentration), since additional data is available if input concentration is not required. The extra data also permits the inclusion of four new water quality parameters - total copper, orthophosphate, nitrate, and biological oxygen demand - in addition to the 11 previously analysed. Each storage record has been allocated to one of three groups - pond only, wetland only, and pond & wetland in series at the one site - and the performance of the three groups has been compared.

The expanded data set comprises 65 data records from 51 different locations. Of the 65 records, 39 are from ponds, lakes, or dry basins, 19 are from wetlands, and 7 are from combined ponds and wetlands.

A summary of the analysis is shown in Appendix E. The dependent variable now is output concentration as a percentage of input concentration (i.e. output percent), and area ratio is the only explanatory variable used. For each water quality parameter, percentage output is plotted against area ratio (still in log-transformed coordinates), and a combined regression line is fitted to the data from all three groups. The hypothesis that wetland percentage output is higher than pond percentage output is tested by comparing the residuals about the combined regression line, using one tailed t-tests.

For consistency and completeness, all 15 water quality parameters were analysed, but no significant differences were observed for those parameters known to be in the settling group or the rate-limited group. This is hardly surprising - ignoring a variable with the explanatory power that input concentration has for these groups can only serve to mask any remaining association.

Among the proportional group and the four new quality parameters there are a number of significant differences. Wetland percentage output is higher than pond percentage output (i.e. the wetland percentage removal is lower) for total copper, orthophosphate, dissolved phosphorus, total phosphorus, organic nitrogen, and nitrate, but not significantly different for the other quality parameters. The small pond & wetland group tends to produce low percentage output (i.e. high percentage removal), although the significance of this result was not formally tested, due to inadequate sample size.

These are surprising results at first sight. Wetlands are generally felt to be more effective than ponds of the same size, but here they are shown to be either less effective or not significantly different. The main reason for this apparent anomaly is the use of area ratio rather than volume to measure basin size. Wetlands on average are shallower than ponds, and so have a smaller volume for a given surface area. A wetland performing somewhat better than a pond *per unit volume* may perform much the same or somewhat worse than the same pond *per unit area.* It is also possible that flow into and through the vegetated areas during a runoff event is restricted by the vegetation, so that these areas are to some extent bypassed by high flows and do not fully participate in the removal processes. Even so, area ratio has been shown to be the preferred measure of basin size.

Why should ponds and wetlands together tend to be more effective than either alone, for the same area ratio? Perhaps it is just chance - after all, sample size of the combined group is very small - or perhaps ponds and wetlands together do indeed have a complementary effect. But more likely it is just another manifestation of the shape effect noted above, in which the transition from pond to wetland forms a constriction which prevents short circuiting. There is an obvious analogy here with the basins in series recommended by Randall (1982), and the upstream bedload traps of Cullen et al. (1988).

6. PERFORMANCE CURVES

The principal objective of the analysis so far has been to identify relationships embedded in the data, and to establish the similarities and differences in behaviour under a range of conditions. Because both the raw data and its residuals after regression analysis approximate the normal distribution in the log domain, all analysis has been carried out using log transformed data. In this way, the assumptions underlying the analysis procedures and tests are most nearly met.

However, the log domain is not suitable for practical applications such as performance curves. In particular, an arithmetic mean in the log domain becomes a geometric mean when transformed back to the linear domain, and will always underestimate the linear arithmetic mean. But for any calculation of total load, or any average over multiple sites, or over time at one site, it is the linear arithmetic mean that is needed.

When the output is a single parameter, the simplest solution is to quote both the arithmetic and geometric means. When the output is a regression line, as in this case, the analogous procedure is to calculate both the arithmetic and geometric means of the residuals about the regression line, and apply the difference between them to the regression line itself. The difference is an additive constant in the log domain, and a multiplying factor in the untransformed domain, and measures the amount by which the arithmetic mean exceeds the geometric mean. It is referred to here as the 'mean bias factor'. It depends upon the scatter of the residuals, and in this study ranges from 1.02 for total nitrogen (where the scatter of residuals is small) to 1.39 for zinc.

Appendix F presents average performance curves for the six main water quality parameters, excluding the individual components of total phosphorus and total nitrogen. The information box on each graph lists the equation of the curves as fitted, the standard error of the residuals, and the mean bias factor used to create the adjusted curves shown.

If the performance curves in Appendix F are to be used in practice, several qualifications and caveats need to be kept in mind. Firstly, although the relationships are statistically significant at the 95% level, the error bands associated with the curves remain wide. For suspended solids, for example, the standard error is +92% and -48% of the fitted value. In other words, about one third of the basins analysed produced an output concentration outside this very substantial error band. Secondly, the data analysed represents actual practice, not necessarily best management practice. Finally, results from a range of storage configurations, measurement techniques, and catchment types have been analysed together. Most measurements are event mean concentrations of several storm events, from permanent wet ponds or lakes, on catchments where flow is very small except during storms.

7. FURTHER DEVELOPMENT

Initial review showed that annual rainfall at a site could be a significant explanatory variable for the quality parameters with the largest sample sizes. Coefficients of annual rainfall are always positive, which means that higher rainfall, for a given input concentration and area ratio, gives a higher output concentration (i.e. lower removal efficiency). This suggests that annual rainfall could be used to capture some of the runoff information contained in parameters such as mean overflow rate or mean residence time, using a readily available measure.

The problem, however, is sample size. Even the largest samples contain just over 30 points, so the use of more than two explanatory variables must be treated with extreme caution. But as more data becomes available, this is a direction which should certainly be followed.

8. CONCLUSIONS

This report has presented a statistical overview of urban stormwater treatment by detention in on-stream storage, concentrating mainly on lakes and ponds. The objective has been to identify relationships embedded in the data rather than to test a pre-existing hypothesis. From the analysis and discussion above, the following conclusions can be drawn.

- All water quality concentration data analysed appears to be log-normally distributed.
- Of the three measures of basin size tested, area ratio (storage surface area/total catchment area) is the preferred measure. In every case where basin size is found to be significant, it is a good measure of basin size, and with only one exception it is the best measure.
- For some water quality parameters, input concentration is a highly significant explanatory variable, regardless of whether output concentration or percentage change is required. Hence input concentration should always be reported in studies of treatment efficiency in storage.
- Area ratio and input concentration together can explain up to 89% of the between study variation in output quality expressed as a concentration, and up to 65% of the variation in output quality expressed as a percentage of input concentration.

- The 11 water quality parameters tested fall into three groups, based on their behaviour in storage:
    - The settling group (suspended solids, total lead, total zinc). Output concentration is roughly proportional to the square root of the input concentration, and inversely proportional to the square root of the area ratio. Under favourable circumstances the removal efficiency can be high.
    - The proportional group (dissolved phosphorus, total phosphorus, organic nitrogen, ammonia nitrogen, total Kjeldahl nitrogen, total nitrogen, chemical oxygen demand). Output concentration is proportional to input concentration (i.e. percentage change is independent of input concentration), and proportional to area ratio to the power minus 0.1. The overall removal efficiency tends to be poor.
    - The rate-limited group (oxidised nitrogen). Output concentration is proportional to input concentration to the power 1.6, and proportional to area ratio to the power minus 0.2. At higher input concentrations, where quality improvement is most needed, the removal efficiency is poor.
- The derived relationships indicate that two smaller basins in series are more effective than one larger basin with the same total area ratio, for all water quality parameters tested.
- There is a suggestion (based on a small sample) that combined ponds and wetlands are more effective than either alone, for the same area ratio. This is probably related to the shape effect described in the previous point.
- Wetlands are significantly (at 95%) less effective than ponds of the same area ratio for removing total copper, all forms of phosphorus, organic nitrogen, and nitrate nitrogen. This may be a result of reduced flow through the vegetated areas. No significant difference was found for the remaining quality parameters.

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APPENDIX A

Water Quality Improvement in Storage

Appendix A

WATER QUALITY IMPROVEMENT IN STORAGE

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
Ginninderra, Canberra, Australia	Diss. P	0.047	0.035	mg/L	75	Area 7000 ha 90% rural 10% urban	Pond and marsh Area 1.2 ha Area ratio 0.00017 Vol. 3.9 ML (0.055 mm)	Low flows	Department of Territories (1986)
	Total P	0.134	0.093	mg/L	69				
	Susp. solids	49.4	48.6	mg/L	98				
	Ammonia N	0.065	0.063	mg/L	97				
	Oxidised N	0.515	0.461	mg/L	89				
	Total N	1.650	1.535	mg/L	93				
	TOC	14.30	13.9	mg/L	97				
	Diss. P	0.054	0.051	mg/L	95			High flows	
	Total P	0.138	0.124	mg/L	90				
	Susp. solids	180	171	mg/L	95				
	Ammonia N	0.143	0.139	mg/L	97				
	Oxidised N	0.478	0.464	mg/L	97				
	Total N	1.835	1.817	mg/L	99				
	TOC	15.72	15.25	mg/L	97				
Stranger GPT, Canberra, Australia	Susp. solids				63	Area 390 ha Ultimate urbanisation 80% Mean annual flow 1000 ML/yr	Vol. 0.25 ML (0.062 mm) Area ~0.02 ha Area ratio 0.00005	3 month study period	Falkland (1994)
Tuggeranong Canberra, Australia	Susp. solids				~81 ~70 ~68 ~59	Area 3800 ha Ultimate urbanisation 70% Mean annual flow 6000 ML/yr	Vol. 110 ML (2.9 mm) Area 4 ha Area ratio 0.0011	4 annual means	Lawrence (1986), Phillips & Goyen (1987)
Katoomba, (New South Wales), Australia	Susp. solids	3.9	3	mg/L	77	Area 26 ha 60% low dens resid 30% commercial 10% park & undeveloped 40% impermeable Ave. slope 9%	2 off-stream wetlands in series Vol. 0.60 ML (2.3 mm) Area 0.165 ha Area ratio 0.0063	Baseflow	Swanson (1992), Swanson (1994)
	Alkalinity	~26	30	mg/L	115				
	pH	~6.5	~7.8	pH	120				
	Conductivity	~80	~80	µS/cm	100				
	Chloride	9	9	mg/L	100				
	Turbidity	~6	~6	NTU	100				
	DO	72	~110	%	153				
	BOD	2.6	3.4	mg/L	131				
	Total P	0.128	0.056	mg/L	44				
	Diss. P	0.051	0.020	mg/L	39				
	TKN	0.40	0.45	mg/L	112				
	Total N	0.96	0.57	mg/L	59				
	Faecal colif.	80	20	#/100mL	25			No rain	
		951	68	#/100mL	7			Rain	
	Faecal strep.	77	60	#/100mL	78			No rain	
		636	124	#/100mL	20			Rain	
	Susp. solids	13.5	5.5	mg/L	41			Stormflow	
	Total P	0.076	0.053	mg/L	70				
	Total N	1.04	0.74	mg/L	71				
	Faecal colif.	2000	10	#/100mL	0.5				
The Paddocks, (South Australia), Australia	pH	7.2	7.5	pH	104	Area 59.7 ha Ave. slope 1:22 41% residential gardens 20% parkland & reserves 18% house roofs 18% roads & footpaths 3% institutional 61% pervious 39% impervious	Pond Vol. 2.54 ML (4.3 mm) Area 0.813 ha Max. depth 1.2 m Ave. depth 0.3m Area ratio 0.014	Sequential samples in 1990 & 1991	Tomlinson et al.(1993)
	Diss. solids	48	84	mg/L	175				
	Aluminium	1.43	0.27	mg/L	19				
	Cadmium	0.0006	0.0004	mg/L	67				
	Diss. copper	0.026	0.0025	mg/L	10				
	Total copper	0.081	0.012	mg/L	15				
	Total lead	0.304	0.034	mg/L	11				
	Tot. mangan.	0.100	0.064	mg/L	64				
	Total zinc	0.358	0.036	mg/L	10				
	Ammonia N	0.037	0.036	mg/L	97				
	TKN	1.43	0.72	mg/L	50				
	Oxidised N	0.10	0.03	mg/L	30				
	Total N	1.39	0.76	mg/L	55				
	Diss. P	0.033	0.042	mg/L	127				
	Total P	0.33	0.11	mg/L	33				
	TOC	12	8	mg/L	67				
	Susp. solids	147	25	mg/L	17				
	Ads. org. hal.	0.040	0.017	µg/L	42				
	BOD_5	7	3	mg/L	43				

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
	Diss. solids	81	103	mg/L	127			Composite samples in 1992	
	Calcium	10.5	15.3	mg/L	146				
	Magnesium	2.6	4.1	mg/L	158				
	Sodium	13.8	16.0	mg/L	116				
	Potassium	2.2	2.5	mg/L	114				
	Bicarbonate	45	74	mg/L	164				
	Sulphate	5.5	4.6	mg/L	84				
	Chloride	17	18	mg/L	106				
	Hardness	38	64	mg/L	168				
	Alkalinity	37	61	mg/L	165				
	Cadmium	0.0003	0.0002	mg/L	67				
	Total copper	0.06	0.0025	mg/L	4				
	Total iron	0.425	0.372	mg/L	88				
	Total lead	0.143	0.016	mg/L	11				
	Tot. mangan.	0.012	0.017	mg/L	142				
	Tot. mercury	0.05	0.1	μg/L	200				
	Total nickel	0.008	0.005	mg/L	62				
	Total zinc	0.228	0.015	mg/L	7				
	Ammonia N	0.057	0.035	mg/L	61				
	TKN	0.77	0.52	mg/L	68				
	Oxidised N	0.28	0.07	mg/L	25				
	Total N	1.05	0.60	mg/L	57				
	Diss. P	0.013	0.006	mg/L	46				
	Total P	0.101	0.038	mg/L	38				
	Susp. solids	52	6	mg/L	12				
	True colour	28	34	Hazen	121				
	Turbidity	34	12	NTU	35				
Fremont, California	Susp. solids				37	Area 1200 ha 93% urban 7% agriculture	Wetland A Area 2.0 ha Area ratio 0.002	DUST (Demonstration Urban Stormwater Treatment) Marsh	Meiorin (1986), in Strecker et al.(1992)
	Ammonia N				108				
	TKN				78				
	Nitrate N				68				
	Ortho P				35				
	Total P				54				
	BOD				125				
	Total lead				70				
	Total zinc				58				
	Total copper				120				
	Total nickel				64				
	Total chrom.				45				
	Oil & grease				68				
	Susp. solids				60		Wetland B Area 2.4 ha Area ratio 0.002		
	Ammonia N				105				
	TKN				127				
	Nitrate N				98				
	Ortho P				72				
	Total P				104				
	BOD				146				
	Total lead				73				
	Total zinc				76				
	Total copper				160				
	Total nickel				112				
	Total chrom.				53				
	Oil & grease				157				
	Susp. solids				49		Wetland C Area 8.5 ha Area ratio 0.007		
	Ammonia N				82				
	TKN				101				
	Nitrate N				88				
	Ortho P				63				
	Total P				64				
	BOD				118				
	Total lead				17				
	Total zinc				129				
	Total copper				83				
	Total nickel				89				
	Total chrom.				87				
	Oil & grease				87				
	Susp. solids				24		Wetland system Area 13 ha Area ratio 0.011 Depth 1.43 m Vol. 185 ML (15 mm)		
	Ammonia N				84				
	TKN				101				
	Nitrate N				71				
	Ortho P				32				
	Total P				42				
	BOD				157				

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
	Total lead				12				
	Total zinc				58				
	Total copper				119				
	Total nickel				74				
	Total chrom.				34				
	Oil & grease				125				
Palo Alto, California	Susp. solids				13	Area 7130 ha 62% residential 12% commercial 26% open	Wetland Area 248 ha Area ratio 0.035 Max. depth 1.8 m Vol. 923 ML (13 mm)		ABAG (1979), in Strecker et al.(1992)
	Vol. susp. sol.				15				
	Total N				63				
	Total P				106				
	BOD				46				
Tahoe Basin, California	Susp. solids				46	Area 1140 ha residential & forest	Wetland Ave flow 0.24 m^3/s	Angora Creek	Morris et al. (1981), in Strecker et al.(1992)
	Ammonia N				80				
	TKN				120				
	Nitrate N				50				
	Total P				95				
	Susp. solids				64	Area 1130 ha	Wetland Ave flow 0.25 m^3/s	Tallac Creek	
	Ammonia N				67				
	TKN				188				
	Nitrate N				65				
	Total P				220				
Guelph, Ontario, Canada	Susp. solids	88	10	mg/L	11	Sum of two catchments: (a) Area 18 ha 78% detach.houses 22% school & park (b) Area 14.2 ha 89% detach.houses 11% grassed park	Sum of two basins: (a) dry basin area 1.1 ha (b) wet pond area 0.16 ha min depth 0.3 m Area ratio 0.039 (a)+(b)	Geometric mean of 18 samples during rain in 1991.	Whiteley et al. (1993)
	Diss. solids	75	212	mg/L	283				
	Volatile solids	48	61	mg/L	127				
	Non-vol solids	167	181	mg/L	108				
	Total solids	215	242	mg/L	113				
	BOD	8	(4)	mg/L	50				
	Total lead	0.04	0.025	mg/L	63				
	Faecal coli.	~8000	~2800	MPN	35				
Viborg, Denmark	Susp. solids	82	15	mg/L	18	Area 22.2 ha Runoff coeff 0.3	Pond Area 0.09 ha Vol. 0.51 ML (2.3 mm) Ave depth 0.6 m. Area ratio 0.0041	5 storm events in spring/ summer	Hvitved-Jacobsen et al. (1987)
	Conductivity	84	157	µS/cm	187				
	Total P	0.66	0.30	mg/L	45				
	pH	6.0	6.7	pH	112				
	Alkalinity	0.11	0.50	meq/L	455				
	Chloride	5.8	18.9	mg/L	326				
	COD	40	37	mg/L	93				
	Total zinc	425	240	µg/L	56				
	Diss. zinc	300	110	µg/L	37				
	Tot. cadmium	1.4	0.6	µg/L	43				
	Dis. cadmium	0.4	0.6	µg/L	150				
	Total lead	73	7	µg/L	10				
	Total copper	13	5	µg/L	38				
	Diss. copper	6	4	µg/L	67				
	Susp. solids	22	9	mg/L	41			5 storm events in autumn	
	Total P	0.74	0.23	mg/L	31				
	Ortho P	0.53	0.13	mg/L	25				
	Alkalinity	0.71	0.51	meq/L	72				
	Hardness	0.046	0.046	meq/L	100				
	COD	60	123	mg/L	205				
	Total zinc	510	293	µg/L	57				
	Tot. cadmium	0.5	0.2	µg/L	40				
	Total lead	15	7	µg/L	47				
Burke, Washington D.C.	Susp. solids	51.3	32.4	kg/ha/yr	63	Area 11.0 ha 7.4 dwellings/ha 33.5% impervious	Wet pond Vol. 33 ML (300 mm) Depth 2.6 m Area 1.27 ha Area ratio 0.115	259 events	Randall (1982) Athayde et al.(1983)
	TKN	5.58	3.51	kg/ha/yr	63				
	Soluble KN	3.96	2.38	kg/ha/yr	60				
	Oxidised N	2.38	0.40	kg/ha/yr	16				
	Total P	0.79	0.32	kg/ha/yr	41				
	Soluble P	0.40	0.17	kg/ha/yr	44				
Westleigh, Washington D.C.	Susp. solids	75	(13)	mg/L	17	Area 19.4 ha 3.0 dwellings/ha 24.2% impervious	Wet pond Vol. 36 ML (186 mm) Depth 2.3 m Area 1.57 ha	geometric mean of 5 (metals) to 41 events	
	COD	51	(34)	mg/L	67				
	Total P	0.397	(0.16)	mg/L	41				
	Soluble P	0.223	(0.067)	mg/L	30				
	TKN	1.901	(1.54)	mg/L	81				

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
	Oxidised N	0.702	(0.50)	mg/L	72		Area ratio 0.081		
	Total copper	0.037	(0.033)	mg/L	90		Basin vol/mean		
	Total zinc	0.067	(0.060)	mg/L	90		event vol = 5.31		
Stedwick, Washington D.C.	Susp. solids	54	(20)	mg/L	37	Area 13.9 ha	Dry pond	geometric mean of 9 (metals) to 47 events	
	COD	45	(27)	mg/L	59	15.1 dwellings/ha	Vol. 3.52 ML		
	Total P	0.388	(0.34)	mg/L	89	30.5% impervious	(25 mm)		
	Soluble P	0.251	(0.26)	mg/L	104				
	TKN	1.895	(1.74)	mg/L	92				
	Oxidised N	0.837	(0.73)	mg/L	87				
	Total zinc	0.091	(0.052)	mg/L	57				
Silk Stream, London, England	Alkanes	665	323	μg/L	49	mainly urban	Area ratio ~0.0036		Jones et al. (1993)
	PAH's	129	37	μg/L	29		(from map)		
Lake Apopka, Florida	TKN	3.76	(3.57)	mg/L	95	100% agricultural	Reservoirs	Further information on loading rates could be extracted	Reddy et al. (1982) Strecker et al.(1992)
	Ammonia N	0.57	(0.24)	mg/L	42		Area 0.36 ha		
	Nitrate N	1.04	(0.33)	mg/L	32		Depth 1.0 m		
	Diss. P	~0.5	(0.12)	mg/L	25		Vol. 3.2 ML		
	Total P	0.66	(0.26)	mg/L	39		Ave. flow 15.7 L/s		
							Ave. det. time 9.4 d		
	TKN	3.76	(4.06)	mg/L	108		Flooded fields	Off-stream storage	
	Ammonia N	0.57	(0.27)	mg/L	48		Area 0.36 ha		
	Nitrate N	1.04	(0.37)	mg/L	36		Depth 0.2 m		
	Diss. P	~0.5	(0.42)	mg/L	83		Vol. 0.74 ML		
	Total P	0.66	(0.61)	mg/L	93		Ave. flow 6.5 L/s		
							Ave. det. time 4.8 d		
EPCOT Interchange, Florida	pH	6.7	6.7	pH	100	Area 8.3 ha	Pond	17 events in 1982 & 1983	Yousef et al. (1986a)
	Diss. ortho. P	140	13	μg/L P	9	Highway surface and surrounds.	Area 1.4 ha		
	Total ortho. P	172	25	μg/L P	15		Depth 1.1 m		
	Total P	224	84	μg/L P	38		Vol. 15 ML	Negligible outflow, so removals based on lake water quality	
	Organic N	1059	830	μg/L N	78		(180 mm)		
	Ammonia N	366	103	μg/L N	28		Area ratio 0.17		
	Nitrite N	6	2.1	μg/L N	35				
	Nitrate N	402	82	μg/L N	20				
	Total N	1833	1017	μg/L N	55				
Hidden Lake, Florida	Susp. solids				17	Area 22.4 ha residential	Wetland		Harper et al. (1986), in Strecker et al.(1992)
	Ammonia N				38		Area 1.0 ha		
	Organic N				124		Area ratio 0.045		
	Nitrate N				20				
	Total N				102				
	Ortho P				209				
	Total P				93				
	BOD				19				
	Total lead				45				
	Diss. lead				44				
	Total zinc				59				
	Diss. zinc				43				
	Tot. cadmium				29				
	Dis. cadmium				21				
	Total nickel				30				
	Diss. nickel				30				
	Total chrom.				27				
	Diss. chrom.				25				
	Total copper				60				
	Diss. copper				71				
Jackson Lake, Florida	Susp. solids				4	Area 900 ha urban	Wet pond		Ersy & Cairns (1988), in Strecker et al.(1992)
	Ammonia N				63		Area 8.1 ha		
	Nitrate N				30		Area ratio 0.009		
	Total N				24		Vol. 185 ML		
	Total P				10		(20 mm)		
	Diss. P				22		Ave depth 2.3 m		
							plus Wetland		
							Area 3.6 ha		
							Area ratio 0.004		
							Vol. 16.6 ML		
							(2 mm)		

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
							Ave depth 0.5 m		
Maitland Interchange, Florida	pH	6.1	7.2	pH	118	Area 19.8 ha Highway surface and surrounds.	Pond Area 1.2 ha Depth 1.8 m Vol. 22 ML (110 mm) Area ratio 0.061	Storm events in 1982 & 1983 Negligible outflow, so removals based on pond water quality.	Hvitved-Jacobsen et al. (1984) Yousef et al. (1986a)
	Alkalinity	53	50	mg/L	94				
	Diss. ortho. P	163	11	μg/L P	7				
	Total ortho. P	225	14	μg/L P	6				
	Total P	533	33	μg/L P	6				
	Organic N	2820	556	μg/L N	20				
	Ammonia N	137	14	μg/L N	10				
	Nitrite N	4	0.3	μg/L N	8				
	Nitrate N	317	33	μg/L N	10				
	Total N	3278	597	μg/L N	18				
	pH	6.9	6.8	pH	99			5 storms in 1983	Yousef et al. (1986b) Yousef et al. (1985)
	Conductivity	123	186	μmho/cm	151				
	Colour	10.0	10.0	units	100				
	Diss. solids	75.9	113.3	mg/L	149				
	Tot. hardness	48.8	70.8	mg/L	145				
	NCH	8.0	20.2	mg/L	252				
	Alkalinity	44.4	50.4	mg/L	114				
	Bicarbonate	54.2	61.7	mg/L	114				
	Sulphate	11.9	26.2	mg/L	220				
	Chloride	2.9	5.1	mg/L	176				
	Total N	0.79	0.51	mg/L N	65				
	Organic N	0.32	0.38	mg/L N	119				
	Ammonia N	0.09	0.04	mg/L N	44				
	Nitrate N	0.33	0.15	mg/L N	45				
	Nitrite N	0.02	0.01	mg/L N	50				
	Total P	0.05	0.01	mg/L P	20				
	Ortho. P	0.03	0.0	mg/L P					
	Calcium	27.0	20.5	mg/L	76				
	Magnesium	1.17	4.5	mg/L	385				
	Sodium	2.9	5.6	mg/L	193				
	Potassium	1.7	4.3	mg/L	253				
	Silica	1.9	1.2	mg/L	63				
	Humic acids	5	4	mg/L	80				
	Diss. lead	33.0	15.0	μg/L	45			5 storm events in 1982/83	Yousef et al. (1986b)
	Partic. lead	148	7.2	μg/L	5				
	Diss. zinc	40.0	4.7	μg/L	12				
	Partic. zinc	33.9	1.3	μg/L	4				
	Diss. copper	28.6	14.4	μg/L	50				
	Partic. copper	10.0	2.3	μg/L	23				
	Diss. P	42.5	4.2	μg/L	10				
	Partic. P	31.7	28.4	μg/L	89				
	Organic N	928	826	μg/L	89				
	Ammonia N	176	34.1	μg/L	19				
	Oxidised N	295	39.8	μg/L	13				
	Dis. cadmium	1.1	0.8	μg/L	73			15 storm water samples in 1983	Yousef et al. (1984)
	Tot. cadmium	1.9	1.0	μg/L	53				
	Diss. zinc	50	5.8	μg/L	12				
	Tot. zinc	347	6.4	μg/L	2				
	Diss. copper	32	14	μg/L	44				
	Tot. copper	60	16	μg/L	27				
	Diss. lead	43	16	μg/L	37				
	Tot. lead	723	22	μg/L	3				
	Diss. nickel	3.2	1.8	μg/L	56				
	Tot. nickel	28	2.3	μg/L	8				
	Diss. chrom.	3.3	2.3	μg/L	70				
	Tot. chrom.	10	3.4	μg/L	34				
	Diss. iron	48	20	μg/L	42				
	Tot. iron	1176	61	μg/L	5				
Orlando, Florida	Susp. solids	~30	~15	mg/L	50	Area 16.8 ha 33% urban road 27% forest 27% high dens res 13% low dens res	Pond Area 0.080 ha Depth 2.4 - 3.4 m Dead storage 9 mm Live storage 5 mm Tot. storage 14 mm Area ratio 0.0047	11 measured storms EMC method	Martin & Miller(1987) Martin (1988)
	Diss. solids	~155	~120	mg/L	77				
	Total solids	~185	~166	mg/L	90				
	COD				96				
	Total lead	~0.062	~0.043	mg/L	69				
	Total zinc	~0.085	~0.099	mg/L	117				
	Total N	~1.4	~1.26	mg/L	90				
	Org. N				95				
	Ammonia N				43				
	TOC				98				

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
	Total P	~0.16	~0.115	mg/L	72				
	Ortho. P				65				
	Chloride	~5.8	~5.7	mg/L	99				
	Sulphate				106				
	Bicarbonate				100				
	Calcium				101				
	Magnesium				99				
	Sodium				97				
	Potassium				93				
	Susp. solids	~15	~8	mg/L	56		Wetland Area 0.30 ha Depth 0 - 1.5 m Dead storage 4 mm Live storage 16 mm Tot. storage 20 mm Area ratio 0.018		
	Diss. solids	~120	~103	mg/L	86				
	Total solids	~166	~138	mg/L	83				
	COD				100				
	Total lead	~0.043	~0.013	mg/L	31				
	Total zinc	~0.099	~0.049	mg/L	49				
	Total N	~1.26	~1.20	mg/L	95				
	Org. N				84				
	Ammonia N				173				
	TOC				99				
	Total P	~0.115	~0.112	mg/L	97				
	Ortho. P				121				
	Chloride	~5.7	~6.3	mg/L	110				
	Sulphate				97				
	Bicarbonate				88				
	Calcium				93				
	Magnesium				94				
	Sodium				104				
	Potassium				111				
Palm Beach, Florida	Susp. solids				50	Area 952 ha residential & golf course	Wetland Area 120 ha Area ratio 0.126		Blackburn et al.(1986), in Strecker et al.(1992)
	Ammonia N				83				
	TKN				84				
	Nitrate N				67				
	Total P				38				
	BOD				65				
Springhill, Florida	Susp. solids	3.5	3.5	mg/L	100	Area 15.2 ha Single family resid. 100 dwellings 40% impervious	Pond Area 1.0 ha Ave. depth 1.8 m Vol. 18 ML (118 mm) Area ratio 0.066	6 storm events in 1985/86	Holler (1989)
	Ortho. P	0.205	0.056	mg/L	27				
	Total P	0.307	0.111	mg/L	36				
	Oxidised N	0.134	0.015	mg/L	11				
	Ammonia N	0.09	0.16	mg/L	178				
	TKN	1.05	1.19	mg/L	113				
	Susp. solids	2.6	2.9	mg/L	112			Routine sampling	
	Ortho. P	0.137	0.049	mg/L	36				
	Total P	0.171	0.098	mg/L	57				
	Oxidised N	0.115	0.018	mg/L	16				
	Ammonia N	0.07	0.15	mg/L	214				
	TKN	1.41	1.16	mg/L	82				
Tampa Office Pond, Florida	Susp. solids				36	Area 2.6 ha commercial	Wetland Area 0.14 ha Area ratio 0.056 Max. depth 0.5 m Vol. 0.39 ML (15 mm)		Rushton and Dye(1990), in Strecker et al.(1992)
	Organic N				104				
	Ortho P				35				
	Total P				45				
	Total zinc				66				
Lake Ellyn, Chicago, Illinois	Susp. solids	118	15	mg/L	13	Area 216 ha 34% impervious 80% low dens res 3% high dens res 5% commercial 5% institutional 7% open space/ water Inflow 727 ML 65% stormflow 35% baseflow	Lake Vol. 55 ML (25 mm) Ave. depth 1.5 m Max. depth 2.0 m Shoreline 900 m Ave det time 674 hr Area 3.67 ha Area ratio 0.017 Basin vol/mean event vol = 10.7	Annual mean over 1980/81	Hey (1982) Striegl (1987) Athayde et al.(1983)
	Chloride	84	112	mg/L	133				
	COD	69	38	mg/L	55				
	BOD	11.4	8.6	mg/L	75				
	TOC	9.9	8.5	mg/L	86				
	Ammonia	0.17	0.27	mg/L	156				
	Oxidised N	0.86	0.08	mg/L	10				
	Total P	0.44	0.17	mg/L	40				
	Diss. P	0.13	0.038	mg/L	28				
	Total copper	0.026	0.005	mg/L	19				
	Diss. copper	0.006	0.004	mg/L	58				
	Total lead	0.137	0.018	mg/L	13				
	Diss. lead	0.005	0.011	mg/L	232				
	Total zinc	0.113	0.023	mg/L	20				
	Diss. zinc	0.022	0.007	mg/L	34				

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
St. Agatha, Maine	Susp. solids				5	Area 7.3 ha 100% agriculture	Basin, swale, wetland, & pond Area 0.61 ha Area ratio 0.083 Max. depth 2.4 m Vol. 1.8 ML (25 mm)	Long Lake Treatment System	Jolly (1990), in Strecker et al. (1992)
	Vol. susp. sol.				6				
	Total P				8				
Montgomery County, Maryland	Susp. solids	42	16.8	mg/L	~40	Area 13.9 ha Impervious 19.2% Ave. slope 0.047 Townhouse/Garden apartments	Pond NPS storage 1.08 ML Volume 8 mm Typical detention time about 6 hours	Medians of 33 storm events	Grizzard et al. (1986)
	COD	21	12.6	mg/L	~60				
	Total P	0.30	0.26	mg/L	~85				
	TKN	1.65	1.16	mg/L	~70				
	Oxidised N	0.68	0.68	mg/L	~100				
	Total zinc	0.075	0.030	mg/L	~40				
	Total lead				~20				
Lansing, Michigan	Susp. solids	172	(182)	mg/L	106	Area 66 ha mixed land use Pop. dens. 12 p/ha 28% impervious	Grace Street North Oversize pipe Basin vol/mean runoff vol = 0.05	geometric mean of 9 to 23 events	Athayde et al. (1983)
	BOD	8	(10)	mg/L	126				
	COD	72	(61)	mg/L	85				
	Total P	0.394	(0.43)	mg/L	110				
	Soluble P	0.047	(0.059)	mg/L	126				
	TKN	1.988	(1.77)	mg/L	89				
	Oxidised N	0.875	(0.88)	mg/L	101				
	Total copper	0.014	(0.015)	mg/L	109				
	Total lead	0.170	(0.10)	mg/L	61				
	Total zinc	0.149	(0.16)	mg/L	109				
	Susp. solids	188	(147)	mg/L	78	Area 30 ha 52% industrial Pop. dens. 12 p/ha 39% impervious	Grace Street South Oversize pipe Basin vol/mean runoff vol = 0.17	geometric mean of 7 to 20 events	
	BOD	5	(4.8)	mg/L	96				
	COD	60	(62)	mg/L	103				
	Total P	0.435	(0.41)	mg/L	94				
	Soluble P	0.059	(0.059)	mg/L	100				
	TKN	1.713	(1.80)	mg/L	105				
	Oxidised N	0.742	(0.89)	mg/L	120				
	Total copper	0.025	(0.019)	mg/L	75				
	Total lead	0.115	(0.095)	mg/L	83				
	Total zinc	0.223	(0.21)	mg/L	93				
	Susp. solids	85	(11)	mg/L	13	Area 12 ha mixed land use Pop. dens. 27 p/ha 68% impervious	Waverly Hills Basin vol/mean runoff vol = 7.57	geometric mean of 16 to 35 events	
	BOD	9	(4.3)	mg/L	48				
	COD	64	(31)	mg/L	48				
	Total P	0.198	(0.061)	mg/L	31				
	Soluble P	0.043	(0.019)	mg/L	44				
	TKN	1.490	(1.04)	mg/L	70				
	Oxidised N	0.775	(0.36)	mg/L	46				
	Total copper	0.015	(0.0071)	mg/L	47				
	Total lead	0.111	(0.0078)	mg/L	7				
	Total zinc	0.121	(0.051)	mg/L	42				
Pittsfield-Ann Arbor, Michigan	Susp. solids	57	(35)	mg/L	62	Area 1973 ha 45% residential 19% commercial 13% agriculture 23% open	Pond Area 10.2 ha Area ratio 0.0052 Max. depth 1.8 m Vol. 216 ML (11 mm) Basin vol/mean runoff vol = 0.52	geometric mean of 5 to 6 events	Scherger & Davis(1982), in Strecker et al.(1992) Athayde et al.(1983)
	BOD	6	(5.0)	mg/L	83				
	COD			mg/L	77				
	Total P	0.19	(0.14)	mg/L	72				
	Soluble P	0.036	(0.037)	mg/L	102				
	TKN	0.95	(0.85)	mg/L	89				
	Oxidised N	0.38	(0.35)	mg/L	92				
	Total lead	0.041	(0.017)	mg/L	41				
	Total zinc			mg/L	78				
Swift Run	Susp. solids	80	(14)	mg/L	17	Area 489 ha 11% residential 2% commercial 72% agriculture 15% open Pop. dens. 5 p/ha 4% impervious	Wetland Area 10.3 ha Area ratio 0.021 Max. depth 0.9 m Vol. 74 ML (15 mm) Basin vol/mean runoff vol = 1.02	geometric mean of 5 events	
	BOD	3	(2.7)	mg/L	89				
	COD	29	(30)	mg/L	103				
	Total P	0.134	(0.18)	mg/L	138				
	Soluble P	0.039	(0.031)	mg/L	79				
	TKN	1.116	(0.84)	mg/L	75				
	Oxidised N	1.033	(0.24)	mg/L	23				
	Total lead			mg/L	14				
Traver	Susp. solids	33	(33)	mg/L	100	Area 933 ha 90% open/ nonurban 6% impervious	Wet basin Basin vol/mean runoff vol = 1.16	geometric mean of 5 events	
	BOD	2	(3.3)	mg/L	166				
	COD	25	(22)	mg/L	88				
	Total P	0.091	(0.057)	mg/L	63				
	Soluble P	0.033	(0.012)	mg/L	37				
	TKN	0.889	(0.72)	mg/L	81				

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
	Oxidised N	1.108	(0.80)	mg/L	72				
	Total zinc				81				
Ramsay-Washington, Minnesota	Susp. solids				37	Area 459 ha residential	Pond Area 0.028 ha Area ratio 0.00006 Depth 0.9 m Vol. 0.12 ML (.027 mm)	Tanners Lake	Oberts et al. (1989), in Strecker et al.(1992)
	Vol. susp. sol.				50				
	TKN				93				
	Nitrate N				99				
	Total N				95				
	Ortho P				80				
	Diss. P				114				
	Total P				93				
	Total lead				41				
	Susp. solids				15	Area 2113 ha residential	Pond Area 2.24 ha Area ratio 0.0011 Depth 1.5 m Vol. 16.2 ML (0.77 mm)	McKnight Lake	
	Vol. susp. sol.				43				
	TKN				85				
	Nitrate N				89				
	Total N				86				
	Ortho P				66				
	Diss. P				88				
	Total P				66				
	Total lead				37				
	Susp. solids				15	Area 215 ha residential	Wetland Area 0.38 ha Area ratio 0.0018 Depth 1.5 m Vol. 2.5 ML (1.1 mm)	Lake Ridge	
	Vol. susp. sol.				33				
	TKN				72				
	Nitrate N				83				
	Total N				76				
	Ortho P				105				
	Diss. P				92				
	Total P				63				
	Total lead				48				
	Susp. solids				80	Area 69 ha residential	Wetland & pond Area 0.15 ha Area ratio 0.0022 Depth 0.6 m Vol. 1.2 ML (1.8 mm)	Carver Ravine	
	Vol. susp. sol.				99				
	TKN				110				
	Nitrate N				91				
	Total N				106				
	Ortho P				103				
	Diss. P				99				
	Total P				99				
	Total lead				94				
Roseville, Minnesota	Susp. solids				9	Area 243 ha urban	Pond Area 12.0 ha Area ratio 0.050	McCarrons Wetland	Wotzka & Obert (1988), in Strecker et al. (1992)
	Vol. susp. sol.				5				
	TKN				12				
	Nitrate N				40				
	Total N				15				
	Diss. P				43				
	Total P				22				
	COD				10				
	Total lead				15				
	Susp. solids				13		Wetland Area 2.5 ha Area ratio 0.010		
	Vol. susp. sol.				13				
	TKN				74				
	Nitrate N				78				
	Total N				76				
	Diss. P				75				
	Total P				64				
	COD				21				
	Total lead				32				
	Susp. solids				6		System Area 14.5 ha Area ratio 0.060 Vol. 11.9 ML (4.9 mm)		
	Vol. susp. sol.				6				
	TKN				15				
	Nitrate N				37				
	Total N				17				
	Diss. P				47				
	Total P				22				
	COD				7				
	Total lead				10				
Twin Cities, Minnesota	Susp. solids				5	Area 284 ha 30% residential	Wetland/pond Area 6.5 ha	Fish Lake	Brown (1985)
	Vol. susp. sol.				22				

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
	Organic N				64	5% commercial	Area ratio 0.023		in Strecker et al.(1992)
	Ammonia N				100	12% agriculture	Ave depth 1.2 m		
	Total N				120	53% open	Vol. 79 ML		
	Diss. P				72		(28 mm)		
	Total P				63				
	Susp. solids				12	Area 834 ha	Wetland	Lake Elmo	
	Vol. susp. sol.				20	12% residential	Area 91 ha		
	Organic N				136	1% commercial	Area ratio 0.109		
	Ammonia N				50	34% agriculture	Ave. depth 1.2 m		
	Total N				62	53% open	Vol. 1110 ML		
	Diss. P				75		(133 mm)		
	Total P				73				
	Susp. solids				120	Area 1000 ha	Wetland	Lake Riley	
	Vol. susp. sol.				80	13% residential	Area 31 ha		
	Organic N				93	2% commercial	Area ratio 0.031		
	Ammonia N				75	30% agriculture	Ave. depth 0.9 m		
	Total N				80	55% open	Vol. 284 ML		
	Diss. P				130		(28 mm)		
	Total P				143				
	Susp. solids				400	Area 2260 ha	Wetland	Spring Lake	
	Vol. susp. sol.				120	5% residential	Area 26 ha		
	Organic N				89	1% commercial	Area ratio 0.011		
	Ammonia N				186	57% agriculture	Ave. depth 1.2 m		
	Total N				114	37% open	Vol. 315 ML		
	Diss. P				110		(14 mm)		
	Total P				107				
Waseca, Minnesota	Susp. solids				24	Area 433 ha	Wetland	Clear Lake	Barten (1987) in Strecker et al.(1992)
	Ammonia N				45	urban	Area 21.4 ha		
	TKN				75		Area ratio 0.049		
	Diss. P				60		Depth 0.15 m		
	Ortho P				48		Vol. 12 ML		
	Total P				46		(2.8 mm)		
Wayzata, Minnesota	Susp. solids				6	Area 26.4 ha	Wetland		Hickok et al. (1977), in Strecker et al.(1992)
	Ammonia N				144	residential & commercial	Area 3.1 ha		
	Total P				22		Area ratio 0.117		
	Total lead				6				
	Total zinc				18				
	Total copper				20				
	Tot. cadmium				33				
Frisco Lake, Rolla, Missouri	Susp. solids	103	13	mg/L	12	Population 6.3 p/ha	Lake	Average of all flows over 6 months	Oliver and Grigoropoulos(1981)
	Total P	0.32	0.12	mg/L	35	Ave. slope 0.010	Area 2.3 ha		
	Organic N	0.47	0.37	mg/L	78	Area 44.9 ha	Max depth 1.71 m		
	Ammonia N	0.35	0.46	mg/L	132	28% single fam res	Vol. 22.7 ML		
	Hardness	182	76	mg/L	42	12% multi fam res	(51 mm)		
	COD	42	20	mg/L	46	8% commercial	Ave. det. time 28 days		
						1% light industrial			
						17% public use	Area ratio 0.051		
						32% pavement			
						2% open space			
East Brunswick, New Jersey	Total petroleum hydrocarbons	3438	43	g	1	Area 40.5 ha Condominium development.	Dry pond Area 2.4 ha Area ratio 0.059	Sum of 3 storms	Maldonato & Uchrin (1994)
Hillsborough New Jersey	Total solids	347	185	mg/L	54	Area 258 ha	Pond	Average concentration for storm of 17.5 mm	Ferrara & Witkowski (1983)
	COD	30.4	24.1	mg/L	80	25% high dens res	Max. depth 2.4 m		
	TKN	1.24	1.49	mg/L	120	17% low dens res	Area ratio ~0.005 (from map)		
	Total P	0.47	0.27	mg/L	58	22% const. area	Volume ~8 mm		
						10% grassland			
	Total solids	282.	180	mg/L	64	7% cropland		Storm of 10.0 mm	
	COD	32.5	28.8	mg/L	89	19% forested			
	TKN	1.33	1.60	mg/L	120				
	Total P	0.32	0.33	mg/L	103	Dry weather flow is negligible			
	Total solids	170	145	mg/L	85			Storm of 2.5 mm	
	COD	34.0	30.7	mg/L	90				
	TKN	1.05	0.84	mg/L	80				

Appendix A

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
	Total P	0.34	0.31	mg/L	91				
	Total solids	311	180	mg/L	58			Weighted mean of 3 storms	
	COD	31.4	26.2	mg/L	84				
	TKN	1.25	1.47	mg/L	117				
	Total P	0.41	0.29	mg/L	72				
Unqua, Long Island, New York	Susp. solids	65	(43)	mg/L	66	100% residential	Wet Basin Basin vol/mean runoff vol = 3.07	geometric mean of 8 events	Athayde et al.(1983)
	TOC			mg/L	74				
	Total P	0.229	(0.14)	mg/L	62				
	TKN	1.408	(1.84)	mg/L	131				
	Oxidised N	1.533	(1.69)	mg/L	110				
	Total lead	0.088	(0.019)	mg/L	22				
Charlotte, North Carolina	Susp. solids	135	62	mg/L	46	Two adjacent catchments of area 26 ha (a) and 122 ha (b), and downstream catchment of 177 ha, including (a) and (b) above.	3 ponds Area ratio 0.0075 Vol. 15.1 ML (9 mm)	Event mean conc. for 5 storms in 1986/87 Input concentrations are claimed to be representative of the whole area	Wu et al. (1988)
	Total P	0.14	0.11	mg/L	76				
	TKN	0.88	0.70	mg/L	80				
	Zinc	0.070	0.041	mg/L	58				
	Iron	6.1	3.4	mg/L	55				
	Susp. solids	135	14	mg/L	10		Area ratio 0.0135 Vol. 21.4 ML (14 mm)		
	Total P	0.14	0.10	mg/L	74				
	TKN	0.88	0.39	mg/L	44				
	Zinc	0.070	0.033	mg/L	47				
	Iron	6.1	1.0	mg/L	16				
	Susp. solids	135	57	mg/L	42		Area ratio 0.0227 Vol. 69.1 ML (39 mm)		
	Total P	0.14	0.08	mg/L	60				
	TKN	0.88	0.52	mg/L	59				
	Zinc	0.070	0.042	mg/L	60				
	Iron	6.1	3.1	mg/L	51				
	Susp. solids	135	12	mg/L	9		Area ratio 0.0751 Vol. 47.7 ML (182 mm)		
	Total P	0.14	0.11	mg/L	77				
	TKN	0.88	0.83	mg/L	94				
	Zinc	0.070	0.015	mg/L	21				
	Iron	6.1	1.1	mg/L	18				
Austin, Texas	COD	43.5	41.6	kg	96	Area 153 ha 39% impervious Slope 4.6% medium dens res	Lake Vol. 21.5 ML (14 mm) Area ratio ~0.02	Mean of 2 events	Castaldi (1983)
	TOC	30.5	44.6	kg	147				
	Ammonia N	1.55	1.14	kg	74				
	Total N	22.3	14.6	kg	66				
	Total P	0.63	0.59	kg	94				
	Susp. solids	192	150	kg	78				
	COD	68	(65)	mg/L				Mean of all events	
	TOC	18.9	(28)	mg/L					
	Ammonia N	1.40	(1.04)	mg/L					
	Total N	5.14	(3.4)	mg/L					
	Total P	0.31	(0.29)	mg/L					
	Susp. solids	127	(99)	mg/L					
Lake Houston, Texas	Susp. solids	301	20	Gg	7	Area 724,000 ha 73% forest 14% pasture Mean flow in 1975 $59\ m^3/s$ (1857 GL)	Lake Vol. ~180,000 ML (25 mm) Area 5200 ha Area ratio 0.0072	Wet year (1973)	Baca et al. (1982)
	Nitrate	2.88	2.10	Gg	73				
	Phosphorus	2.44	1.57	Gg	64				
	Susp. solids	159	36	Gg	23			Average year (1975)	
	Nitrate	1.80	1.78	Gg	99				
	Phosphorus	1.46	0.71	Gg	48				
	Susp. solids	81.5	8.5	Gg	10			Dry year (1977)	
	Nitrate	1.13	0.23	Gg	21				
	Phosphorus	0.91	0.15	Gg	17				
	Susp. solids	86	19	mg/L	23			Mean conc. in average year (1975)	
	Nitrate	0.97	0.96	mg/L	99				
	Phosphorus	0.79	0.38	mg/L	48				
The Woodlands, Texas	Ortho. P	0.005	0.015	mg/L	300	Area 332 ha Developing residential, commercial, restricted industrial, and open space	Lakes Vol. 135 ML (41 mm) Area 6.7 ha Area ratio 0.020	One storm of 3.97 inches	Characklis et al. (1978) Characklis et al. (1989)
	Total P	0.11	0.10	mg/L	91				
	Ammonia	0.11	0.16	mg/L	145				
	Nitrite	0.009	0.032	mg/L	356				
	Nitrate	0.15	0.28	mg/L	187				

Location	Contaminant	Input Load or Conc.	Output Load or Conc.	Units	Output Load or Conc. (%)	Catchment Conditions	Storage Conditions	Other Conditions	References
	TKN	1.86	1.3	mg/L	70		2 ponds in series Receive stormwater runoff and treated sewage effluent		
	Susp. solids	1273	245	mg/L	19				
	TOC	16.2	13.6	mg/L	84				
	Total COD	63.7	41.8	mg/L	66				
	Sol. COD	32	26.4	mg/L	83				
	Conductance	85	130	µmhos	153				
	Turbidity	375	160	JTU	43				
Seattle, Washington	Susp. solids	9.6	9.45	mg/L	98	Area 31 ha residential	Dry pond Vol. 0.430 ML (1.4 mm)	Mean of 6 storms	Dally (1984)
	Susp. solids	88	79	mg/L	90	Area 6 ha bus depot	Wet pond Vol. 0.17 ML (2.8 mm)	Mean of 5 storms	
	Oil & grease	9.9	7.5	mg/L	76				
	Total P	118	173	µg/L P	148			Mean of 3 storms	
	Tot. cadmium	0.79	1.04	µg/L P	131				
	Sol. cadmium	0.43	0.95	µg/L P	219				
	Total lead	30	32	µg/L N	108				
	Sol. lead	6.3	11.8	µg/L N	187				
	Total zinc	530	730	µg/L N	138				
	Sol. zinc	94	66	µg/L N	69				
King County, Washington	Susp. solids				86	Area 187 ha urban	Wetland Area 2.0 ha Area ratio 0.011 Vol. 0.53 ML (0.28 mm)	B3I	Reinelt et al. (1990), in Strecker et al.(1992)
	Nitrate N				96				
	Total P				102				
	Susp. solids				44	Area 87 ha rural	Wetland Area 1.5 ha Area ratio 0.017 Vol. 0.74 ML (0.85 mm)	PC12	
	Nitrate N				80				
	Total P				102				

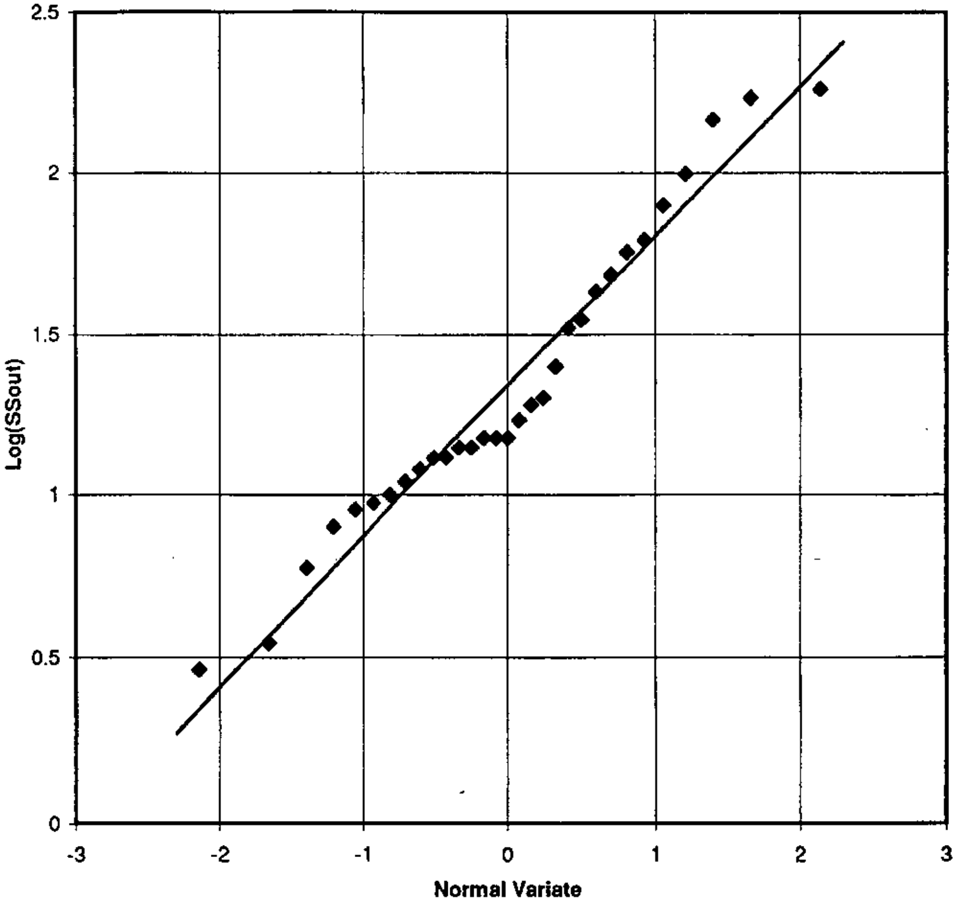
Notes:

~	Approximate. For example, data scaled from graphs.
( )	Derived data. For example, output concentrations derived from input concentration data and % change data from different sets of events.
ML	Megalitres. 1 megalitre = 1000 kilolitres = 1000 cubic metres.
mm	Millimetres. Storage in millimetres is the basin storage divided by the total catchment area.

APPENDIX B

Log-Normal Distributions of Output Concentrations

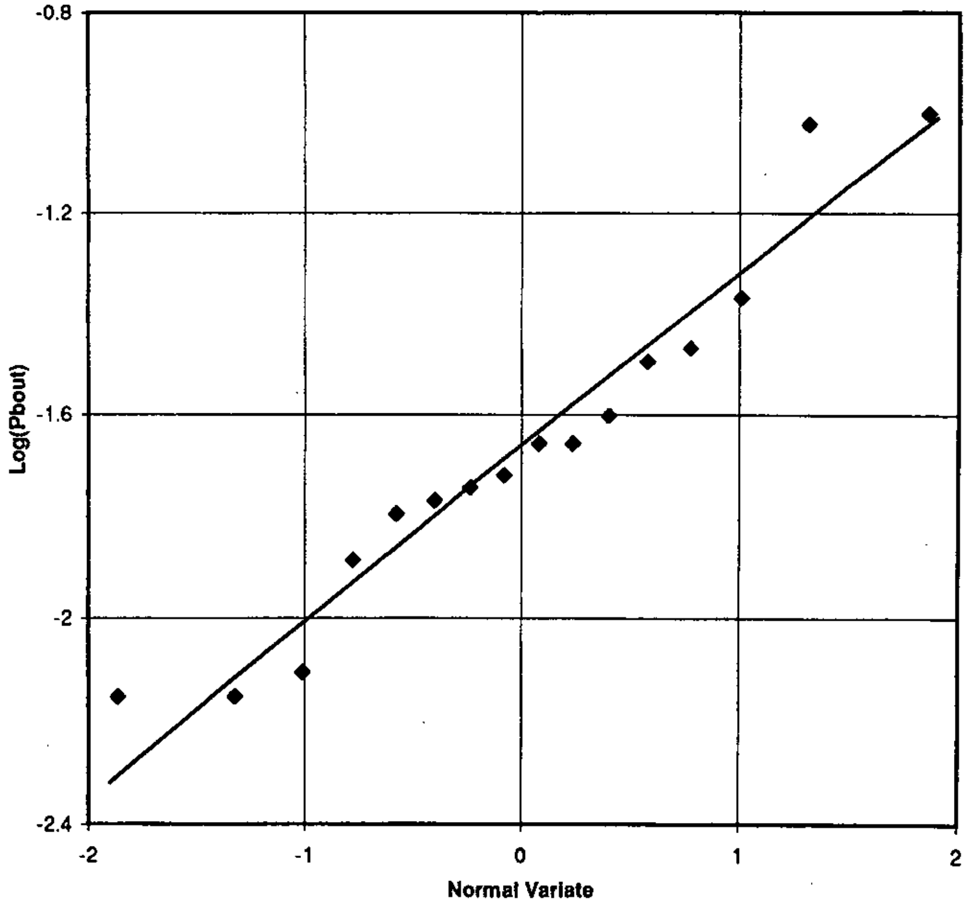
Suspended Solids



Correlation coefficient	0.98
Observations	31
Shapiro-Wilk critical R (95%)	0.965

Hypothesis of normality not rejected at 95% level

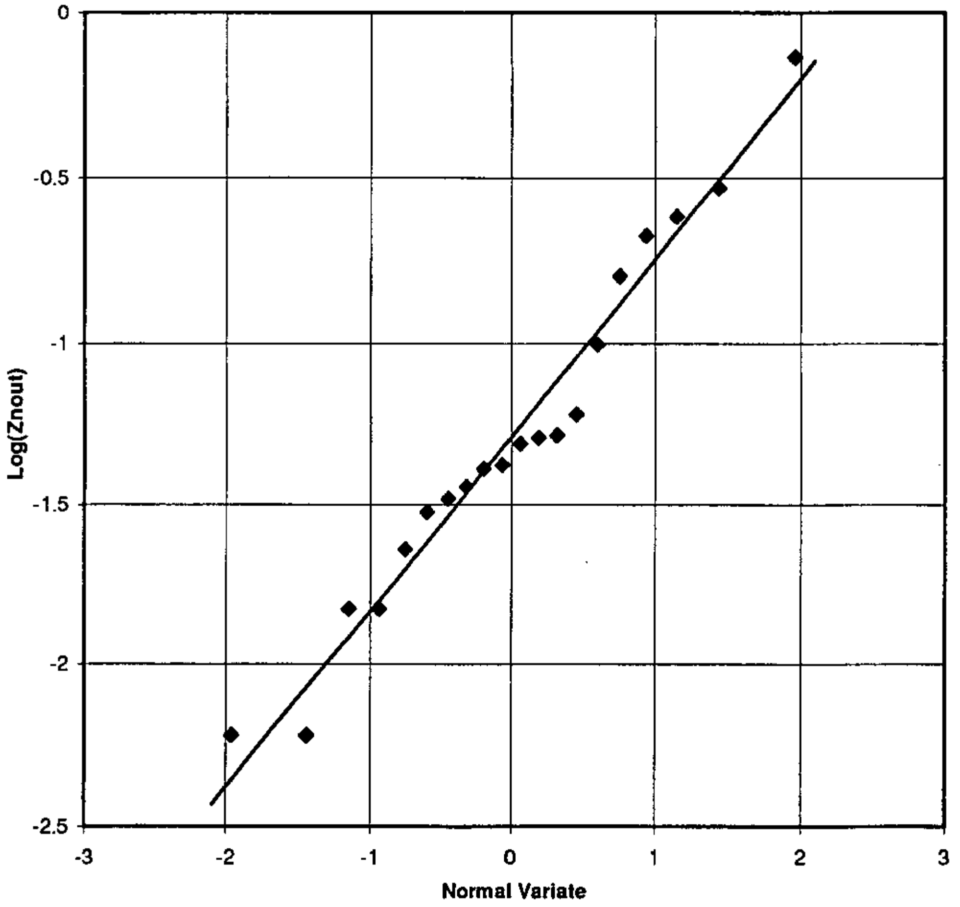
Total Lead



Correlation coefficient	0.972
Observations	16
Shapiro-Wilk critical R (95%)	0.941

Hypothesis of normality not rejected at 95% level

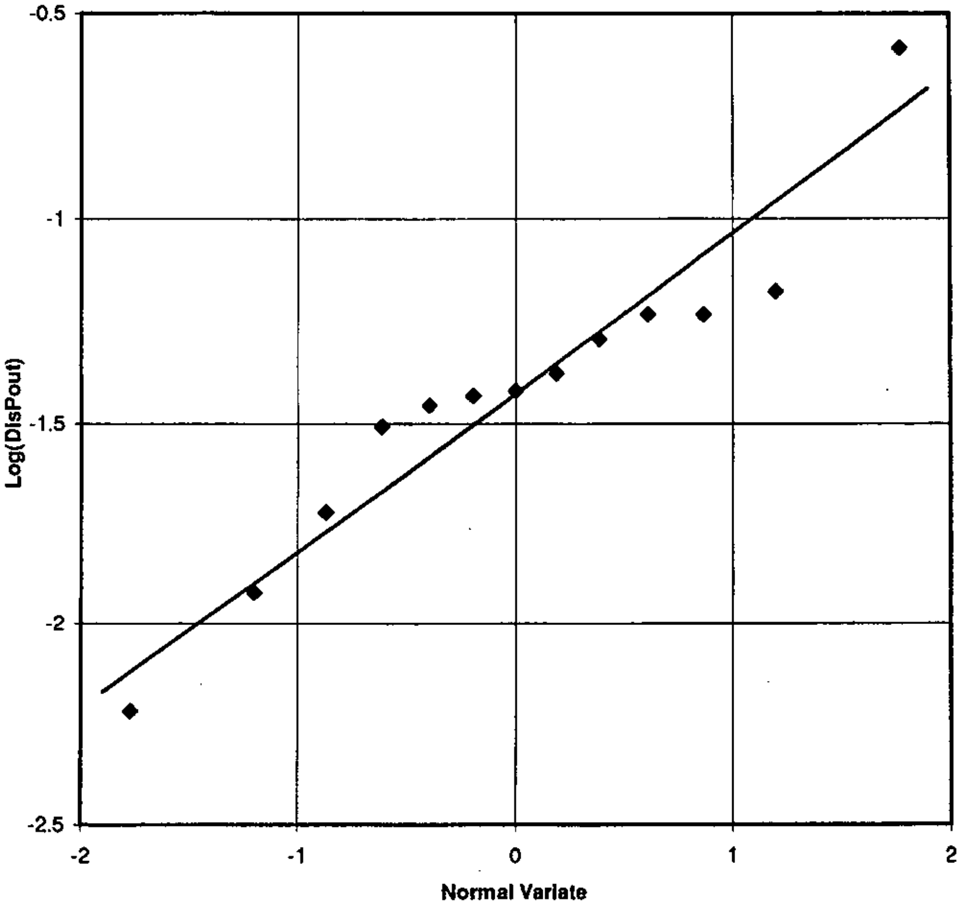
Total Zinc



Correlation coefficient	0.985
Observations	20
Shapiro-Wilk critical R (95%)	0.95

Hypothesis of normality not rejected at 95% level

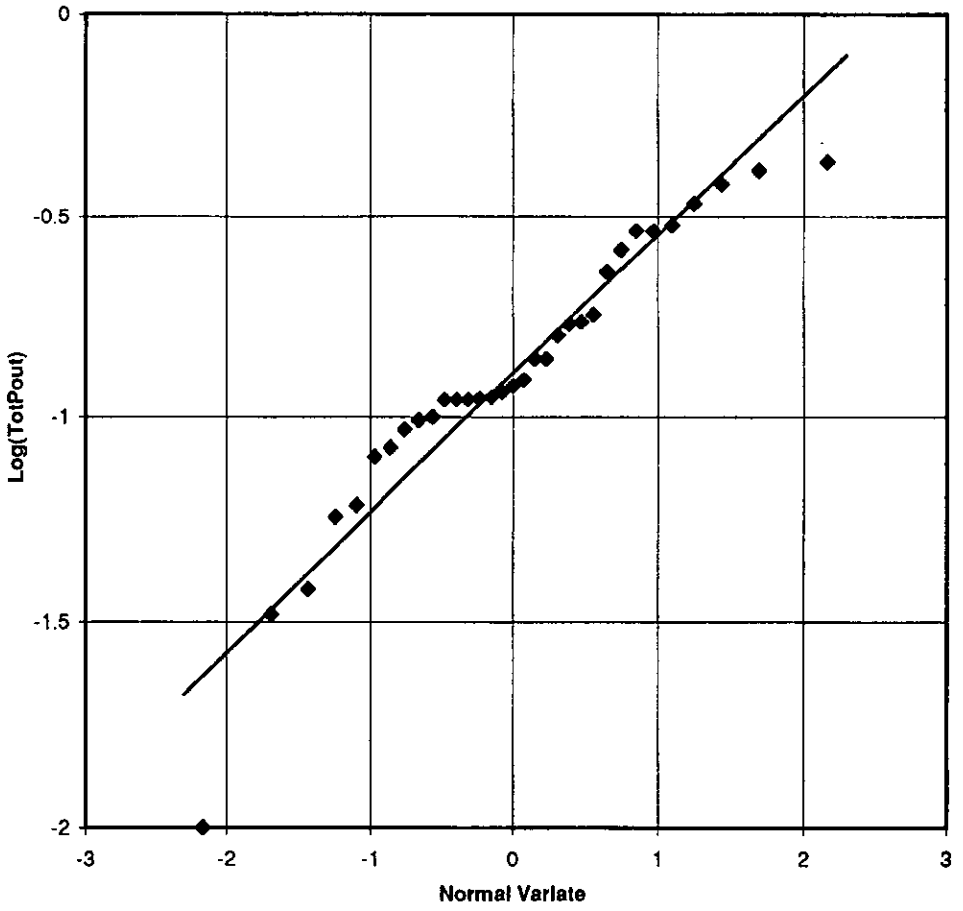
Dissolved Phosphorus



Correlation coefficient	0.958
Observations	13
Shapiro-Wilk critical R (95%)	0.93

Hypothesis of normality not rejected at 95% level

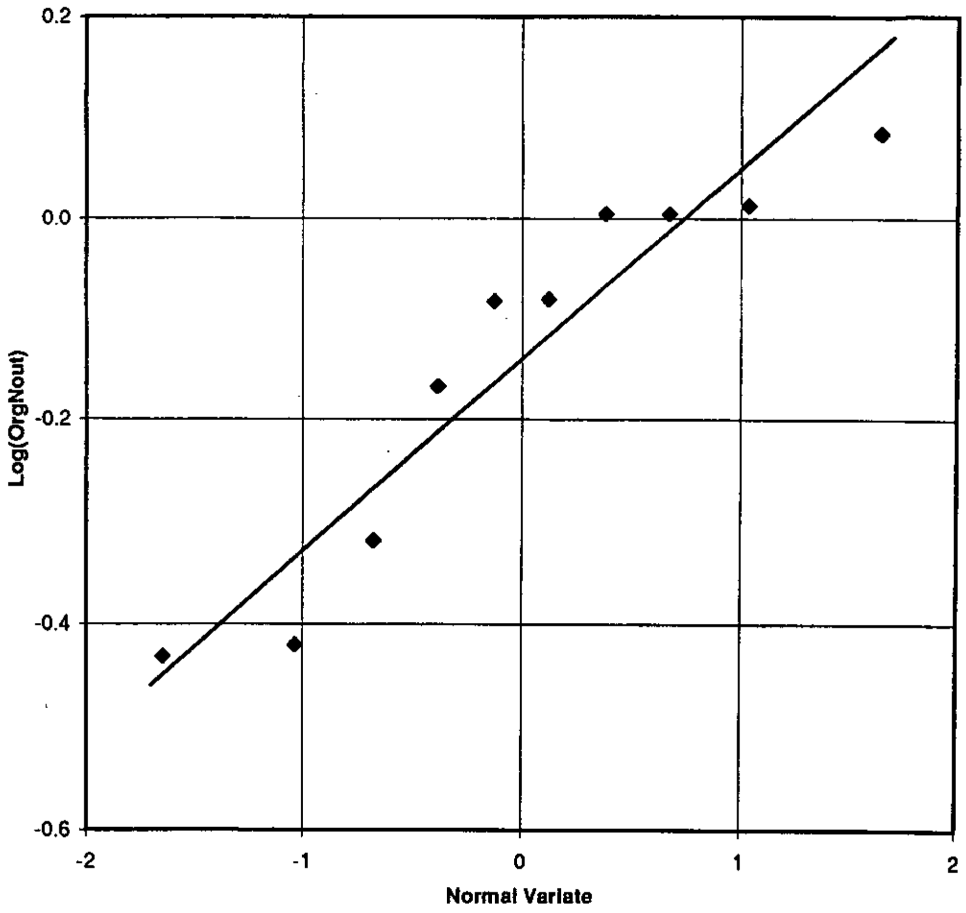
Total Phosphorus



Correlation coefficient	0.962
Observations	33
Shapiro-Wilk critical R (95%)	0.966
Shapiro-Wilk critical R (99%)	0.952

Hypothesis of normality not rejected at 99% level

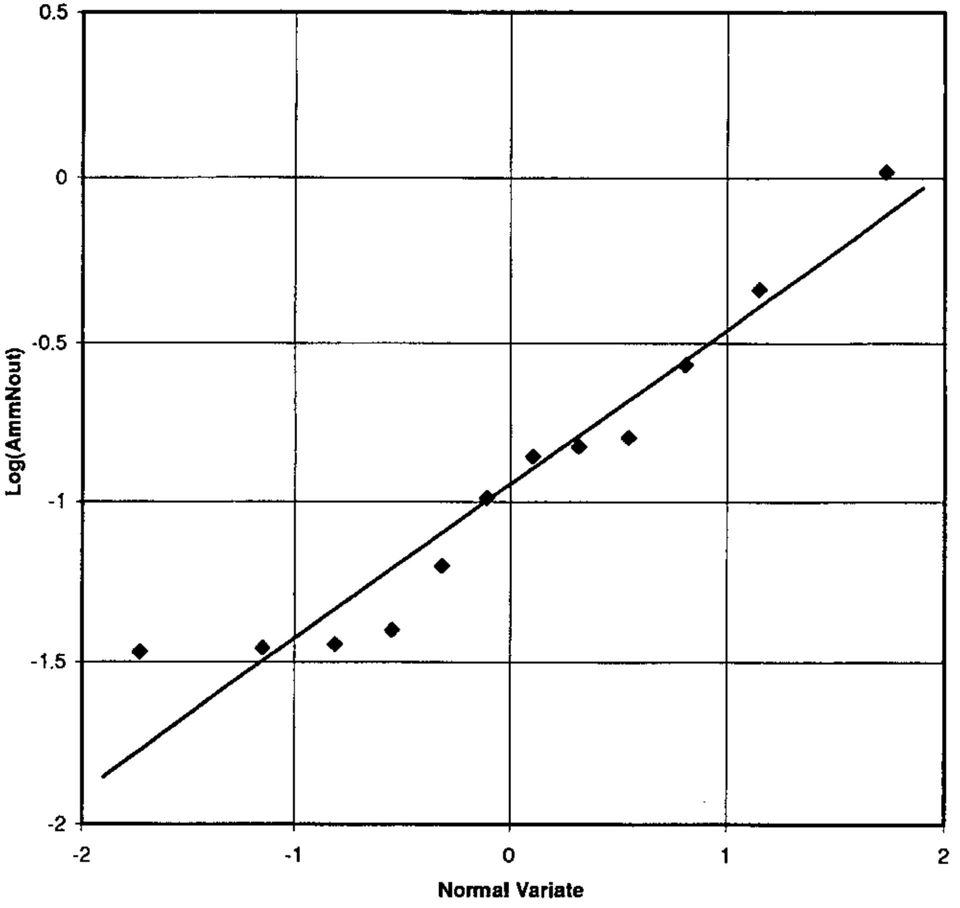
Organic Nitrogen



Correlation coefficient	0.945
Observations	10
Shapiro-Wilk critical R (95%)	0.918

Hypothesis of normality not rejected at 95% level

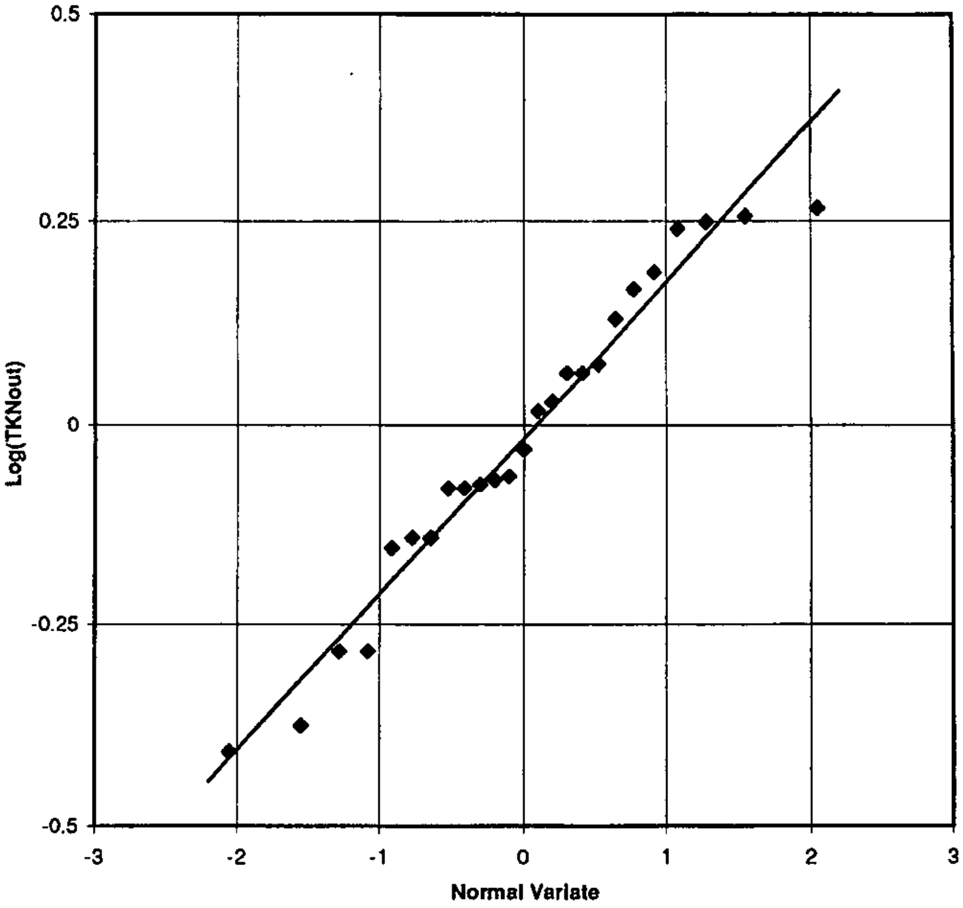
Ammonia Nitrogen



Correlation coefficient	0.962
Observations	12
Shapiro-Wilk critical R (95%)	0.926

Hypothesis of normality not rejected at 95% level

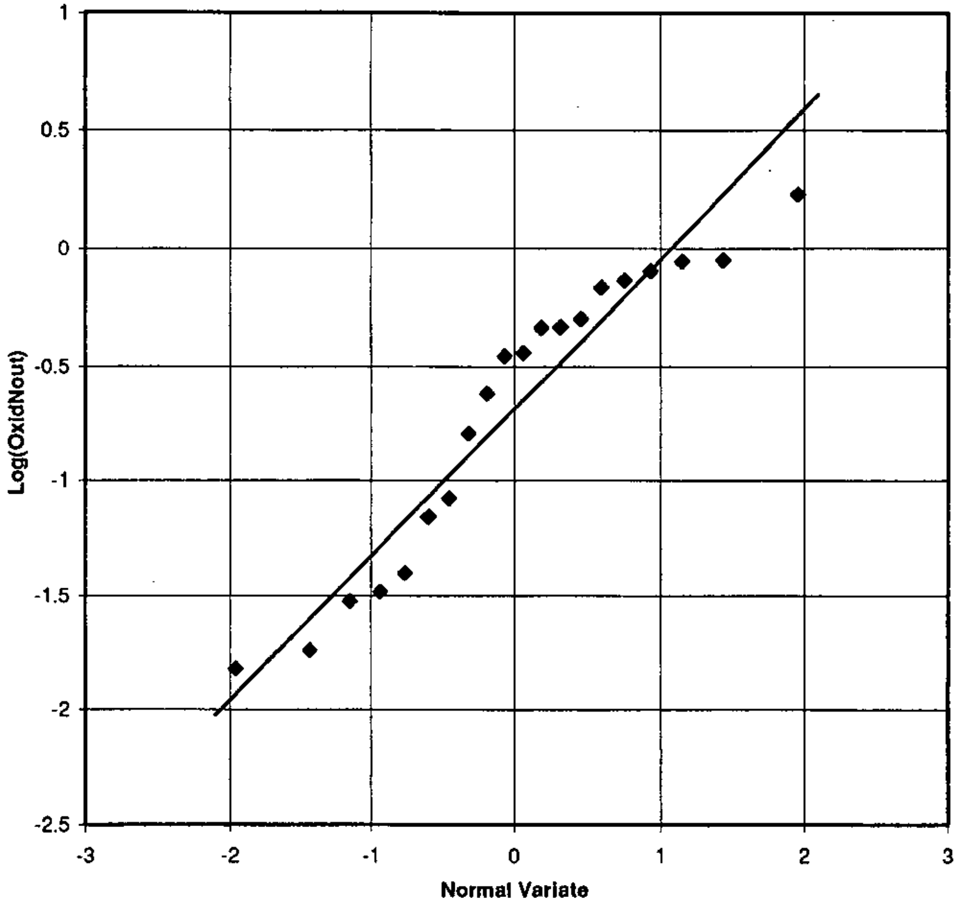
Total Kjeldahl Nitrogen



Correlation coefficient	0.982
Observations	25
Shapiro-Wilk critical R (95%)	0.958

Hypothesis of normality not rejected at 95% level

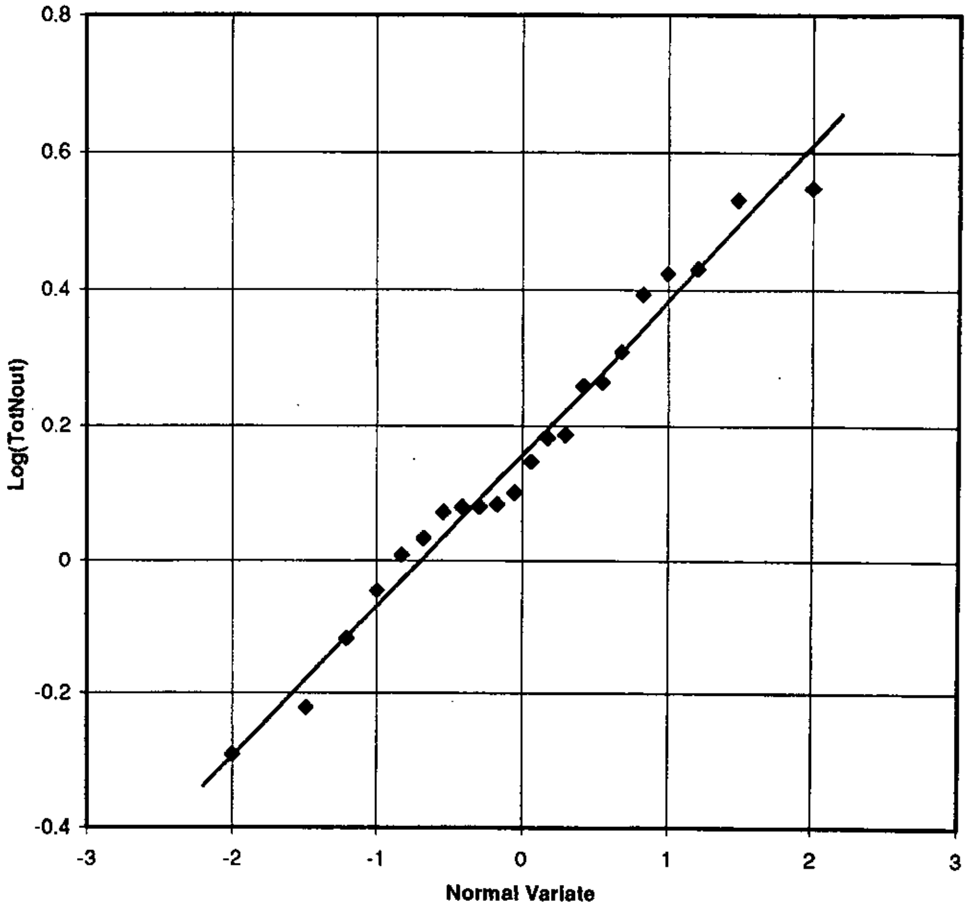
Oxidised Nitrogen



Correlation coefficient	0.959
Observations	20
Shapiro-Wilk critical R (95%)	0.95

Hypothesis of normality not rejected at 95% level

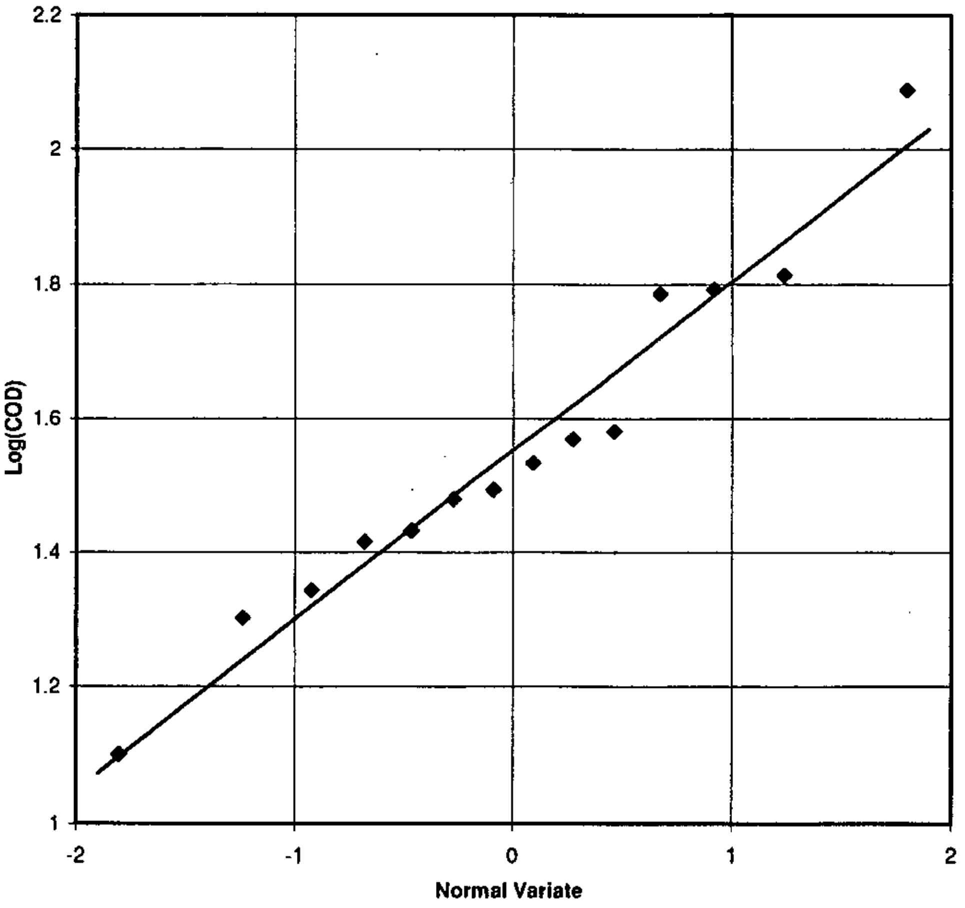
Total Nitrogen



Correlation coefficient	0.99
Observations	22
Shapiro-Wilk critical R (95%)	0.953

Hypothesis of normality not rejected at 95% level

Chemical Oxygen Demand



Correlation coefficient	0.98
Observations	14
Shapiro-Wilk critical R (95%)	0.934

Hypothesis of normality not rejected at 95% level

APPENDIX C

Multiple Regressions

Suspended Solids (SS)

Arearatio is the best measure of pond size, followed by storage.
Pond depth is not a significant explanatory variable.
No outliers were identified.

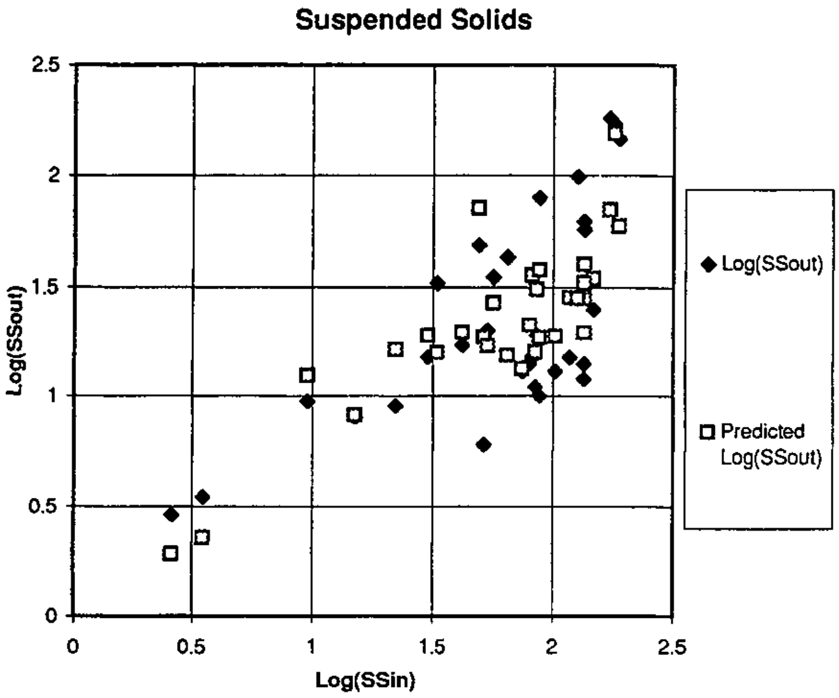
SS (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	0.202	0.251	0.804	0.428	-0.313	0.717	Multiple R	0.699
Log(depth)	-0.285	0.221	-1.289	0.208	-0.739	0.168	R Square	0.488
Log(SSin)	0.644	0.137	4.691	6.5E-05	0.363	0.925	Adj R Sq	0.452
							Std Error	0.344

SS (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	0.511	0.238	2.146	0.041	0.023	0.999	Multiple R	0.787
Log(storage)	-0.220	0.064	-3.454	1.8E-03	-0.351	-0.090	R Square	0.620
Log(SSin)	0.597	0.119	5.029	2.6E-05	0.354	0.840	Adj R Sq	0.593
							Std Error	0.296

SS (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.338	0.236	-1.434	0.163	-0.821	0.145	Multiple R	0.809
Log(arearatio)	-0.313	0.078	-3.995	4.3E-04	-0.473	-0.152	R Square	0.655
Log(SSin)	0.598	0.113	5.312	1.2E-05	0.368	0.829	Adj R Sq	0.630
See graph below							Std Error	0.282

SS (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.665	0.236	7.054	1.1E-07	1.182	2.149	Multiple R	0.685
Log(arearatio)	-0.315	0.078	-4.012	4.1E-04	-0.475	-0.154	R Square	0.470
Log(SSin)	-0.406	0.113	-3.599	1.2E-03	-0.637	-0.175	Adj R Sq	0.432
							Std Error	0.283

Log(SSin)		*Log(SSout)*		*Log(%SSout)*	
Mean	1.770	Mean	1.338	Mean	1.567
Std Dev	0.465	Std Dev	0.464	Std Dev	0.375
Count	31	Count	31	Count	31



Total Lead (TotPb)

Arearatio is the best measure of pond size.
Depth and storage are not significant explanatory variables.
No outliers were identified.

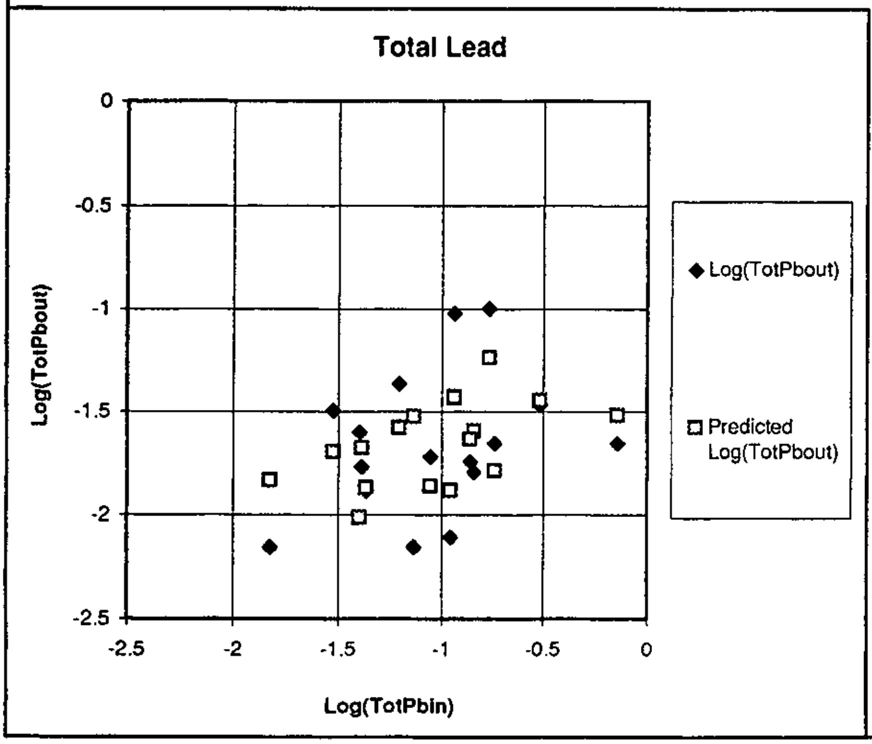
TotPb (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-1.392	0.245	-5.690	7.4E-05	-1.921	-0.864	Multiple R	0.312
Log(depth)	0.019	0.307	0.060	0.953	-0.644	0.681	R Square	0.097
Log(TotPbin)	0.260	0.219	1.184	0.257	-0.214	0.733	Adj R Sq	-0.041
							Std Error	0.351

TotPb (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-1.083	0.310	-3.499	3.9E-03	-1.752	-0.415	Multiple R	0.475
Log(storage)	-0.192	0.131	-1.466	0.166	-0.474	0.091	R Square	0.225
Log(TotPbin)	0.354	0.213	1.660	0.121	-0.107	0.814	Adj R Sq	0.106
							Std Error	0.326

TotPb (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-1.914	0.309	-6.204	3.2E-05	-2.581	-1.248	Multiple R	0.596
Log(arearatio)	-0.378	0.166	-2.279	0.040	-0.736	-0.020	R Square	0.355
Log(TotPbin)	0.451	0.204	2.217	0.045	0.012	0.891	Adj R Sq	0.256
See graph below							Std Error	0.297

TotPb (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	0.071	0.308	0.231	0.821	-0.595	0.737	Multiple R	0.791
Log(arearatio)	-0.384	0.166	-2.317	0.037	-0.742	-0.026	R Square	0.625
Log(TotPbin)	-0.553	0.203	-2.718	0.018	-0.993	-0.114	Adj R Sq	0.567
							Std Error	0.297

Log(TotPbin)		*Log(TotPbout)*		*Log(%TotPbout)*	
Mean	-1.042	Mean	-1.663	Mean	1.381
Std Dev	0.414	Std Dev	0.344	Std Dev	0.452
Count	16	Count	16	Count	16


Total Lead

Total Zinc (TotZn)

Arearatio is the best measure of pond size, followed by storage
Depth is not a significant explanatory variable.
No outliers were identified.

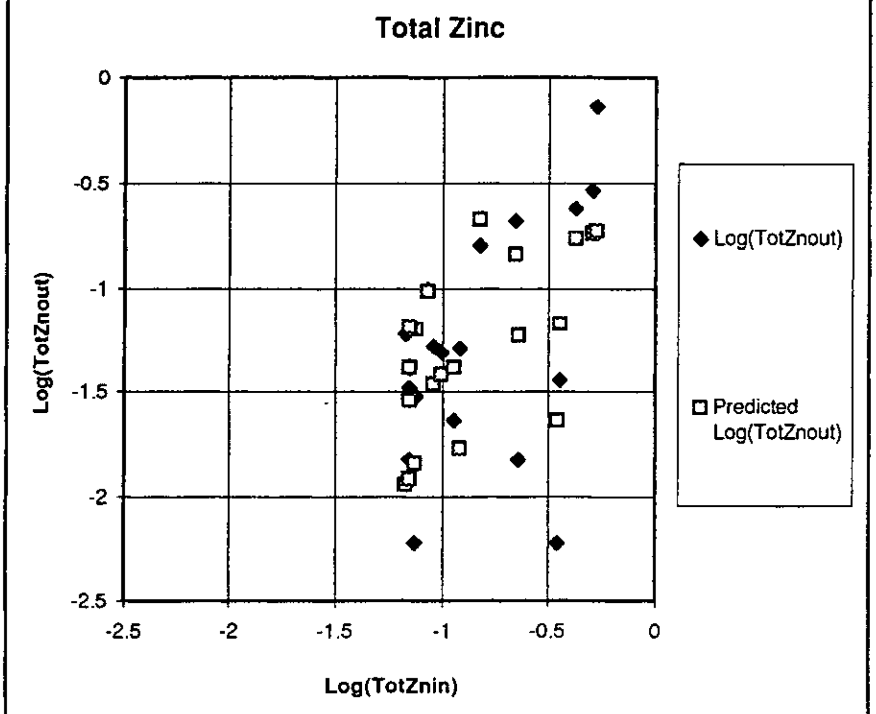
TotZn (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.663	0.414	-1.601	0.128	-1.538	0.211	Multiple R	0.461
Log(depth)	-0.057	0.566	-0.101	0.921	-1.252	1.138	R Square	0.213
Log(TotZnin)	0.736	0.483	1.524	0.146	-0.283	1.754	Adj R Sq	0.120
							Std Error	0.510

TotZn (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.569	0.273	-2.083	0.053	-1.145	0.007	Multiple R	0.672
Log(storage)	-0.476	0.175	-2.721	0.015	-0.846	-0.107	R Square	0.451
Log(TotZnin)	0.190	0.367	0.516	0.612	-0.585	0.965	Adj R Sq	0.387
							Std Error	0.426

TotZn (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-2.384	0.522	-4.567	2.7E-04	-3.486	-1.283	Multiple R	0.756
Log(arearatio)	-0.727	0.193	-3.768	1.5E-03	-1.134	-0.320	R Square	0.571
Log(TotZnin)	0.300	0.293	1.025	0.320	-0.317	0.917	Adj R Sq	0.520
See graph below							Std Error	0.377

TotZn (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.338	0.511	-0.661	0.517	-1.416	0.740	Multiple R	0.685
Log(arearatio)	-0.714	0.189	-3.783	1.5E-03	-1.112	-0.316	R Square	0.469
Log(TotZnin)	-0.676	0.286	-2.362	0.030	-1.280	-0.072	Adj R Sq	0.406
							Std Error	0.369

Log(TotZnin)		*Log(TotZnout)*		*Log(%TotZnout)*	
Mean	-0.850	Mean	-1.291	Mean	1.561
Std Dev	0.326	Std Dev	0.544	Std Dev	0.478
Count	20	Count	20	Count	20



Dissolved Phosphorus (DisP)

None of the measures of pond size are statistically significant at the 5% level.
Storage is the best measure, followed by astrearatio.
Coefficient of input conc not sig diff from 1 (i.e. % out may be independent of input).
One outlier (Maitland) has been removed.

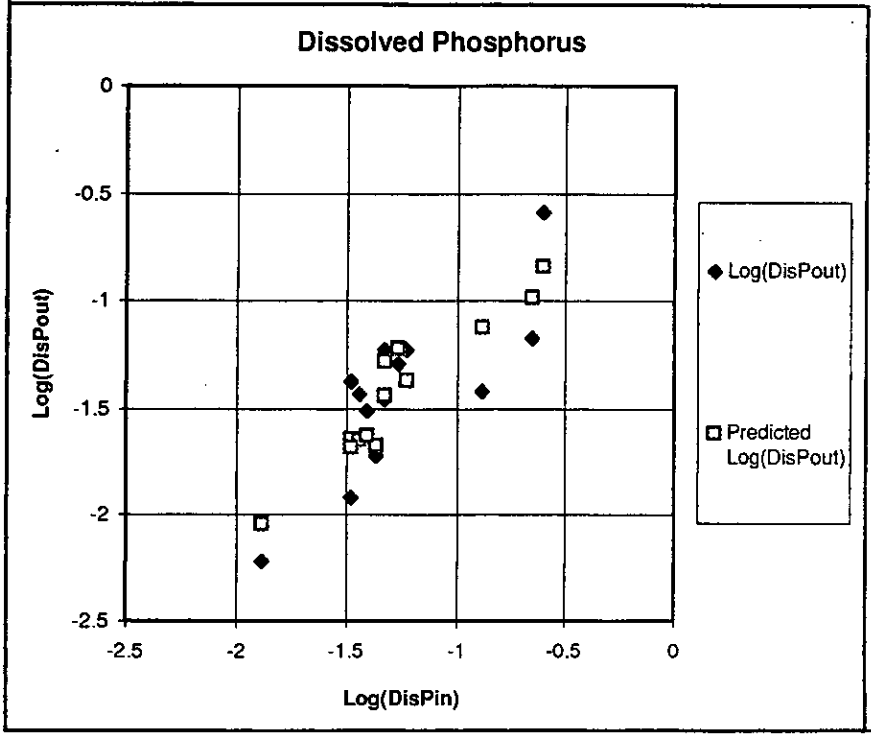
DisP (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.137	0.284	-0.481	0.641	-0.770	0.496	Multiple R	0.836
Log(depth)	-0.318	0.251	-1.268	0.233	-0.878	0.241	R Square	0.699
Log(DisPin)	1.050	0.230	4.574	1.0E-03	0.539	1.562	Adj R Sq	0.638
							Std Error	0.236

DisP (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.088	0.273	-0.321	0.754	-0.697	0.521	Multiple R	0.852
Log(storage)	-0.108	0.065	-1.651	0.130	-0.253	0.038	R Square	0.725
Log(DisPin)	1.001	0.195	5.135	4.4E-04	0.567	1.436	Adj R Sq	0.670
See graph below							Std Error	0.225

DisP (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.496	0.270	-1.842	0.095	-1.097	0.104	Multiple R	0.848
Log(arearatio)	-0.126	0.081	-1.563	0.149	-0.306	0.054	R Square	0.719
Log(DisPin)	0.957	0.190	5.038	5.1E-04	0.534	1.380	Adj R Sq	0.663
							Std Error	0.228

DisP (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.911	0.074	25.782	3.5E-11	1.748	2.074	Multiple R	0.490
Log(storage)	-0.109	0.059	-1.866	0.089	-0.238	0.020	R Square	0.240
							Adj R Sq	0.171
							Std Error	0.216

Log(DisPin)		*Log(DisPout)*		*Log(%DisPout)*	
Mean	-1.258	Mean	-1.428	Mean	1.829
Std Dev	0.355	Std Dev	0.392	Std Dev	0.237
Count	13	Count	13	Count	13



Total Phosphorus (TotP)

Arearatio is the best measure of pond size, followed by storage.
Depth is not a significant explanatory variable.
Coefficient of input conc not sig diff from 1 (i.e. % out may be independent of input).
One outlier (Maitland) has been removed.

TotP(mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.262	0.091	-2.870	7.5E-03	-0.449	-0.076	Multiple R	0.807
Log(depth)	-0.096	0.130	-0.738	0.466	-0.363	0.170	R Square	0.651
Log(TotPin)	0.940	0.126	7.459	0.000	0.683	1.198	Adj R Sq	0.628
							Std Error	0.209

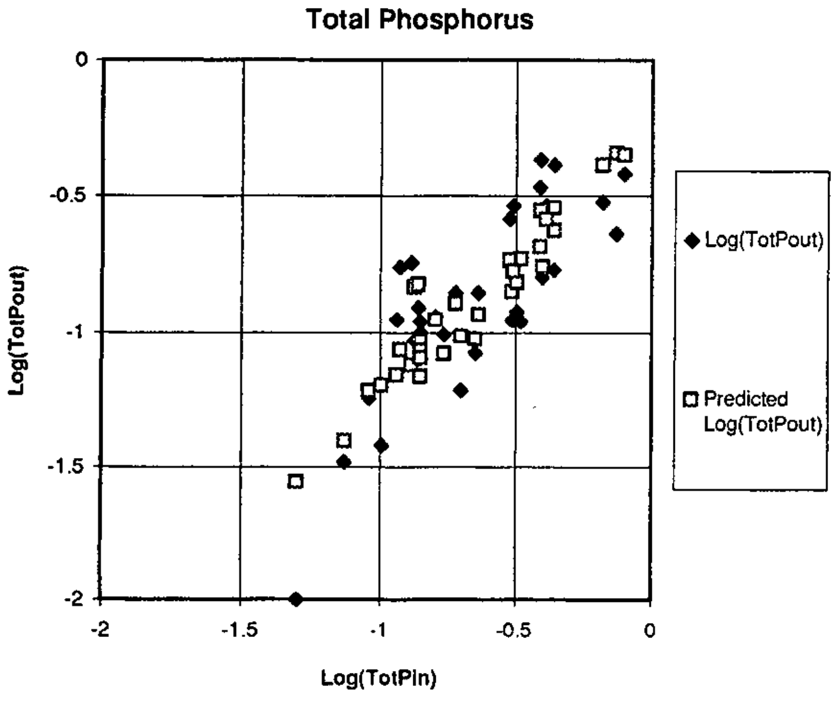
TotP(mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.176	0.093	-1.885	0.069	-0.367	0.015	Multiple R	0.836
Log(storage)	-0.092	0.040	-2.318	0.027	-0.173	-0.011	R Square	0.699
Log(TotPin)	0.918	0.118	7.814	1.0E-08	0.678	1.158	Adj R Sq	0.679
							Std Error	0.195

TotP (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.538	0.130	-4.120	2.7E-04	-0.804	-0.271	Multiple R	0.845
Log(arearatio)	-0.132	0.049	-2.687	0.012	-0.232	-0.032	R Square	0.714
Log(TotPin)	0.908	0.115	7.904	8.0E-09	0.673	1.142	Adj R Sq	0.695
See graph below							Std Error	0.190

TotP (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.463	0.131	11.179	3.2E-12	1.196	1.731	Multiple R	0.445
Log(arearatio)	-0.132	0.049	-2.673	0.012	-0.232	-0.031	R Square	0.198
Log(TotPin)	-0.092	0.115	-0.802	0.429	-0.328	0.143	Adj R Sq	0.145
							Std Error	0.190

TotP (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.532	0.098	15.633	3.0E-16	1.332	1.732	Multiple R	0.426
Log(arearatio)	-0.128	0.049	-2.619	0.014	-0.227	-0.028	R Square	0.181
							Adj R Sq	0.155
							Std Error	0.189

Log(TotPin)		*Log(TotPout)*		*Log(%TotPout)*	
Mean	-0.664	Mean	-0.890	Mean	1.774
Std Dev	0.294	Std Dev	0.343	Std Dev	0.206
Count	33	Count	33	Count	33



Organic Nitrogen (OrgN)

None of the measures of pond size even approach significance at the 5% level.
Sample size is very small, and range is narrow.
Coeff of input conc not sig diff from 1 (i.e. % out may be independent of input)
One outlier (Maitland) has been removed.

OrgN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.078	0.038	-2.084	0.076	-0.167	0.011	Multiple R	0.868
Log(depth)	0.108	0.103	1.046	0.330	-0.136	0.352	R Square	0.754
Log(OrgNin)	0.832	0.181	4.604	2.5E-03	0.405	1.259	Adj R Sq	0.683
							Std Error	0.106

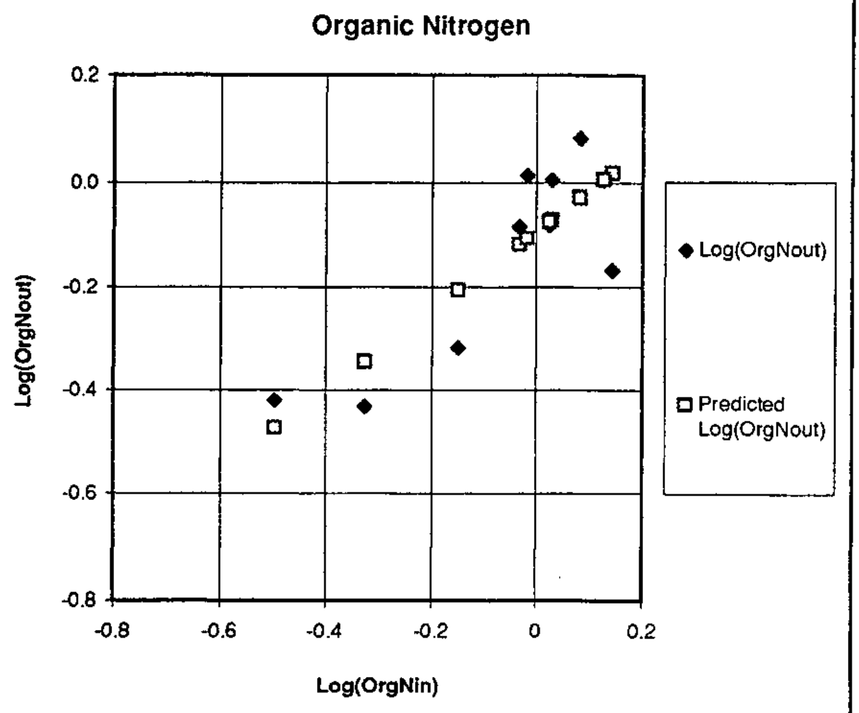
OrgN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.082	0.047	-1.764	0.121	-0.192	0.028	Multiple R	0.849
Log(storage)	-0.011	0.029	-0.375	0.719	-0.079	0.058	R Square	0.721
Log(OrgNin)	0.747	0.192	3.885	6.0E-03	0.292	1.201	Adj R Sq	0.641
							Std Error	0.113

OrgN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.148	0.076	-1.946	0.093	-0.327	0.032	Multiple R	0.861
Log(arearatio)	-0.029	0.035	-0.826	0.436	-0.112	0.054	R Square	0.741
Log(OrgNin)	0.724	0.184	3.937	5.6E-03	0.289	1.159	Adj R Sq	0.666
							Std Error	0.109

OrgN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.092	0.035	-2.624	0.030	-0.174	-0.011	Multiple R	0.846
Log(OrgNin)	0.770	0.172	4.483	2.0E-03	0.374	1.166	R Square	0.715
See graph below							Adj R Sq	0.680
							Std Error	0.106

OrgN (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.897	0.075	25.418	6.1E-09	1.725	2.069	Multiple R	0.130
Log(arearatio)	-0.013	0.036	-0.370	0.721	-0.096	0.069	R Square	0.017
							Adj R Sq	-0.106
							Std Error	0.116

Log(OrgNin)		*Log(OrgNout)*		*Log(%OrgNout)*	
Mean	-0.061	Mean	-0.140	Mean	1.921
Std Dev	0.206	Std Dev	0.188	Std Dev	0.111
Count	10	Count	10	Count	10



Ammonia Nitrogen (AmmN)

None of the measures of pond size even approach significance at the 5% level.
Sample size is very small, and range is narrow.
Coeff of input conc not sig diff from 1 (i.e. % out may be independent of input).
One outlier (Maitland) has been removed.

AmmN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.233	0.226	-1.032	0.329	-0.745	0.278	Multiple R	0.761
Log(depth)	0.014	0.318	0.045	0.965	-0.705	0.733	R Square	0.579
Log(AmmNin)	0.832	0.244	3.412	7.7E-03	0.280	1.383	Adj R Sq	0.486
							Std Error	0.344

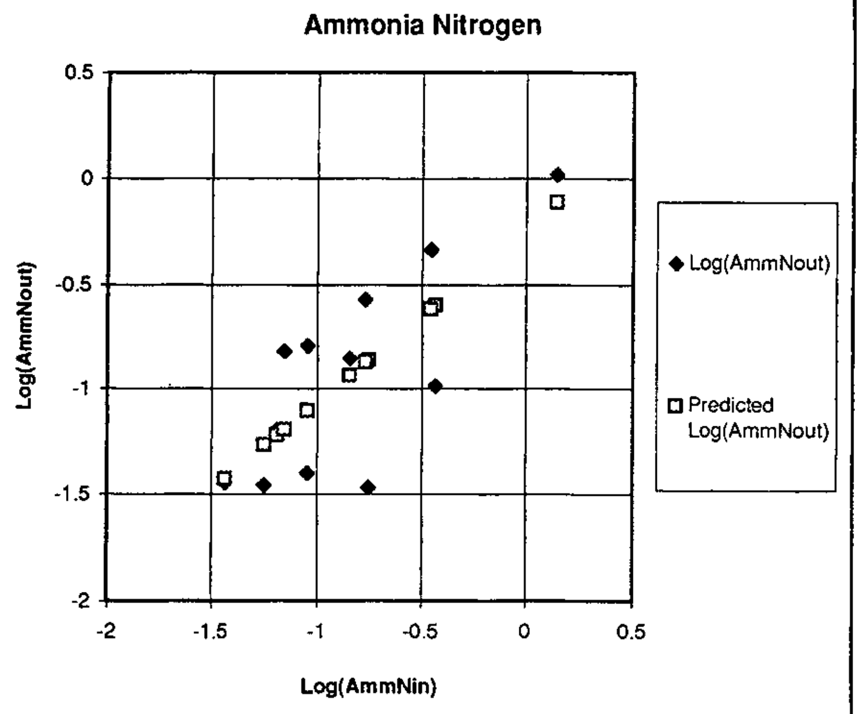
AmmN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.177	0.267	-0.665	0.523	-0.780	0.426	Multiple R	0.765
Log(storage)	-0.032	0.085	-0.379	0.713	-0.225	0.161	R Square	0.586
Log(AmmNin)	0.856	0.242	3.535	6.4E-03	0.308	1.405	Adj R Sq	0.494
							Std Error	0.342

AmmN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.306	0.266	-1.148	0.281	-0.908	0.297	Multiple R	0.768
Log(arearatio)	-0.054	0.107	-0.498	0.630	-0.296	0.189	R Square	0.591
Log(AmmNin)	0.861	0.240	3.588	5.9E-03	0.318	1.404	Adj R Sq	0.500
							Std Error	0.340

AmmN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.232	0.214	-1.088	0.302	-0.708	0.243	Multiple R	0.761
Log(AmmNin)	0.834	0.225	3.710	4.0E-03	0.333	1.335	R Square	0.579
See graph below							Adj R Sq	0.537
							Std Error	0.327

AmmN (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.784	0.206	8.671	5.8E-06	1.326	2.242	Multiple R	0.208
Log(arearatio)	-0.068	0.101	-0.672	0.517	-0.294	0.158	R Square	0.043
							Adj R Sq	-0.052
							Std Error	0.330

Log(AmmNin)		*Log(AmmNout)*		*Log(%AmmNout)*	
Mean	-0.852	Mean	-0.943	Mean	1.907
Std Dev	0.438	Std Dev	0.480	Std Dev	0.321
Count	12	Count	12	Count	12



Total Kjeldahl Nitrogen (TKN)

None of the measures of pond size are statistically significant at the 5% level.
Coeff of input conc not sig diff from 1 (i.e. % out may be independent of input).
One outlier (Maitland) has been removed.

TKN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.087	0.025	-3.539	1.8E-03	-0.139	-0.036	Multiple R	0.831
Log(depth)	0.097	0.083	1.167	0.256	-0.075	0.269	R Square	0.691
Log(TKNin)	1.037	0.148	6.994	5.1E-07	0.730	1.345	Adj R Sq	0.662
							Std Error	0.113

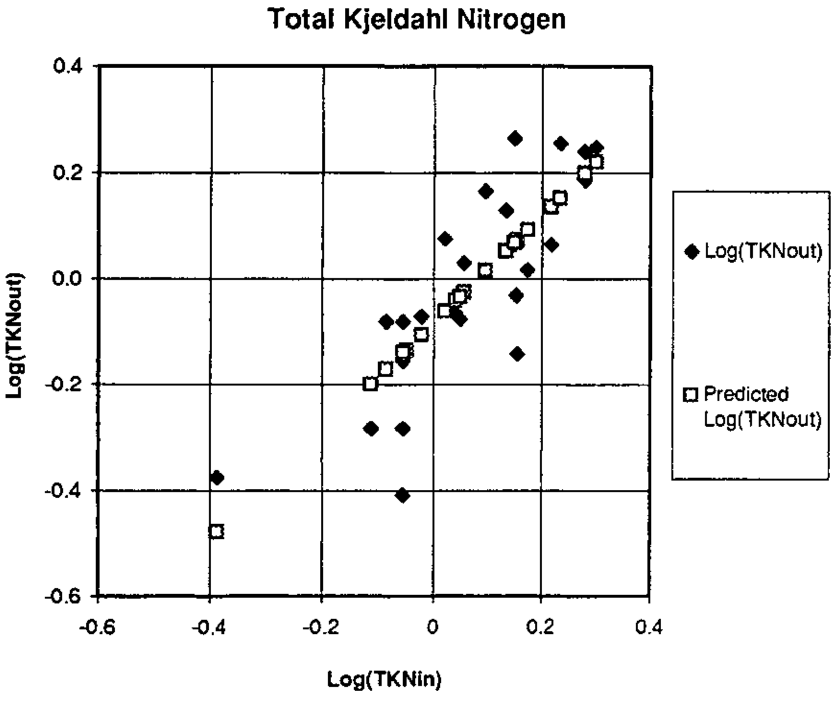
TKN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.078	0.040	-1.941	0.065	-0.162	0.005	Multiple R	0.820
Log(storage)	-0.004	0.025	-0.170	0.866	-0.056	0.047	R Square	0.672
Log(TKNin)	1.015	0.154	6.603	1.2E-06	0.696	1.334	Adj R Sq	0.642
							Std Error	0.116

TKN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.119	0.061	-1.952	0.064	-0.246	0.007	Multiple R	0.823
Log(arearatio)	-0.020	0.031	-0.640	0.529	-0.085	0.045	R Square	0.677
Log(TKNin)	1.004	0.153	6.582	1.3E-06	0.688	1.320	Adj R Sq	0.648
							Std Error	0.115

TKN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.084	0.025	-3.385	2.5E-03	-0.135	-0.032	Multiple R	0.819
Log(TKNin)	1.019	0.149	6.856	5.4E-07	0.712	1.327	R Square	0.671
See graph below							Adj R Sq	0.657
							Std Error	0.114

TKN (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.880	0.060	31.447	2.1E-20	1.756	2.004	Multiple R	0.140
Log(arearatio)	-0.021	0.030	-0.680	0.503	-0.083	0.042	R Square	0.020
							Adj R Sq	-0.023
							Std Error	0.113

Log(TKNin)		*Log(TKNout)*		*Log(%TKNout)*	
Mean	0.064	Mean	-0.018	Mean	1.918
Std Dev	0.156	Std Dev	0.194	Std Dev	0.112
Count	25	Count	25	Count	25



Oxidised Nitrogen (OxidN)

Arearatio is the best measure of pond size, followed by storage.
Depth is not a significant explanatory variable.
Coefficient of input concentration is significantly greater than 1.
One outlier (Lake Ellyn) has been removed.

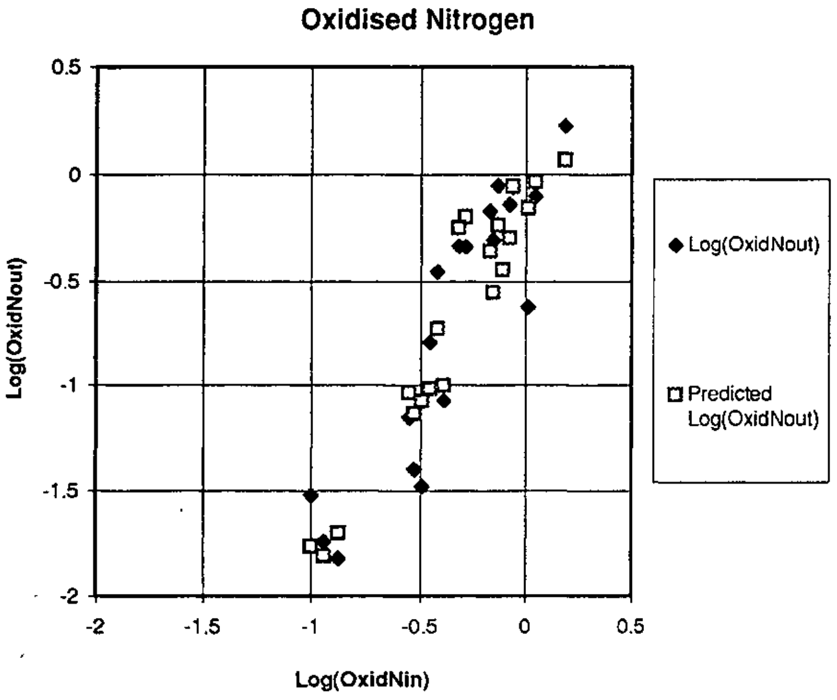
OxidN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.098	0.090	-1.096	0.288	-0.288	0.091	Multiple R	0.911
Log(depth)	-0.306	0.212	-1.441	0.168	-0.754	0.142	R Square	0.830
Log(OxidNin)	1.753	0.193	9.072	6.3E-08	1.345	2.160	Adj R Sq	0.810
							Std Error	0.277

OxidN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	0.053	0.094	0.569	0.577	-0.144	0.251	Multiple R	0.935
Log(storage)	-0.155	0.052	-2.967	8.6E-03	-0.264	-0.045	R Square	0.875
Log(OxidNin)	1.668	0.168	9.957	1.6E-08	1.315	2.021	Adj R Sq	0.860
							Std Error	0.238

OxidN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.534	0.148	-3.615	2.1E-03	-0.846	-0.222	Multiple R	0.941
Log(arearatio)	-0.215	0.064	-3.352	3.8E-03	-0.350	-0.080	R Square	0.885
Log(OxidNin)	1.630	0.162	10.077	1.4E-08	1.289	1.971	Adj R Sq	0.872
See graph below							Std Error	0.228

OxidN (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.465	0.150	9.750	2.2E-08	1.148	1.782	Multiple R	0.807
Log(arearatio)	-0.215	0.065	-3.297	4.3E-03	-0.352	-0.077	R Square	0.651
Log(OxidNin)	0.630	0.164	3.830	1.3E-03	0.283	0.977	Adj R Sq	0.610
							Std Error	0.232

Log(OxidNin)		*Log(OxidNout)*		*Log(%OxidNout)*	
Mean	-0.336	Mean	-0.688	Mean	1.646
Std Dev	0.330	Std Dev	0.637	Std Dev	0.371
Count	20	Count	20	Count	20



Total Nitrogen (TotN)

None of the measures of pond size are statistically significant at the 5% level.
Areararatio is the best measure of pond size (although not significant), followed by storage.
Coeff of input conc not sig diff from 1 (i.e. % out may be independent of input).
One outlier (Maitland) has been removed.

TotN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.134	0.042	-3.218	4.5E-03	-0.222	-0.047	Multiple R	0.888
Log(depth)	0.071	0.080	0.891	0.384	-0.096	0.237	R Square	0.788
Log(TotNin)	1.099	0.131	8.399	8.1E-08	0.825	1.373	Adj R Sq	0.766
							Std Error	0.109

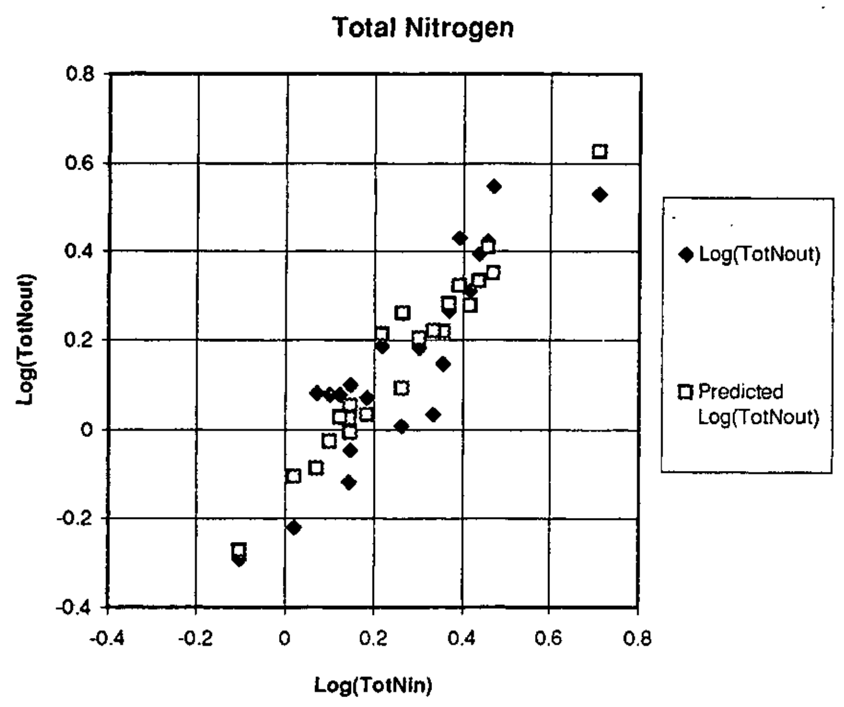
TotN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.096	0.050	-1.904	0.072	-0.202	0.010	Multiple R	0.891
Log(storage)	-0.028	0.024	-1.198	0.246	-0.078	0.021	R Square	0.795
Log(TotNin)	1.079	0.129	8.380	8.4E-08	0.810	1.349	Adj R Sq	0.773
							Std Error	0.107

TotN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.231	0.064	-3.614	1.8E-03	-0.364	-0.097	Multiple R	0.903
Log(arearatio)	-0.055	0.028	-1.957	0.065	-0.114	0.004	R Square	0.816
Log(TotNin)	1.075	0.122	8.830	3.8E-08	0.820	1.330	Adj R Sq	0.797
See graph below							Std Error	0.102

TotN (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.131	0.041	-3.175	4.8E-03	-0.218	-0.045	Multiple R	0.883
Log(TotNin)	1.091	0.130	8.400	5.4E-08	0.820	1.362	R Square	0.779
							Adj R Sq	0.768
							Std Error	0.109

TotN (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	1.785	0.056	31.811	1.3E-18	1.668	1.902	Multiple R	0.419
Log(arearatio)	-0.057	0.028	-2.065	0.052	-0.115	0.001	R Square	0.176
							Adj R Sq	0.135
							Std Error	0.100

Log(TotNin)		*Log(TotNout)*		*Log(%TotNout)*	
Mean	0.264	Mean	0.157	Mean	1.892
Std Dev	0.183	Std Dev	0.226	Std Dev	0.108
Count	22	Count	22	Count	22



Chemical Oxygen Demand (COD)

All of the measures of pond size are statistically significant at the 5% level.
Storage is the best measure, followed by depth, then arearatio.
Coeff of input conc not sig diff from 1 (i.e. % out may be independent of input).
No outliers were identified.

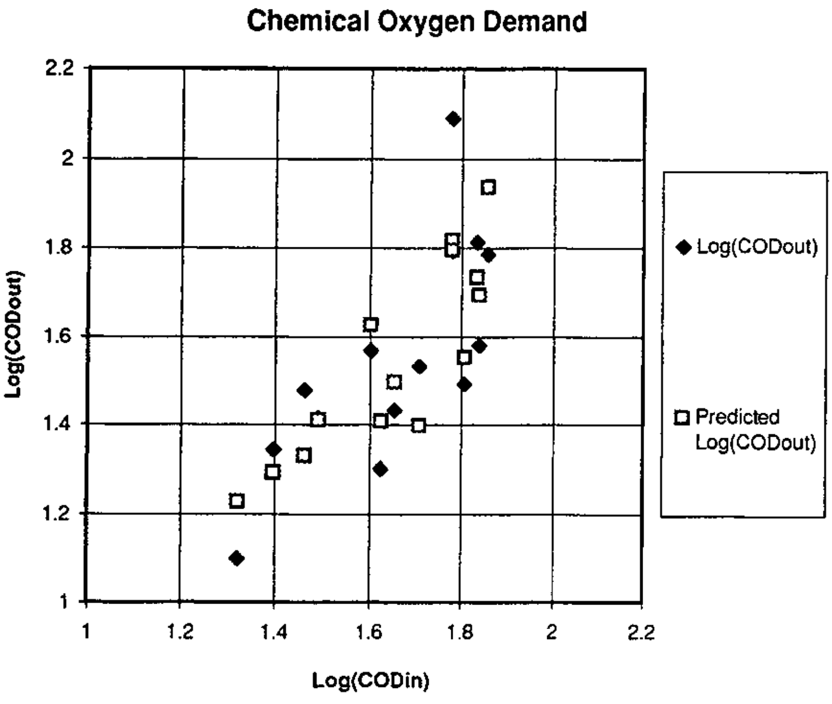
COD (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.188	0.352	-0.536	0.603	-0.963	0.586	Multiple R	0.870
Log(depth)	-0.597	0.199	-3.004	0.012	-1.034	-0.160	R Square	0.757
Log(CODin)	1.052	0.212	4.972	4.2E-04	0.586	1.518	Adj R Sq	0.713
							Std Error	0.135

COD (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.036	0.354	-0.102	0.921	-0.816	0.744	Multiple R	0.872
Log(storage)	-0.180	0.059	-3.042	0.011	-0.310	-0.050	R Square	0.760
Log(CODin)	1.079	0.210	5.126	3.3E-04	0.615	1.542	Adj R Sq	0.716
See graph below							Std Error	0.134

COD (mg/L)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	-0.631	0.415	-1.522	0.156	-1.543	0.281	Multiple R	0.848
Log(arearatio)	-0.204	0.081	-2.507	0.029	-0.382	-0.025	R Square	0.719
Log(CODin)	1.085	0.228	4.759	5.9E-04	0.583	1.586	Adj R Sq	0.668
							Std Error	0.145

COD (%)	*Coefficient*	*Std Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Regression Statistics*	
Intercept	2.095	0.072	29.125	1.7E-12	1.938	2.252	Multiple R	0.674
Log(storage)	-0.182	0.058	-3.164	8.2E-03	-0.308	-0.057	R Square	0.455
							Adj R Sq	0.409
							Std Error	0.131

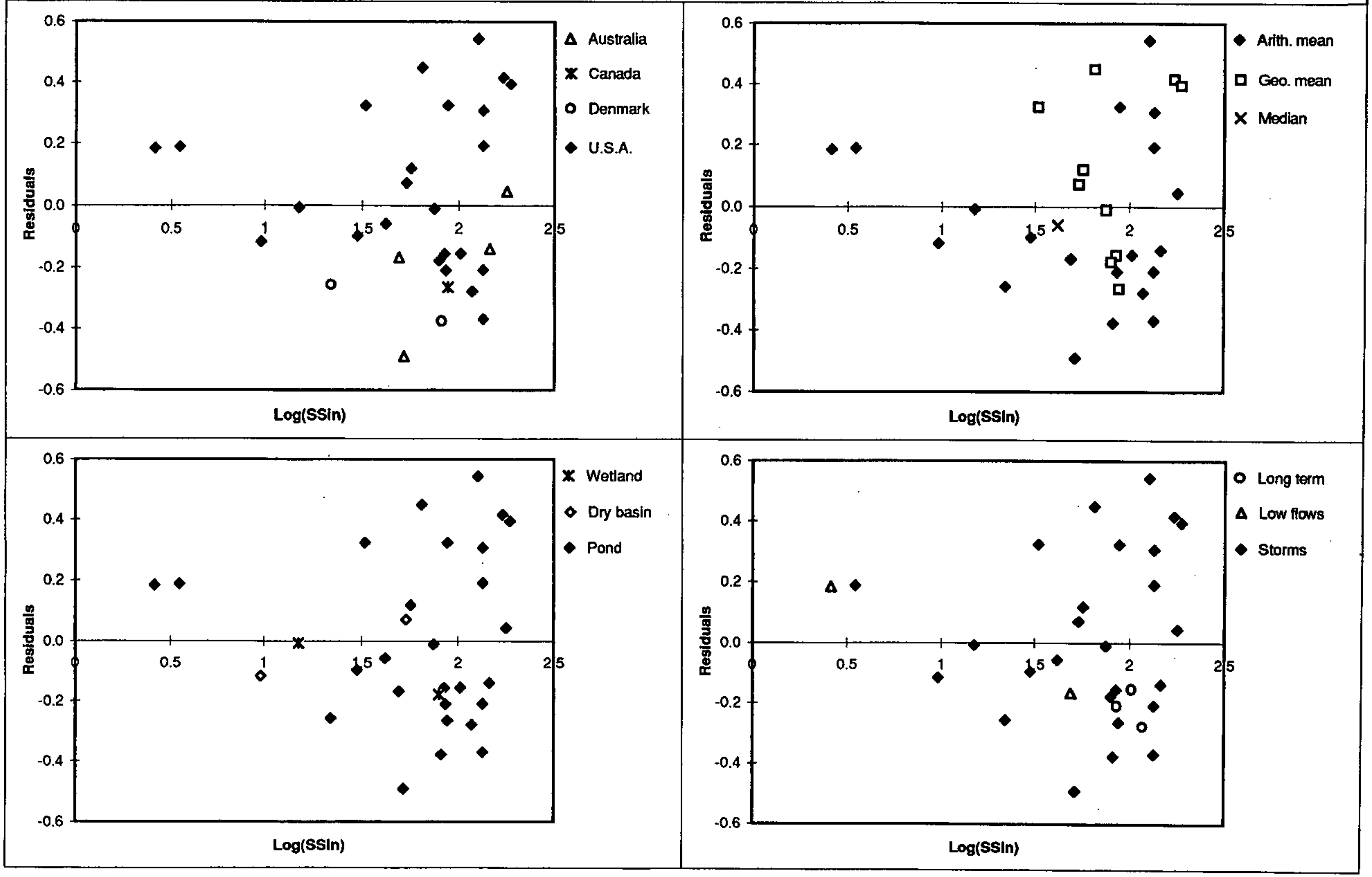
Log(CODin)		*Log(CODout)*		*Log(%CODout)*	
Mean	1.654	Mean	1.551	Mean	1.896
Std Dev	0.177	Std Dev	0.252	Std Dev	0.170
Count	14	Count	14	Count	14



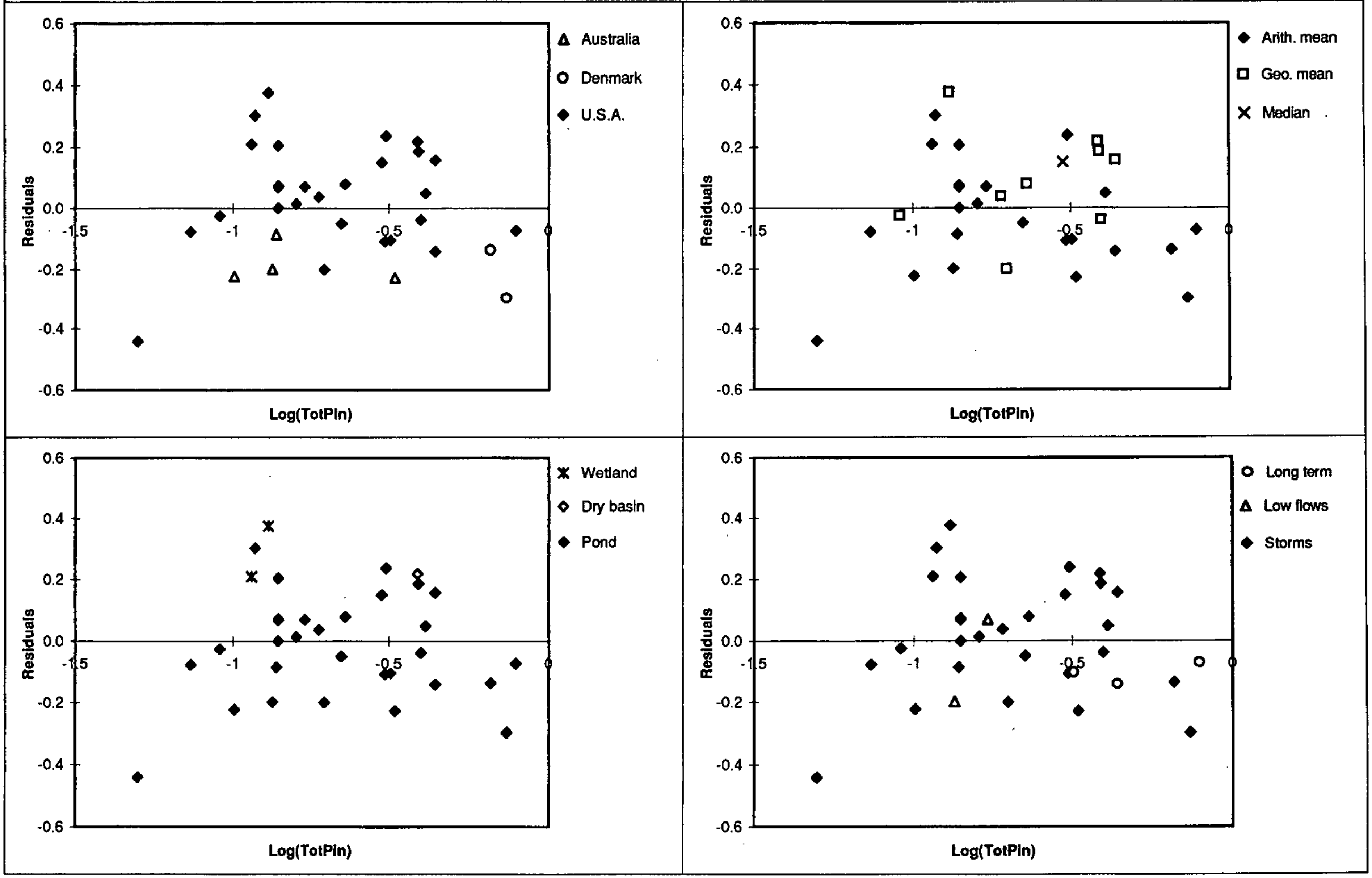
APPENDIX D

Descriptive Factors

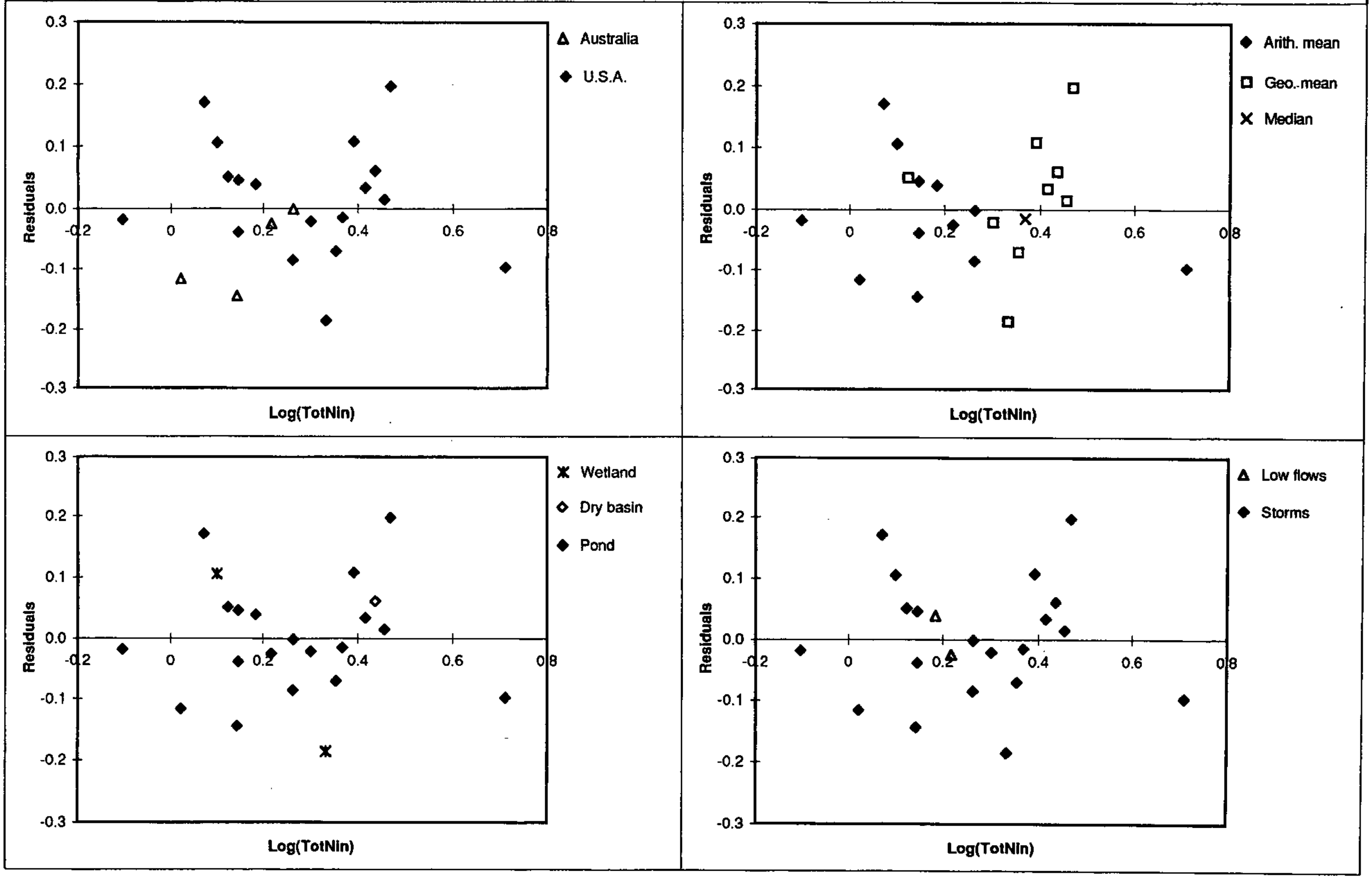
Suspended Solids



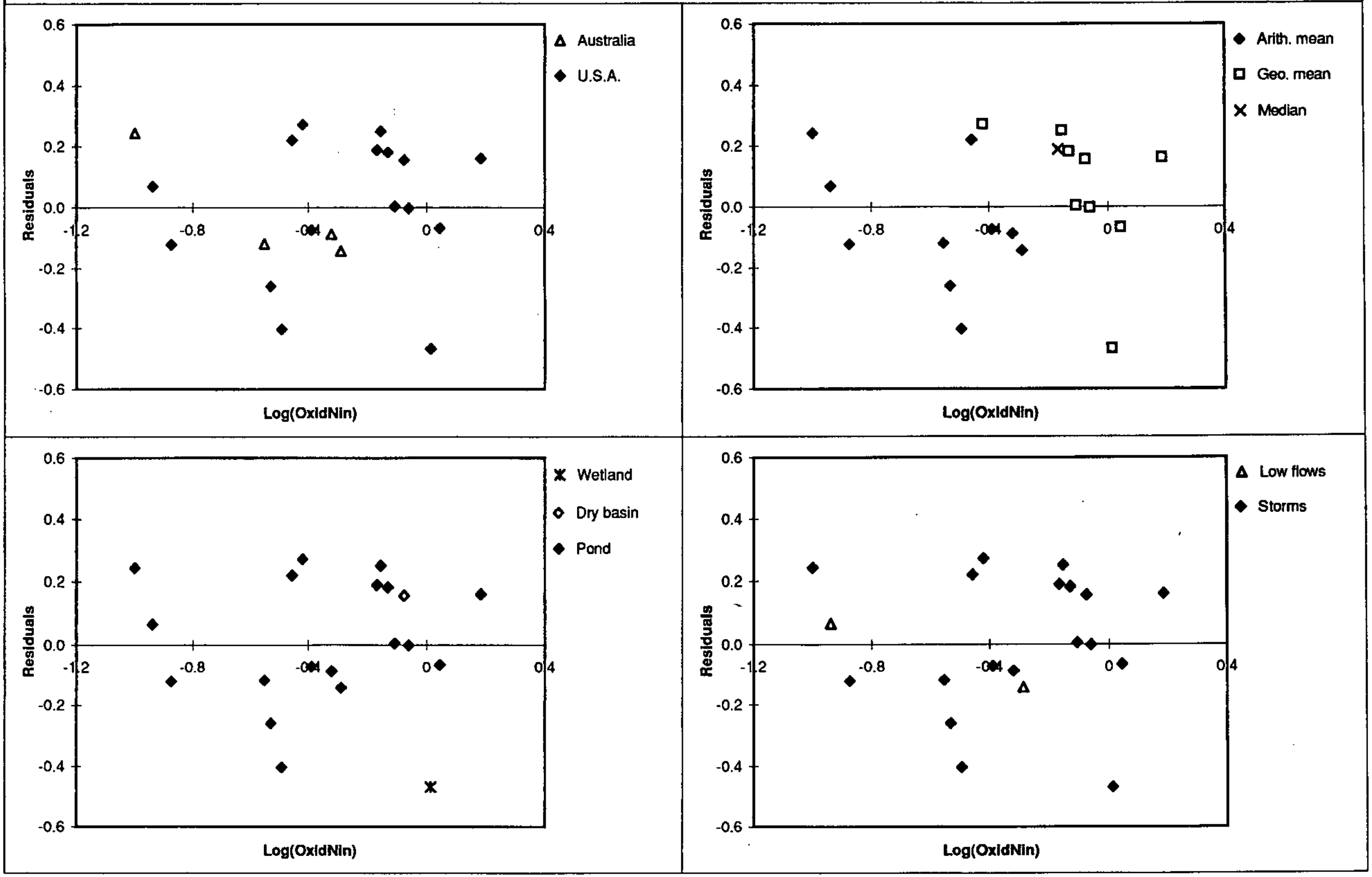
Total Phosphorus



Total Nitrogen



Oxidised Nitrogen



APPENDIX E

Ponds vs Wetlands

SUSPENDED SOLIDS

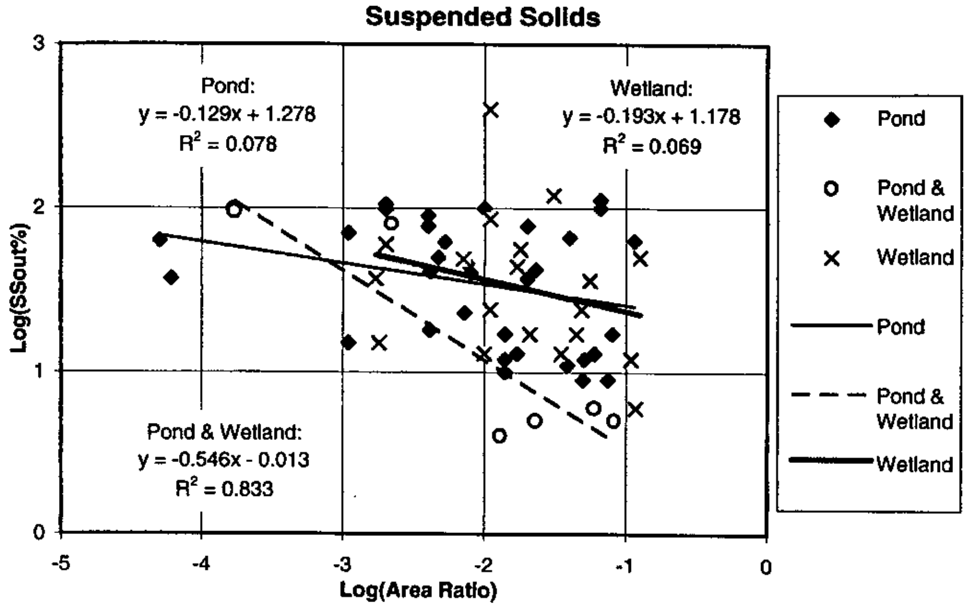
Combined regression line:

Regression Statistics	
Multiple R	0.374
R Square	0.140
Adj R Sq	0.125
Std Err	0.407
Obs	59

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	1.534	1.534	9.271	3.5E-03
Residual	57	9.434	0.166		
Total	58	10.968			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.091	0.143	7.623	2.9E-10	0.804	1.377
Arearatio	-0.206	0.068	-3.045	3.5E-03	-0.341	-0.070



Group statistics:

	All Data	*Pond*	*Pond/Wetl.*	*Wetland*
Mean	1.495	1.539	1.236	1.515
Std Err	0.057	0.065	0.256	0.098
Median	1.568	1.613	0.778	1.556
Mode	1.230	1.230	0.699	1.380
Std Dev	0.435	0.372	0.677	0.425
Sample Var	0.189	0.138	0.459	0.181
Kurtosis	-0.604	-1.479	-2.745	1.058
Skewness	-0.106	-0.231	0.358	0.713
Range	2.000	1.095	1.389	1.824
Minimum	0.602	0.954	0.602	0.778
Maximum	2.602	2.049	1.991	2.602
Sum	88.218	50.786	8.650	28.782
Count	59	33	7	19
95% Level	0.111	0.127	0.502	0.191

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	0.031	0.066
Variance	0.131	0.168
Obs	33	19
df	32	18
F	1.282	
P(F<=f) 1-t	0.263	
F Crit 1-tail	0.477	

t-Test: Two-Sample Assuming Equal Variances

	Pond	*Wetland*
Mean	0.031	0.066
Variance	0.131	0.168
Obs	33	19
Pooled Var	0.145	
Hyp mn diff	0	
df	50	
t Stat	-0.315	
P(T<=t) 1-t	0.377	
t Crit 1-tail	1.676	
P(T<=t) 2-t	0.754	
t Crit 2-tail	2.009	

Residuals about combined regression line **are not** significantly different between ponds and wetlands.

Combined regression line:

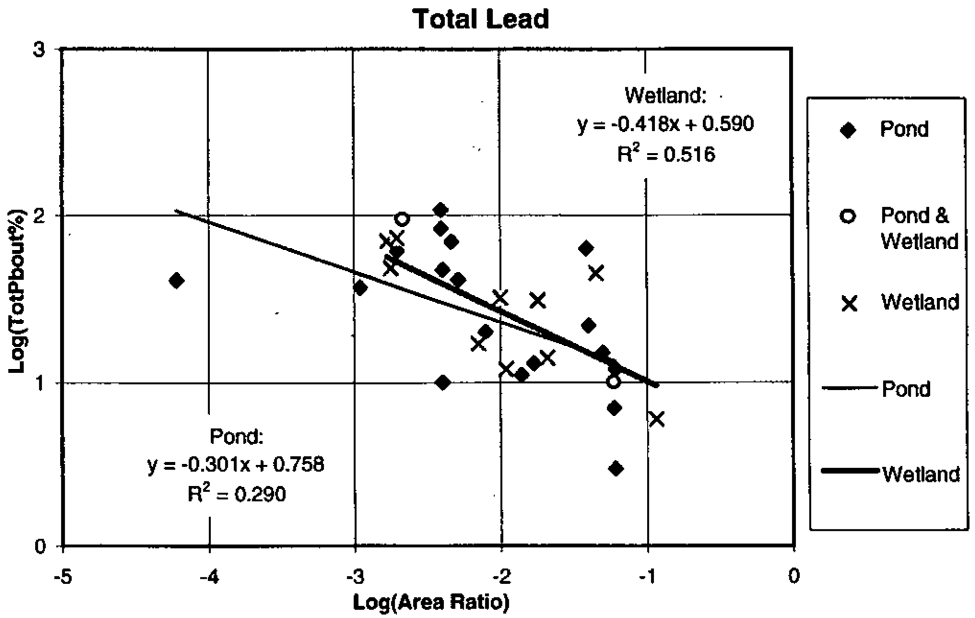
TOTAL LEAD

Regression Statistics	
Multiple R	0.611
R Square	0.373
Adj R Sq	0.352
Std Err	0.323
Obs	31

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	1.805	1.805	17.275	2.6E-04
Residual	29	3.030	0.104		
Total	30	4.835			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.687	0.182	3.780	7.2E-04	0.315	1.059
Arearatio	-0.351	0.084	-4.156	2.6E-04	-0.523	-0.178



Group statistics:

	All Data	*Pond*	*Wetland*
Mean	1.403	1.382	1.427
Std Err	0.072	0.096	0.113
Median	1.491	1.342	1.498
Mode	1.041	1.041	#N/A
Std Dev	0.401	0.421	0.358
Sample Var	0.161	0.177	0.128
Kurtosis	-0.772	-0.607	-0.689
Skewness	-0.292	-0.307	-0.490
Range	1.556	1.556	1.085
Minimum	0.477	0.477	0.778
Maximum	2.033	2.033	1.863
Sum	43.506	26.260	14.273
Count	31	19	10
95% Level	0.141	0.189	0.222

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.032	0.038
Variance	0.127	0.064
Obs	19	10
df	18	9
F	1.998	
P(F<=f) 1-t	0.145	
F Crit 1-tail	2.960	

t-Test: Two-Sample Assuming Equal Variances

	Pond	*Wetland*
Mean	-0.032	0.038
Variance	0.127	0.064
Obs	19	10
Pooled Var	0.106	
Hyp mn diff	0	
df	27	
t Stat	-0.553	
P(T<=t) 1-t	0.293	
t Crit 1-tail	1.703	
P(T<=t) 2-t	0.585	
t Crit 2-tail	2.052	

Residuals about combined regression line **are not** significantly different between ponds and wetlands.

Combined regression line:

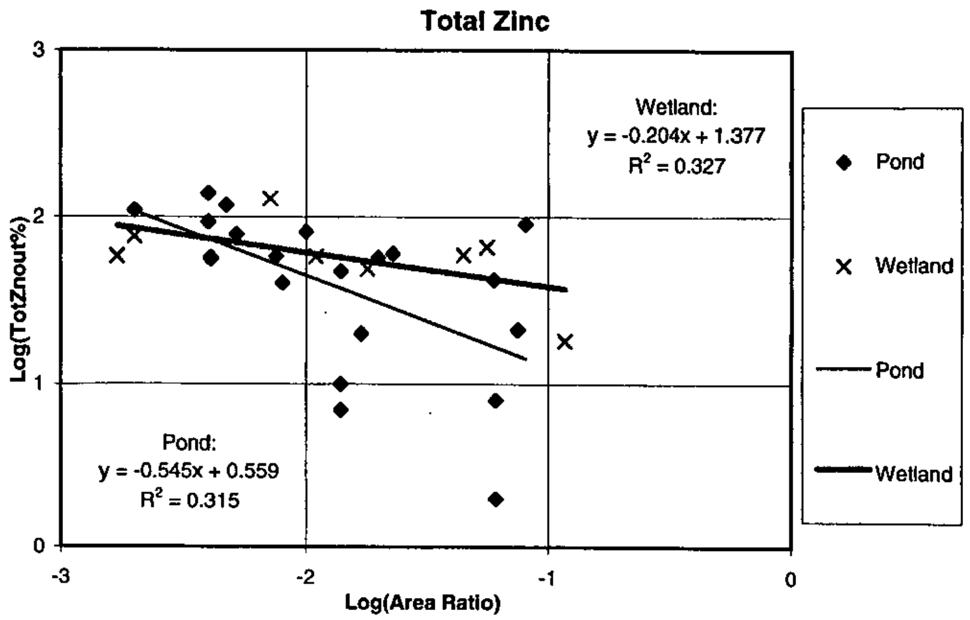
TOTAL ZINC

Regression Statistics	
Multiple R	0.508
R Square	0.258
Adj R Sq	0.230
Std Err	0.375
Obs	29

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	1.318	1.318	9.379	4.9E-03
Residual	27	3.793	0.140		
Total	28	5.111			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.870	0.259	3.356	2.4E-03	0.338	1.402
Arearatio	-0.407	0.133	-3.062	4.9E-03	-0.679	-0.134



Group statistics:

	All Data	*Pond*	*Wetland*
Mean	1.634	1.588	1.757
Std Err	0.079	0.104	0.085
Median	1.763	1.756	1.767
Mode	1.763	1.756	1.763
Std Dev	0.427	0.477	0.239
Sample Var	0.183	0.227	0.057
Kurtosis	2.304	1.259	3.385
Skewness	-1.524	-1.297	-1.112
Range	1.839	1.839	0.855
Minimum	0.301	0.301	1.255
Maximum	2.140	2.140	2.111
Sum	47.394	33.340	14.054
Count	29	21	8
95% Level	0.155	0.204	0.166

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.050	0.132
Variance	0.160	0.057
Obs	21	8
df	20	7
F	2.818	
P(F<=f) 1-t	0.082	
F Crit 1-tail	3.445	

t-Test: Two-Sample Assuming Equal Variances

	Pond	*Wetland*
Mean	-0.050	0.132
Variance	0.160	0.057
Obs	21	8
Pooled Var	0.133	
Hyp mn diff	0	
df	27	
t Stat	-1.198	
P(T<=t) 1-t	0.121	
t Crit 1-tail	1.703	
P(T<=t) 2-t	0.241	
t Crit 2-tail	2.052	

Residuals about combined regression line **are not** significantly different between ponds and wetlands.

TOTAL COPPER

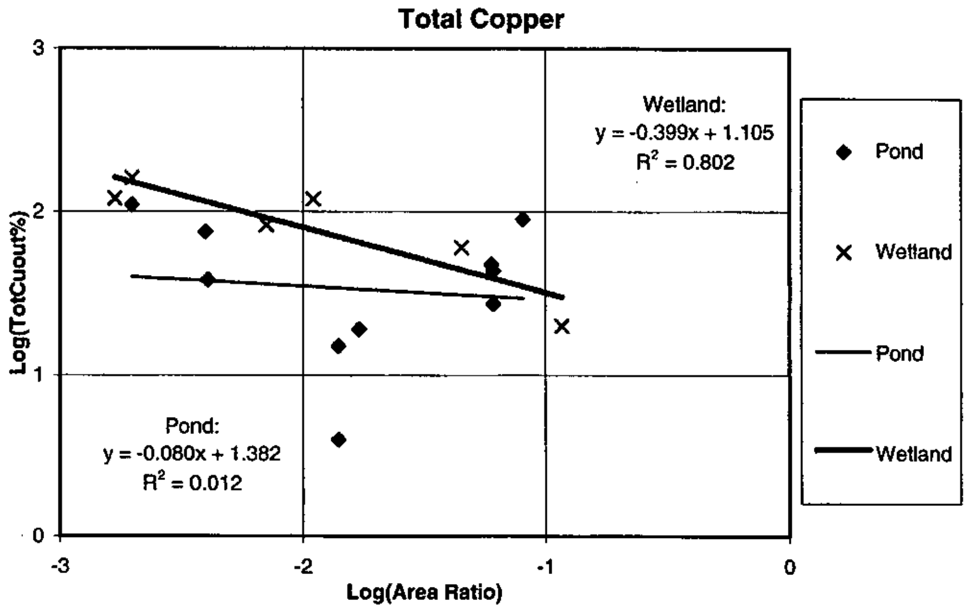
Combined regression line:

Regression Statistics	
Multiple R	0.401
R Square	0.161
Adj R Sq	0.101
Std Err	0.401
Obs	16

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.432	0.432	2.684	0.124
Residual	14	2.256	0.161		
Total	15	2.688			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.160	0.322	3.599	2.9E-03	0.469	1.852
Arearatio	-0.272	0.166	-1.638	0.124	-0.627	0.084



Group statistics:

	All Data	*Pond*	*Wetland*
Mean	1.662	1.524	1.893
Std Err	0.106	0.135	0.133
Median	1.725	1.607	1.997
Mode	#N/A	#N/A	#N/A
Std Dev	0.423	0.428	0.325
Sample Var	0.179	0.183	0.106
Kurtosis	1.071	1.257	2.162
Skewness	-1.020	-1.025	-1.447
Range	1.602	1.435	0.903
Minimum	0.602	0.602	1.301
Maximum	2.204	2.037	2.204
Sum	26.597	15.240	11.357
Count	16	10	6
95% Level	0.207	0.265	0.260

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.117	0.196
Variance	0.193	0.030
Obs	10	6
df	9	5
F	6.547	
P(F<=f) 1-t	0.026	
F Crit 1-tail	4.772	

t-Test: Two-Sample Assuming Unequal Variances

	Pond	*Wetland*
Mean	-0.117	0.196
Variance	0.193	0.030
Obs	10	6
Hyp mn diff	0	
df	13	
t Stat	-2.010	
P(T<=t) 1-t	0.033	
t Crit 1-tail	1.771	
P(T<=t) 2-t	0.066	
t Crit 2-tail	2.160	

Residuals about combined regression line **are** significantly different between ponds and wetlands.

ORTHOPHOSPHATE

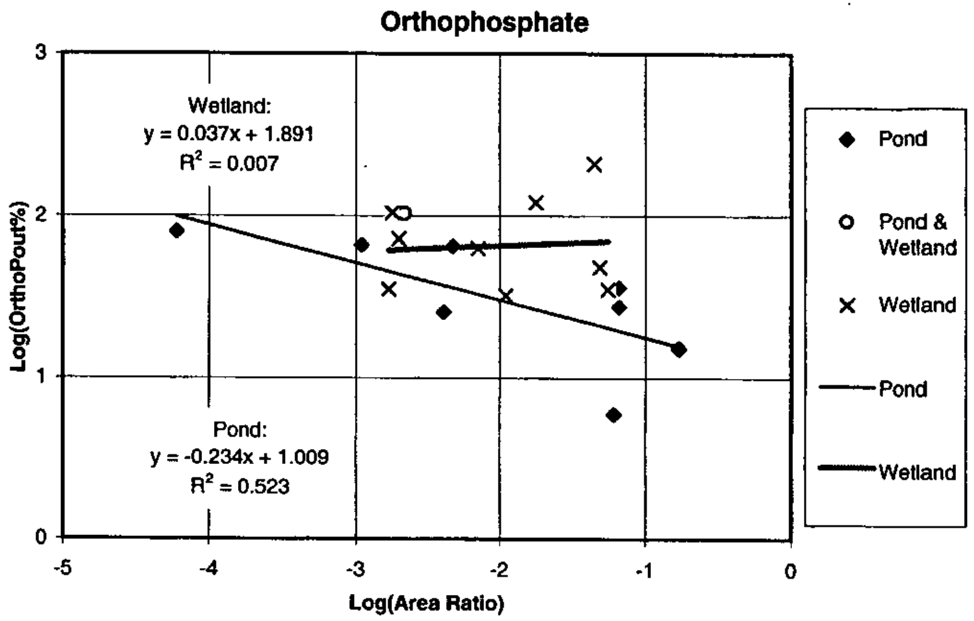
Combined regression line:

Regression Statistics	
Multiple R	0.424
R Square	0.180
Adj R Sq	0.129
Std Err	0.338
Obs	18

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.400	0.400	3.508	0.079
Residual	16	1.823	0.114		
Total	17	2.223			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.323	0.207	6.407	8.7E-06	0.885	1.761
Arearatio	-0.174	0.093	-1.873	0.079	-0.372	0.023



Group statistics:

	All Data	*Pond*	*Wetland*
Mean	1.680	1.484	1.817
Std Err	0.085	0.134	0.094
Median	1.740	1.494	1.799
Mode	1.544	#N/A	1.544
Std Dev	0.362	0.379	0.281
Sample Var	0.131	0.144	0.079
Kurtosis	1.106	0.307	-0.640
Skewness	-0.679	-0.825	0.584
Range	1.542	1.125	0.815
Minimum	0.778	0.778	1.505
Maximum	2.320	1.903	2.320
Sum	30.244	11.875	16.355
Count	18	8	9
95% Level	0.167	0.263	0.184

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.193	0.146
Variance	0.073	0.096
Obs	8	9
df	7	8
F	1.312	
P(F<=f) 1-t	0.367	
F Crit 1-tail	0.286	

t-Test: Two-Sample Assuming Equal Variances

	Pond	*Wetland*
Mean	-0.193	0.146
Variance	0.073	0.096
Obs	8	9
Pooled Var	0.086	
Hyp mn diff	0	
df	15	
t Stat	-2.382	
P(T<=t) 1-t	0.015	
t Crit 1-tail	1.753	
P(T<=t) 2-t	0.031	
t Crit 2-tail	2.131	

Residuals about combined regression line are significantly different between ponds and wetlands.

DISSOLVED PHOSPHORUS

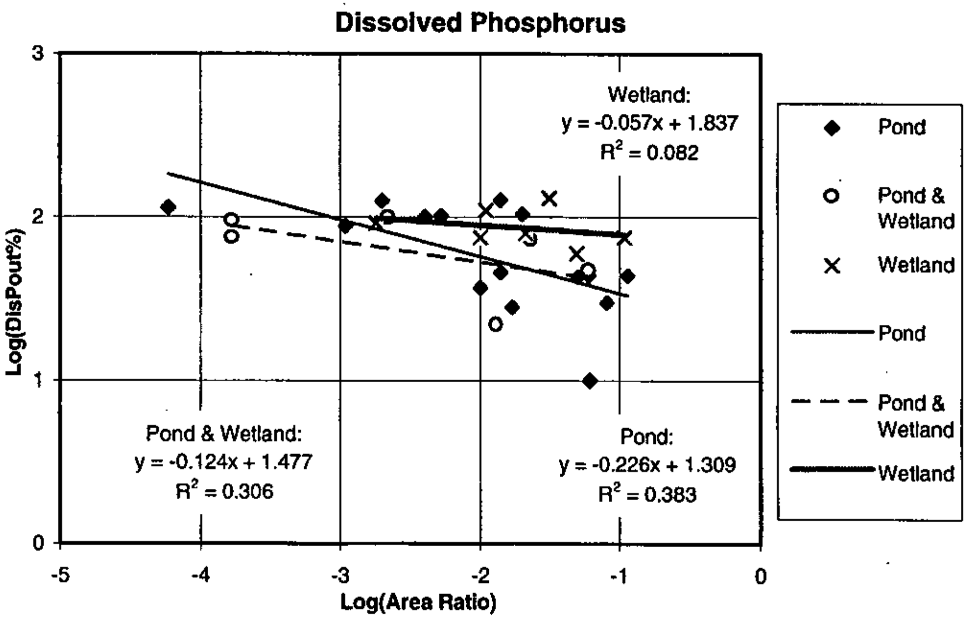
Combined regression line:

Regression Statistics	
Multiple R	0.470
R Square	0.221
Adj R Sq	0.191
Std Err	0.240
Obs	28

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.426	0.426	7.384	0.012
Residual	26	1.500	0.058		
Total	27	1.926			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.513	0.117	12.943	7.7E-13	1.273	1.754
Arearatio	-0.145	0.053	-2.717	0.012	-0.254	-0.035



Group statistics:

	All Data	*Pond*	*Pond/Wetl.*	*Wetland*
Mean	1.806	1.754	1.787	1.935
Std Err	0.050	0.081	0.101	0.043
Median	1.875	1.663	1.866	1.898
Mode	1.875	1.643	#N/A	1.875
Std Dev	0.267	0.315	0.246	0.114
Sample Var	0.071	0.099	0.061	0.013
Kurtosis	1.569	0.617	1.819	-0.382
Skewness	-1.220	-0.849	-1.446	0.417
Range	1.114	1.104	0.653	0.336
Minimum	1.000	1.000	1.342	1.778
Maximum	2.114	2.104	1.996	2.114
Sum	50.572	26.307	10.720	13.545
Count	28	15	6	7
95% Level	0.099	0.159	0.197	0.084

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.044	0.170
Variance	0.066	0.014
Obs	15	7
df	14	6
F	4.579	
P(F<=f) 1-t	0.036	
F Crit 1-tail	3.956	

t-Test: Two-Sample Assuming Unequal Variances

	Pond	*Wetland*
Mean	-0.044	0.170
Variance	0.066	0.014
Obs	15	7
Hyp mn diff	0	
df	20	
t Stat	-2.670	
P(T<=t) 1-t	0.007	
t Crit 1-tail	1.725	
P(T<=t) 2-t	0.015	
t Crit 2-tail	2.086	

Residuals about combined regression line **are** significantly different between ponds and wetlands.

Combined regression line:

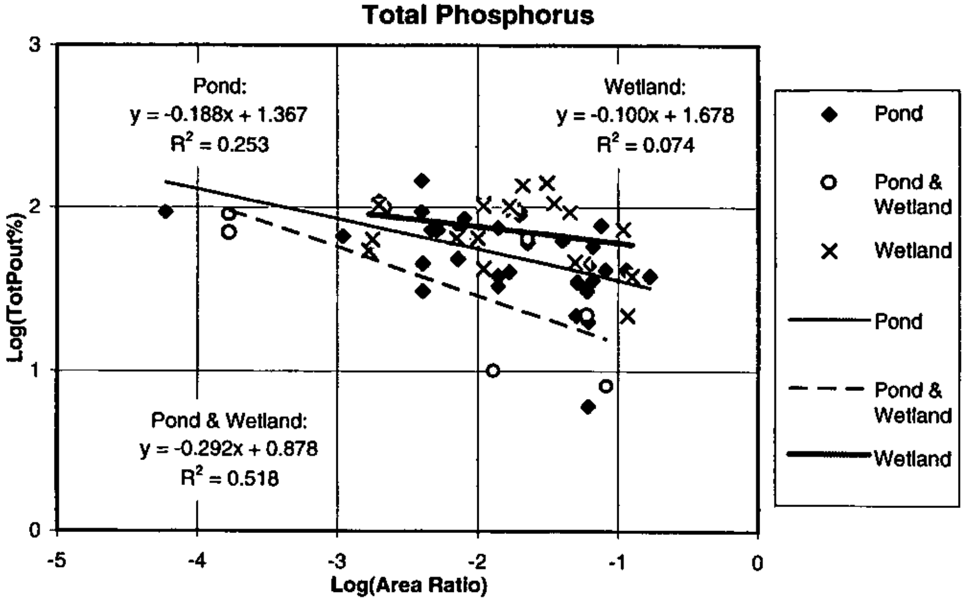
TOTAL PHOSPHORUS

Regression Statistics	
Multiple R	0.410
R Square	0.168
Adj R Sq	0.154
Std Err	0.264
Obs	60

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.821	0.821	11.752	1.1E-03
Residual	58	4.053	0.070		
Total	59	4.874			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.437	0.094	15.299	5.1E-22	1.249	1.625
Arearatio	-0.162	0.047	-3.428	1.1E-03	-0.256	-0.067



Group statistics:

	All Data	*Pond*	*Pond/Wetl.*	*Wetland*
Mean	1.736	1.710	1.548	1.853
Std Err	0.037	0.045	0.174	0.049
Median	1.799	1.767	1.799	1.863
Mode	1.580	1.857	#N/A	1.806
Std Dev	0.287	0.261	0.460	0.214
Sample Var	0.083	0.068	0.212	0.046
Kurtosis	2.078	3.703	-1.835	0.059
Skewness	-1.261	-1.333	-0.581	-0.662
Range	1.392	1.392	1.093	0.813
Minimum	0.778	0.778	0.903	1.342
Maximum	2.170	2.170	1.996	2.155
Sum	104.189	58.147	10.834	35.208
Count	60	34	7	19
95% Level	0.073	0.088	0.341	0.096

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.022	0.135
Variance	0.051	0.044
Obs	34	19
df	33	18
F	1.166	
P(F<=f) 1-t	0.373	
F Crit 1-tail	2.091	

t-Test: Two-Sample Assuming Equal Variances

	Pond	*Wetland*
Mean	-0.022	0.135
Variance	0.051	0.044
Obs	34	19
Pooled Var	0.049	
Hyp mn diff	0	
df	51	
t Stat	-2.490	
P(T<=t) 1-t	0.008	
t Crit 1-tail	1.675	
P(T<=t) 2-t	0.016	
t Crit 2-tail	2.008	

Residuals about combined regression line **are** significantly different between ponds and wetlands.

Combined regression line:

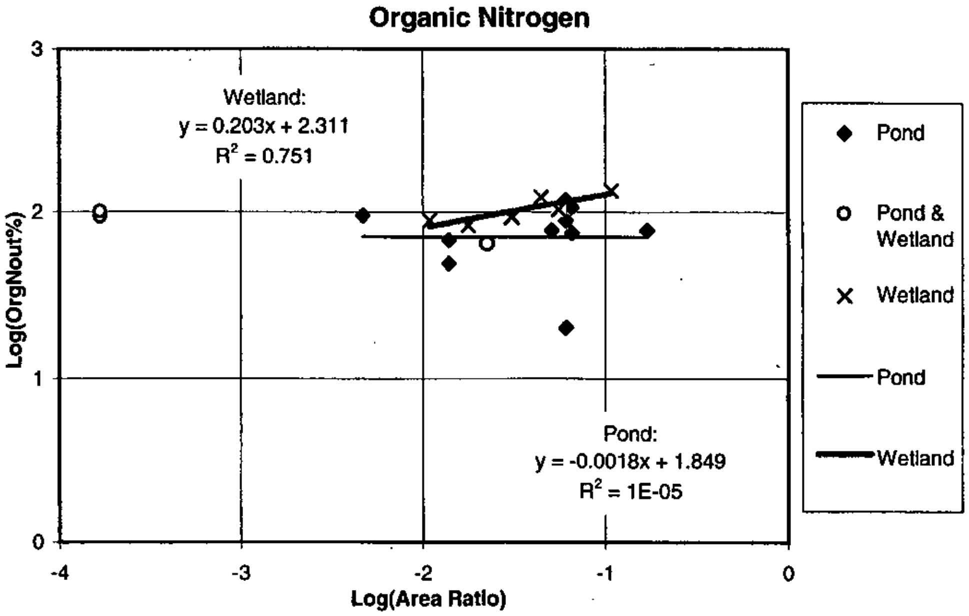
ORGANIC NITROGEN

Regression Statistics	
Multiple R	0.081
R Square	0.007
Adj R Sq	-0.052
Std Err	0.187
Obs	19

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.004	0.004	0.113	0.741
Residual	17	0.594	0.035		
Total	18	0.597			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.885	0.100	18.901	7.5E-13	1.674	2.095
Arearatio	-0.018	0.053	-0.335	0.741	-0.130	0.095



Group statistics:

	All Data	*Pond*	*Pond/Wetl.*	*Wetland*
Mean	1.915	1.852	1.926	2.014
Std Err	0.042	0.070	0.061	0.034
Median	1.949	1.892	1.973	1.993
Mode	1.892	1.892	#N/A	#N/A
Std Dev	0.182	0.221	0.105	0.084
Sample Var	0.033	0.049	0.011	0.007
Kurtosis	6.919	4.437	#DIV/0!	-1.525
Skewness	-2.261	-1.937	-1.605	0.558
Range	0.833	0.775	0.194	0.209
Minimum	1.301	1.301	1.806	1.924
Maximum	2.134	2.076	2.000	2.134
Sum	36.380	18.515	5.779	12.086
Count	19	10	3	6
95% Level	0.082	0.137	0.119	0.067

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.058	0.104
Variance	0.049	0.008
Obs	10	6
df	9	5
F	6.168	
P(F<=f) 1-t	0.030	
F Crit 1-tail	4.772	

t-Test: Two-Sample Assuming Unequal Variances

	Pond	*Wetland*
Mean	-0.058	0.104
Variance	0.049	0.008
Obs	10	6
Hyp mn diff	0	
df	13	
t Stat	-2.052	
P(T<=t) 1-t	0.030	
t Crit 1-tail	1.771	
P(T<=t) 2-t	0.061	
t Crit 2-tail	2.160	

Residuals about combined regression line **are** significantly different between ponds and wetlands.

Combined regression line:

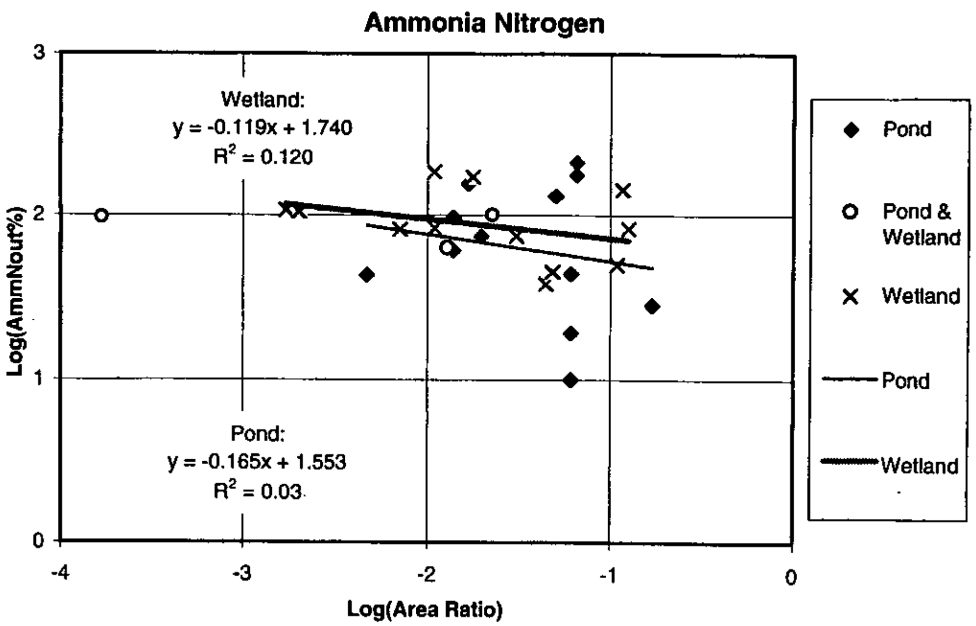
AMMONIA NITROGEN

Regression Statistics	
Multiple R	0.240
R Square	0.058
Adj R Sq	0.021
Std Err	0.306
Obs	28

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.149	0.149	1.590	0.218
Residual	26	2.431	0.094		
Total	27	2.580			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.709	0.146	11.705	7.3E-12	1.409	2.009
Arearatio	-0.097	0.077	-1.261	0.218	-0.255	0.061



Group statistics:

	All Data	*Pond*	*Pond/Wetl.*	*Wetland*
Mean	1.878	1.795	1.943	1.940
Std Err	0.058	0.119	0.048	0.064
Median	1.922	1.827	1.987	1.922
Mode	1.987	#N/A	1.987	#N/A
Std Dev	0.309	0.412	0.096	0.221
Sample Var	0.096	0.170	0.009	0.049
Kurtosis	1.195	-0.492	3.920	-0.777
Skewness	-0.968	-0.523	-1.974	-0.114
Range	1.330	1.330	0.201	0.690
Minimum	1.000	1.000	1.799	1.580
Maximum	2.330	2.330	2.000	2.270
Sum	52.596	21.539	7.773	23.285
Count	28	12	4	12
95% Level	0.114	0.233	0.094	0.125

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.056	0.068
Variance	0.166	0.043
Obs	12	12
df	11	11
F	3.847	
P(F<=f) 1-t	0.017	
F Crit 1-tail	2.818	

t-Test: Two-Sample Assuming Unequal Variances

	Pond	*Wetland*
Mean	-0.056	0.068
Variance	0.166	0.043
Obs	12	12
Hyp mn diff	0	
df	16	
t Stat	-0.940	
P(T<=t) 1-t	0.181	
t Crit 1-tail	1.746	
P(T<=t) 2-t	0.361	
t Crit 2-tail	2.120	

Residuals about combined regression line **are not** significantly different between ponds and wetlands.

Combined regression line:

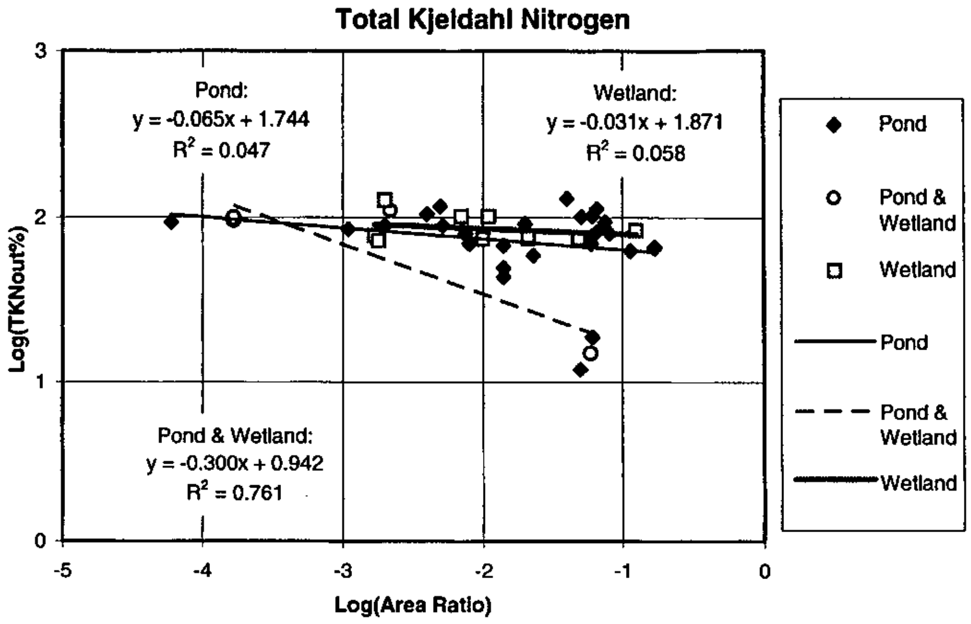
TOTAL KJELDAHL NITROGEN

Regression Statistics	
Multiple R	0.307
R Square	0.094
Adj R Sq	0.070
Std Err	0.216
Obs	40

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.184	0.184	3.940	0.054
Residual	38	1.770	0.047		
Total	39	1.954			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.710	0.087	19.675	1.6E-21	1.534	1.886
Arearatio	-0.083	0.042	-1.985	0.054	-0.167	0.002



Group statistics:

	All Data	*Ponds*	*Pond/Wetl.*	*Wetland*
Mean	1.869	1.857	1.798	1.934
Std Err	0.035	0.043	0.208	0.028
Median	1.911	1.908	1.987	1.892
Mode	2.004	1.908	#N/A	2.004
Std Dev	0.224	0.225	0.415	0.085
Sample Var	0.050	0.051	0.172	0.007
Kurtosis	5.762	5.906	3.920	0.393
Skewness	-2.351	-2.285	-1.975	1.156
Range	1.038	1.038	0.865	0.246
Minimum	1.079	1.079	1.176	1.857
Maximum	2.117	2.117	2.041	2.104
Sum	74.741	50.145	7.191	17.406
Count	40	27	4	9
95% Level	0.069	0.085	0.407	0.055

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	0.0030	0.057
Variance	0.048	0.008
Obs	27	9
df	26	8
F	6.112	
P(F<=f) 1-t	0.006	
F Crit 1-tail	3.102	

t-Test: Two-Sample Assuming Unequal Variances

	Pond	*Wetland*
Mean	0.0030	0.057
Variance	0.048	0.008
Obs	27	9
Hyp mn diff	0	
df	32	
t Stat	-1.040	
P(T<=t) 1-t	0.153	
t Crit 1-tail	1.694	
P(T<=t) 2-t	0.306	
t Crit 2-tail	2.037	

Residuals about combined regression line **are not** significantly different between ponds and wetlands.

Combined regression line:

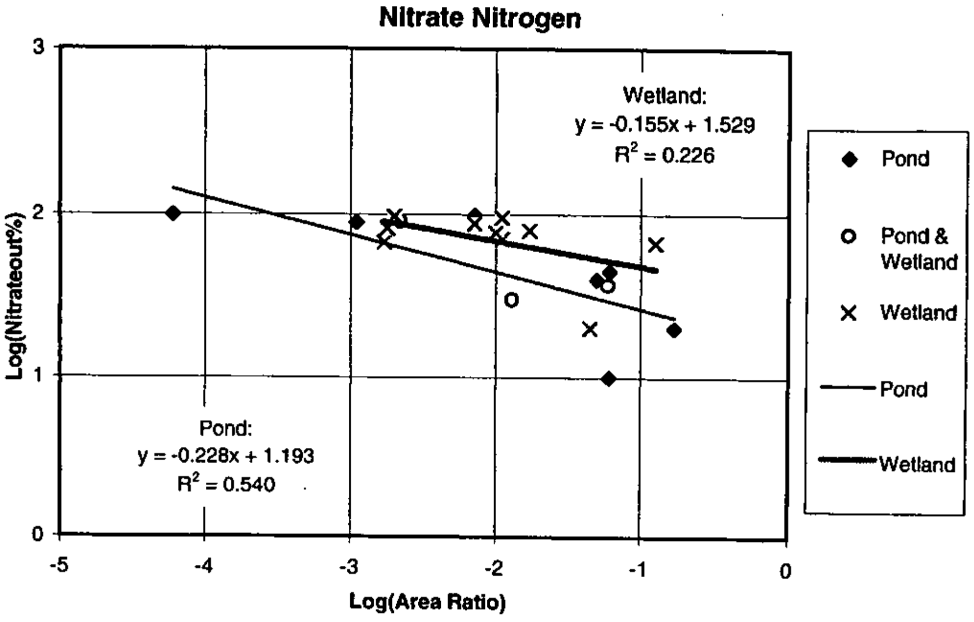
NITRATE NITROGEN

Regression Statistics	
Multiple R	0.644
R Square	0.415
Adj R Sq	0.382
Std Err	0.225
Obs	20

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.644	0.644	12.745	2.2E-03
Residual	18	0.909	0.051		
Total	19	1.553			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.312	0.132	9.947	9.7E-09	1.035	1.589
Arearatio	-0.218	0.061	-3.570	2.2E-03	-0.347	-0.090



Group statistics:

	All Data	*Pond*	*Pond/Wetl.*	*Wetland*
Mean	1.747	1.642	1.668	1.844
Std Err	0.064	0.144	0.148	0.063
Median	1.872	1.653	1.568	1.898
Mode	1.301	1.996	#N/A	#N/A
Std Dev	0.286	0.382	0.256	0.199
Sample Var	0.082	0.146	0.066	0.040
Kurtosis	0.993	-0.484	#DIV/0!	7.836
Skewness	-1.317	-0.788	1.489	-2.679
Range	0.996	0.996	0.482	0.690
Minimum	1.000	1.000	1.477	1.301
Maximum	1.996	1.996	1.959	1.991
Sum	34.944	11.497	5.004	18.443
Count	20	7	3	10
95% Level	0.125	0.283	0.290	0.124

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.101	0.089
Variance	0.067	0.032
Obs	7	10
df	6	9
F	2.086	
P(F<=f) 1-t	0.155	
F Crit 1-tail	3.374	

t-Test: Two-Sample Assuming Equal Variances

	Pond	*Wetland*
Mean	-0.101	0.089
Variance	0.067	0.032
Obs	7	10
Pooled Var	0.046	
Hyp mn diff	0	
df	15	
t Stat	-1.792	
P(T<=t) 1-t	0.047	
t Crit 1-tail	1.753	
P(T<=t) 2-t	0.093	
t Crit 2-tail	2.131	

Residuals about combined regression line **are** significantly different between ponds and wetlands.

Combined regression line:

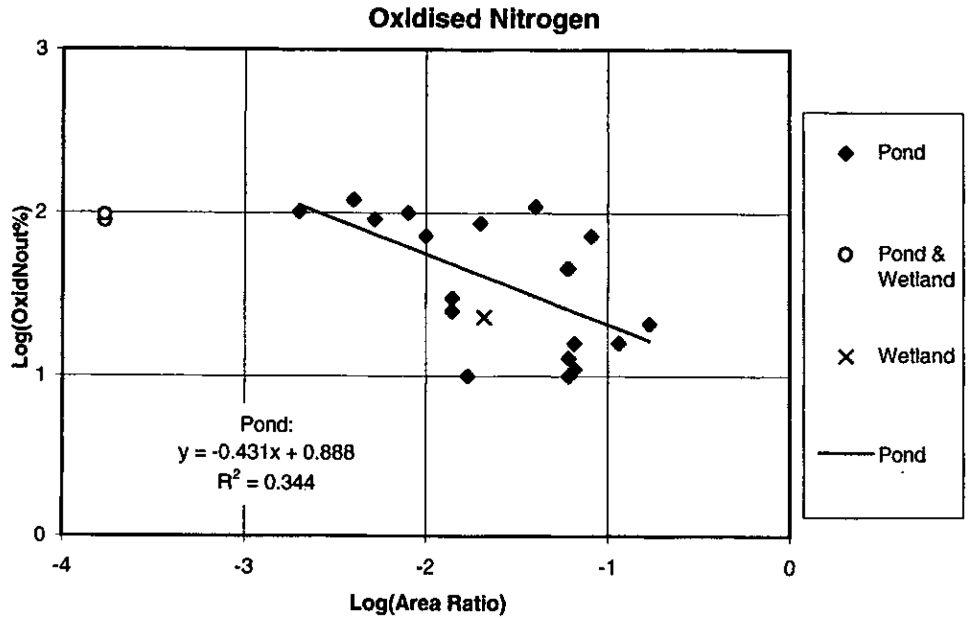
OXIDISED NITROGEN

Regression Statistics	
Multiple R	0.581
R Square	0.337
Adj R Sq	0.304
Std Err	0.325
Obs	22

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	1.072	1.072	10.180	4.6E-03
Residual	20	2.107	0.105		
Total	21	3.179			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.101	0.170	6.470	2.6E-06	0.746	1.456
Arearatio	-0.278	0.087	-3.191	4.6E-03	-0.459	-0.096



Group statistics:

	All Data	*Pond*
Mean	1.597	1.570
Std Err	0.083	0.091
Median	1.663	1.663
Mode	1.204	1.204
Std Dev	0.389	0.397
Sample Var	0.151	0.157
Kurtosis	-1.577	-1.645
Skewness	-0.276	-0.172
Range	1.079	1.079
Minimum	1.000	1.000
Maximum	2.079	2.079
Sum	35.127	29.829
Count	22	19
95% Level	0.163	0.178

Insufficient data for comparative analysis.

Combined regression line:

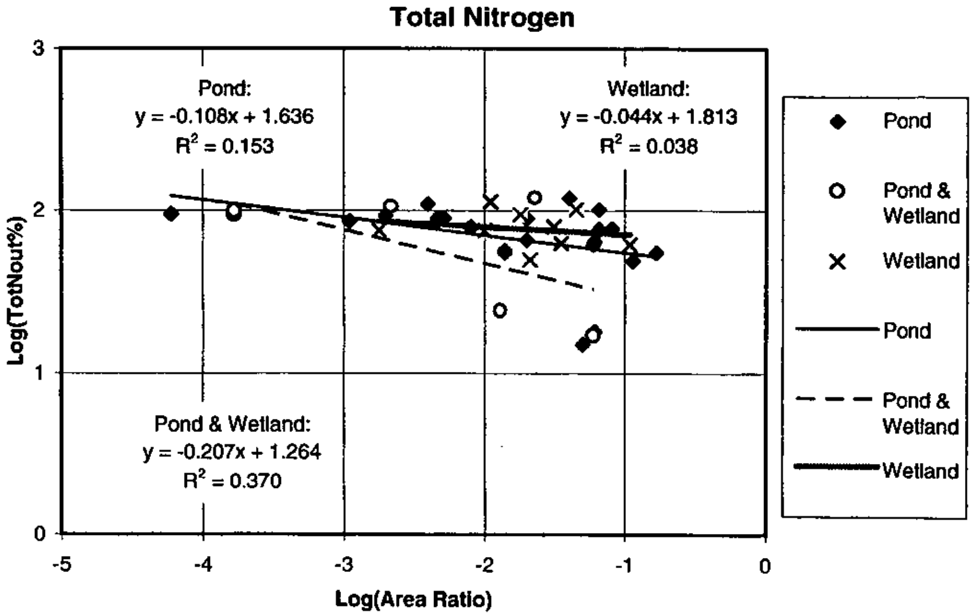
TOTAL NITROGEN

Regression Statistics	
Multiple R	0.375
R Square	0.140
Adj R Sq	0.117
Std Err	0.213
Obs	38

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.266	0.266	5.883	0.020
Residual	36	1.629	0.045		
Total	37	1.896			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.639	0.087	18.762	3.6E-20	1.462	1.817
Arearatio	-0.104	0.043	-2.426	0.020	-0.191	-0.017



Group statistics:

	All Data	*Pond*	*Pond/Wetl.*	*Wetland*
Mean	1.834	1.827	1.780	1.889
Std Err	0.037	0.046	0.152	0.038
Median	1.889	1.886	1.982	1.881
Mode	1.954	1.954	#N/A	1.881
Std Dev	0.226	0.219	0.372	0.114
Sample Var	0.051	0.048	0.139	0.013
Kurtosis	2.719	4.268	-1.457	-0.598
Skewness	-1.748	-1.999	-0.995	-0.136
Range	0.903	0.903	0.849	0.358
Minimum	1.176	1.176	1.230	1.699
Maximum	2.079	2.079	2.079	2.057
Sum	69.697	42.019	10.679	16.999
Count	38	23	6	9
95% Level	0.072	0.089	0.298	0.075

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	0.003	0.071
Variance	0.041	0.013
Obs	23	9
df	22	8
F	3.016	
P(F<=f) 1-t	0.056	
F Crit 1-tail	3.131	

t-Test: Two-Sample Assuming Equal Variances

	Pond	*Wetland*
Mean	0.003	0.071
Variance	0.041	0.013
Obs	23	9
Pooled Var	0.033	
Hyp mn diff	0	
df	30	
t Stat	-0.954	
P(T<=t) 1-t	0.174	
t Crit 1-tail	1.697	
P(T<=t) 2-t	0.348	
t Crit 2-tail	2.042	

Residuals about combined regression line **are not** significantly different between ponds and wetlands.

CHEMICAL OXYGEN DEMAND

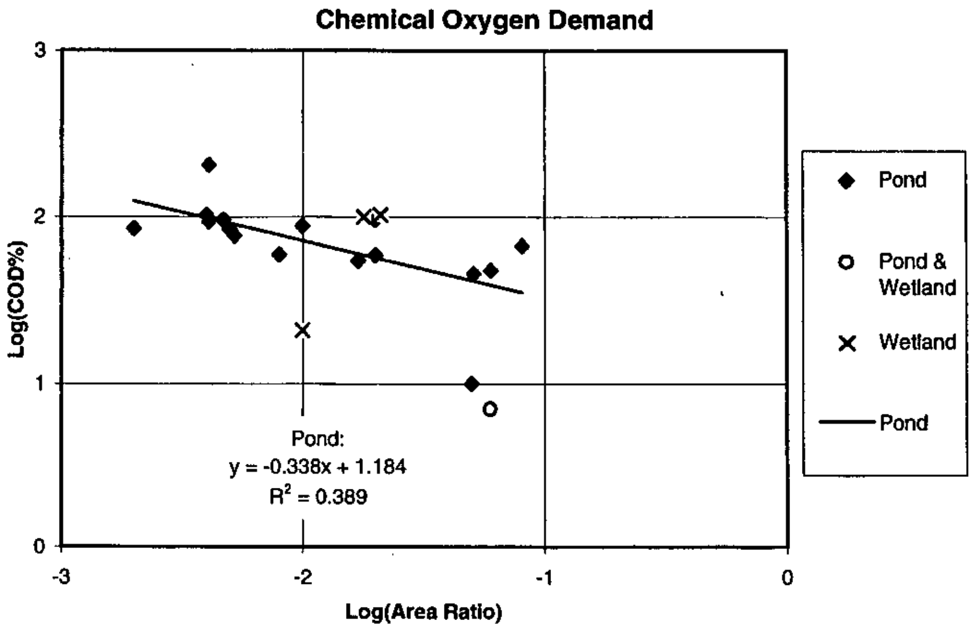
Combined regression line:

Regression Statistics	
Multiple R	0.568
R Square	0.322
Adj R Sq	0.285
Std Err	0.298
Obs	20

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.760	0.760	8.568	9.0E-03
Residual	18	1.597	0.089		
Total	19	2.358			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.995	0.276	3.608	2.0E-03	0.416	1.575
Arearatio	-0.417	0.142	-2.927	9.0E-03	-0.716	-0.118



Group statistics:

	All Data	*Pond*	*Wetland*
Mean	1.779	1.838	1.778
Std Err	0.079	0.068	0.228
Median	1.905	1.905	2.000
Mode	1.982	1.982	#N/A
Std Dev	0.352	0.273	0.395
Sample Var	0.124	0.075	0.156
Kurtosis	2.412	6.090	#DIV/0!
Skewness	-1.555	-1.778	-1.730
Range	1.467	1.312	0.691
Minimum	0.845	1.000	1.322
Maximum	2.312	2.312	2.013
Sum	35.582	29.402	5.335
Count	20	16	3
95% Level	0.154	0.134	0.447

Insufficient data for comparative analysis.

Combined regression line:

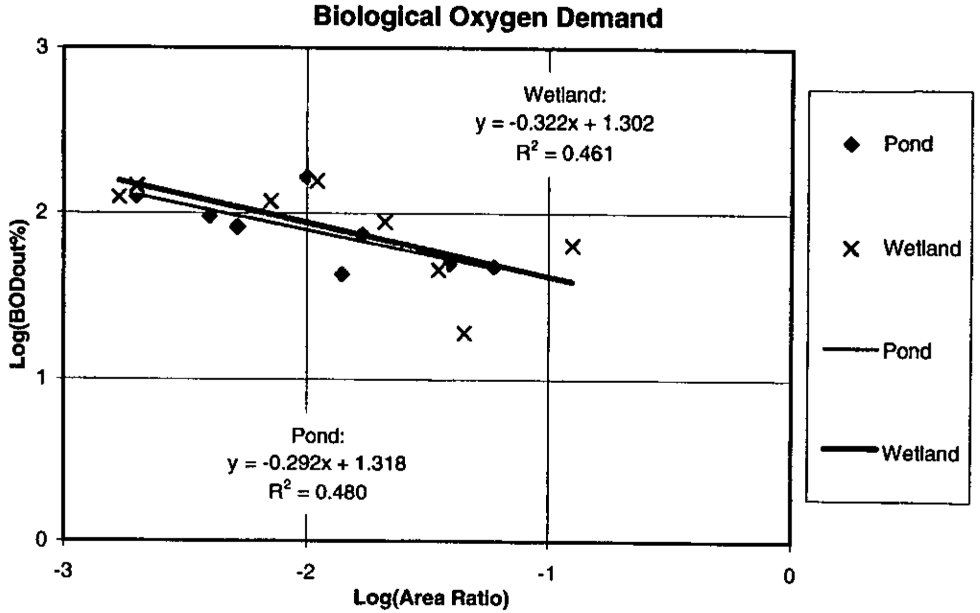
BIOLOGICAL OXYGEN DEMAND

Regression Statistics	
Multiple R	0.678
R Square	0.459
Adj R Sq	0.421
Std Err	0.195
Obs	16

ANOVA

	df	*SS*	*MS*	*F*	*Sig F*
Regression	1	0.453	0.453	11.886	3.9E-03
Residual	14	0.534	0.038		
Total	15	0.987			

	Coefficient	*Std Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.307	0.178	7.355	3.6E-06	0.926	1.688
Arearatio	-0.308	0.089	-3.448	3.9E-03	-0.500	-0.116



Group statistics:

	All Data	*Pond*	*Wetland*
Mean	1.896	1.889	1.904
Std Err	0.064	0.074	0.110
Median	1.934	1.897	2.011
Mode	#N/A	#N/A	#N/A
Std Dev	0.257	0.210	0.311
Sample Var	0.066	0.044	0.097
Kurtosis	0.558	-1.103	1.330
Skewness	-0.822	0.293	-1.295
Range	0.941	0.587	0.917
Minimum	1.279	1.633	1.279
Maximum	2.220	2.220	2.196
Sum	30.343	15.111	15.233
Count	16	8	8
95% Level	0.126	0.146	0.216

Residuals about combined regression line:

F-Test Two-Sample for Variances

	Pond	*Wetland*
Mean	-0.021	0.021
Variance	0.023	0.052
Obs	8	8
df	7	7
F	2.276	
P(F<=f) 1-t	0.150	
F Crit 1-tail	0.264	

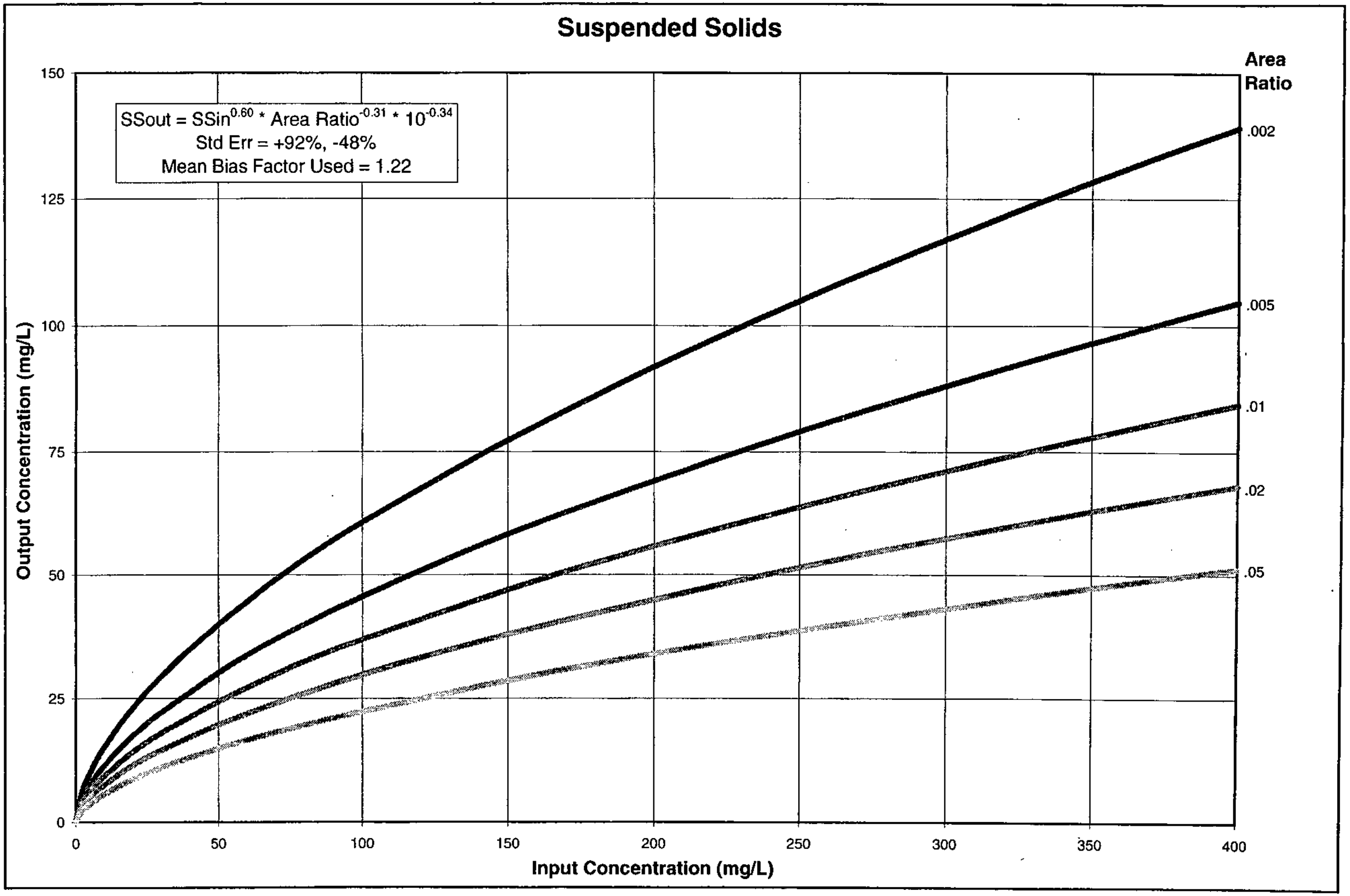
t-Test: Two-Sample Assuming Equal Variances

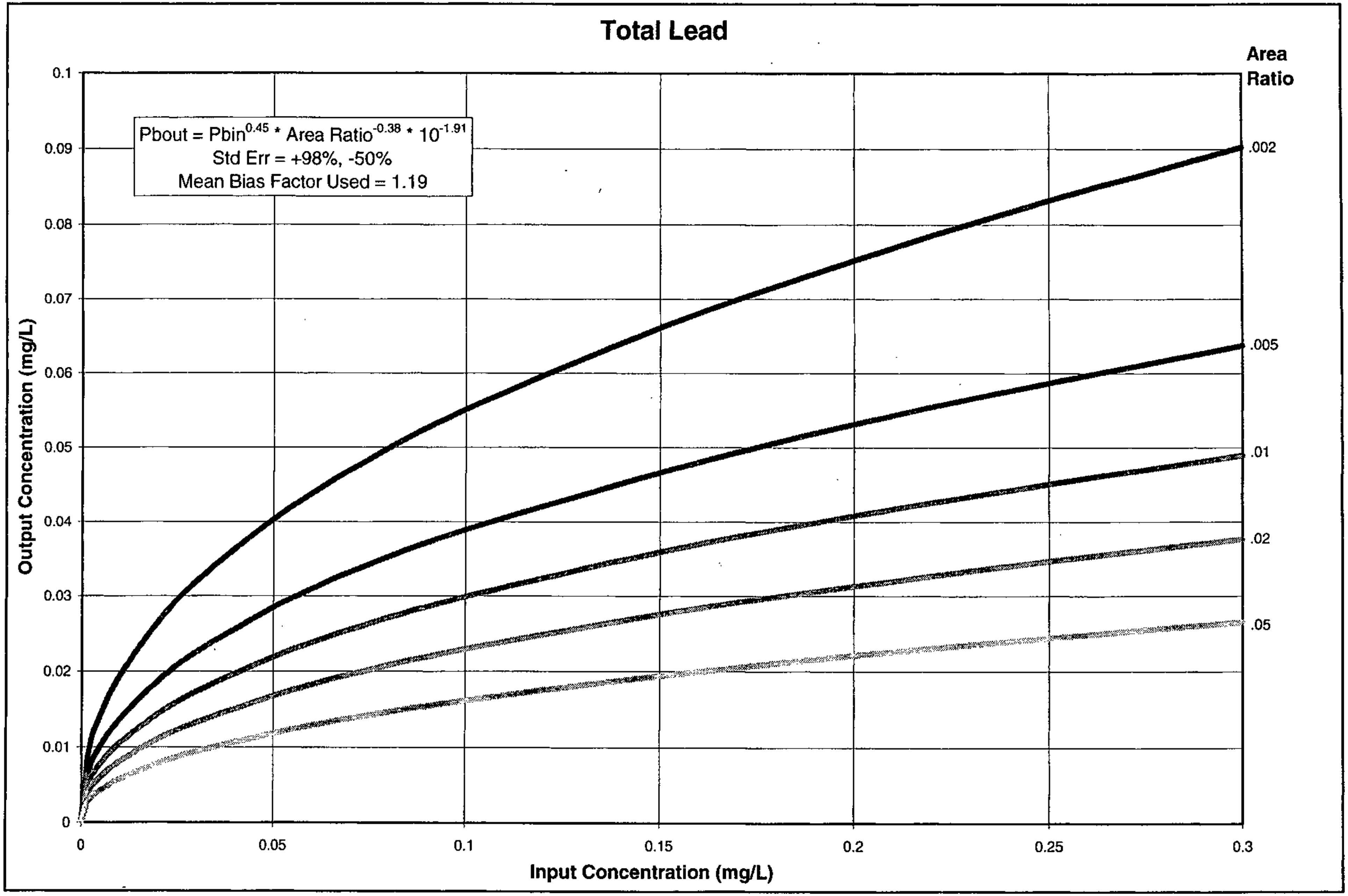
	Pond	*Wetland*
Mean	-0.021	0.021
Variance	0.023	0.052
Obs	8	8
Pooled Var	0.038	
Hyp mn diff	0	
df	14	
t Stat	-0.427	
P(T<=t) 1-t	0.338	
t Crit 1-tail	1.761	
P(T<=t) 2-t	0.676	
t Crit 2-tail	2.145	

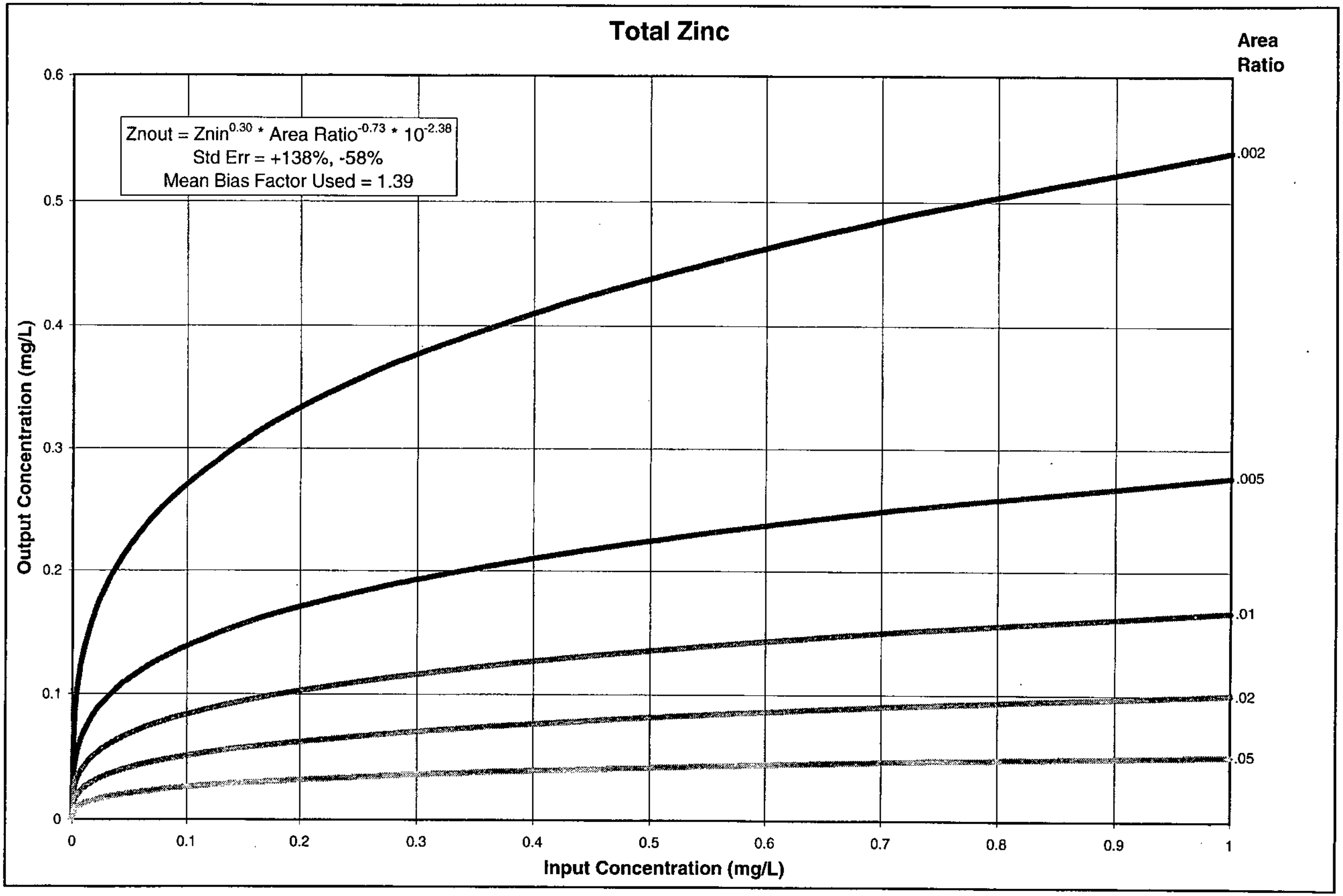
Residuals about combined regression line **are not** significantly different between ponds and wetlands.

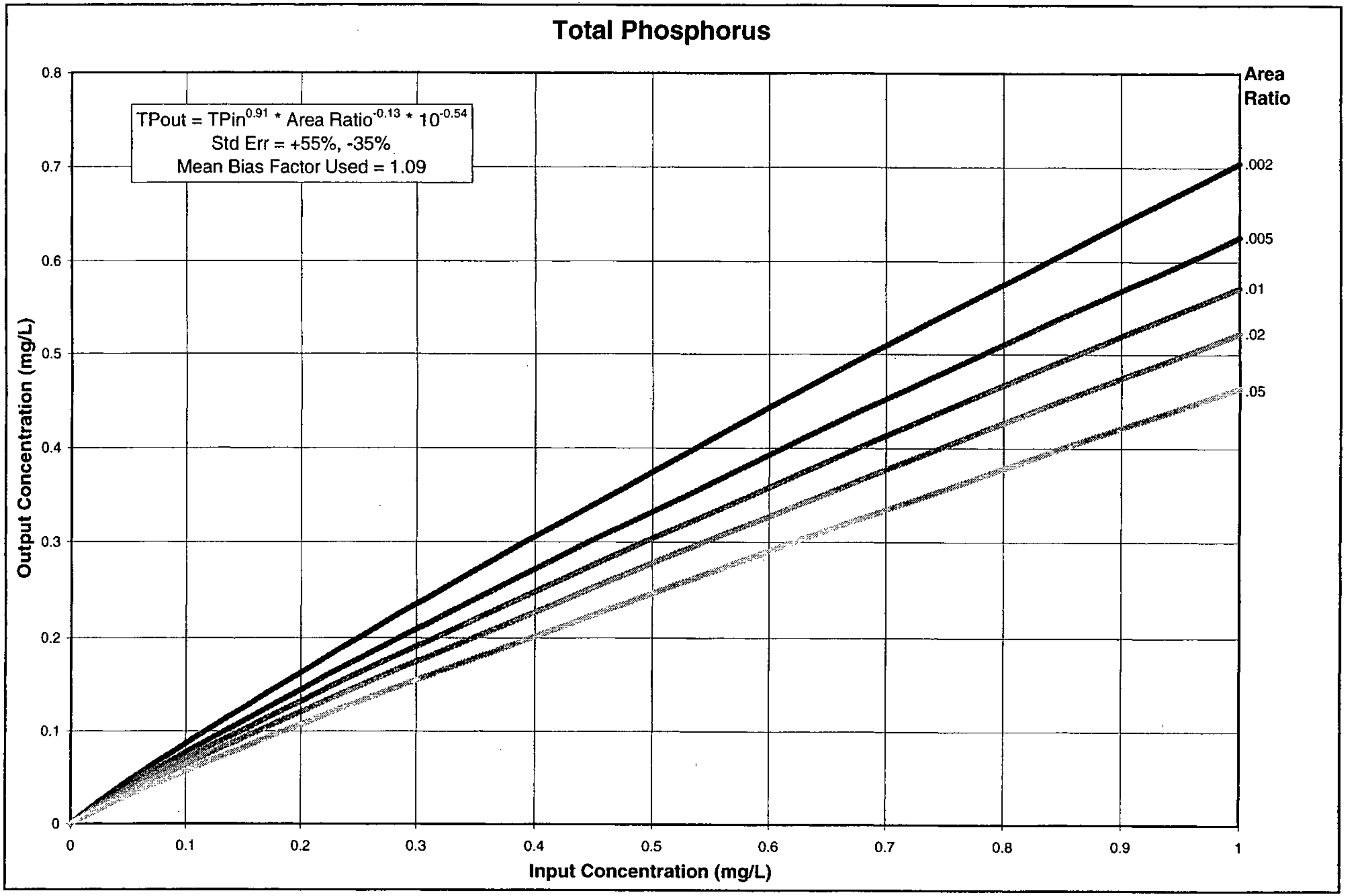
APPENDIX F

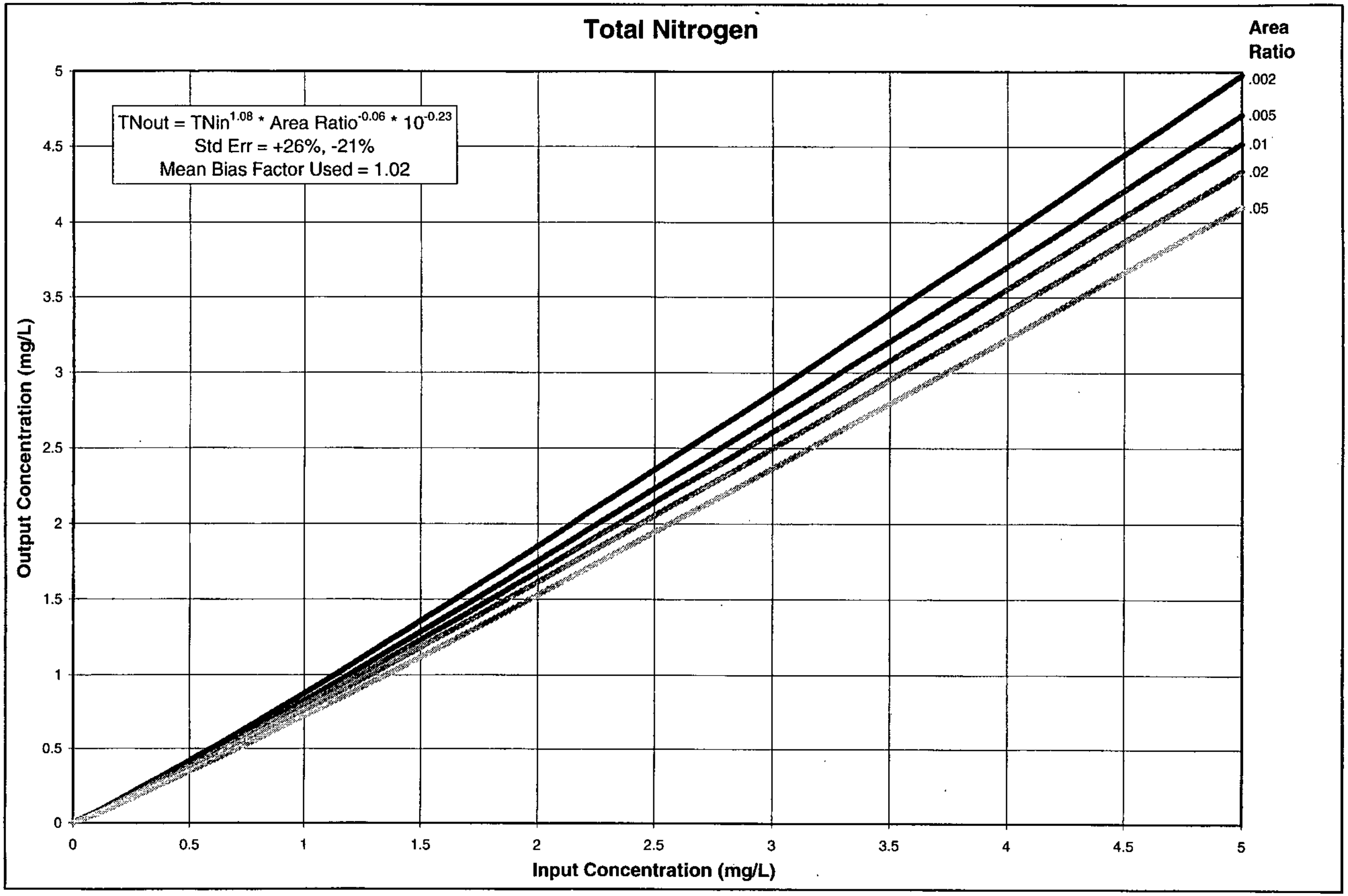
Performance Curves

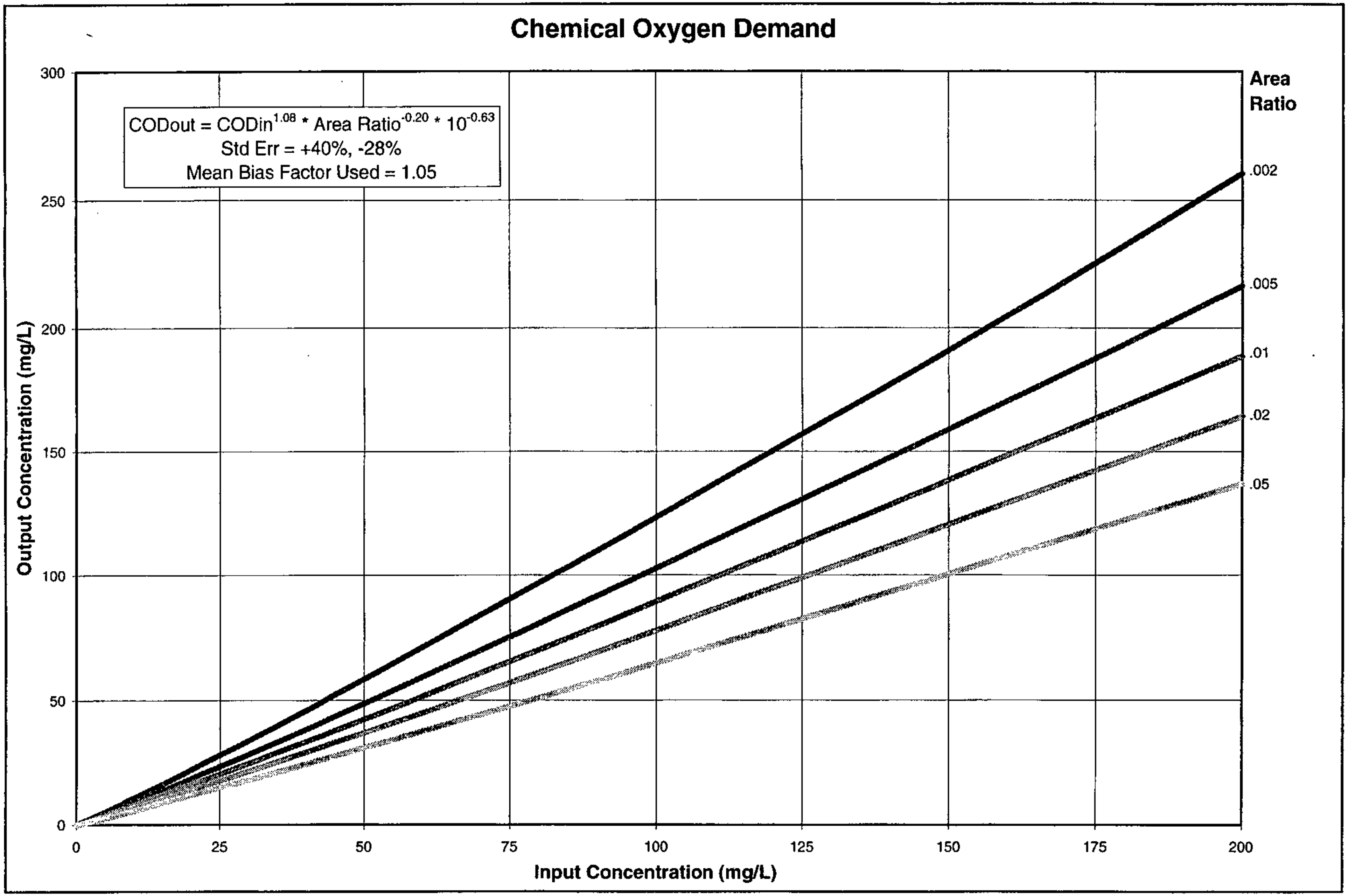

Suspended Solids
$SSout = SSin^{0.60} * Area\ Ratio^{-0.31} * 10^{-0.34}$
Std Err = +92%, -48%
Mean Bias Factor Used = 1.22
Area Ratio
.002
.005
.01
.02
.05
Output Concentration (mg/L)
0
25
50
75
100
125
150
Input Concentration (mg/L)
0
50
100
150
200
250
300
350
400


Total Lead
Pbout = Pbin$^{0.45}$ * Area Ratio$^{-0.38}$ * 10$^{-1.91}$
Std Err = +98%, -50%
Mean Bias Factor Used = 1.19
Area Ratio
.002
.005
.01
.02
.05
Output Concentration (mg/L)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Input Concentration (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0.3


Total Zinc
Area Ratio
$Znout = Znin^{0.30} * Area Ratio^{-0.73} * 10^{-2.38}$
Std Err = +138%, -58%
Mean Bias Factor Used = 1.39
.002
.005
.01
.02
.05
Output Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
Input Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Total Phosphorus
TPout = TPin^0.91 * Area Ratio^-0.13 * 10^-0.54
Std Err = +55%, -35%
Mean Bias Factor Used = 1.09
Area Ratio
.002
.005
.01
.02
.05
Output Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Input Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Total Nitrogen
TNout = TNin^1.08 * Area Ratio^-0.06 * 10^-0.23
Std Err = +26%, -21%
Mean Bias Factor Used = 1.02
Area Ratio
.002
.005
.01
.02
.05
Output Concentration (mg/L)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Input Concentration (mg/L)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5


Chemical Oxygen Demand
$\text{CODout} = \text{CODin}^{1.08} * \text{Area Ratio}^{-0.20} * 10^{-0.63}$
Std Err = +40%, -28%
Mean Bias Factor Used = 1.05
Area Ratio
.002
.005
.01
.02
.05
Output Concentration (mg/L)
0
50
100
150
200
250
300
Input Concentration (mg/L)
0
25
50
75
100
125
150
175
200

The Cooperative Research Centre for Catchment Hydrology
is a cooperative venture formed under the Commonwealth CRC Program between:

Bureau of Meteorology

CSIRO Division of Water Resources

Department of Natural Resources and Environment

Goulburn-Murray Water

Melbourne Water

Monash University

Murray-Darling Basin Commission

Southern Rural Water

The University of Melbourne

Wimmera-Mallee Water

Associates
CSIRO Division of Soils
State Forests of NSW

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

Centre Office
Department of Civil Engineering, Monash University, Clayton, Victoria 3168, Australia.
Telephone: (03) 9905 2704 Facsimile: (03) 9905 5033 International: +61 3 9905 2704
http://www-civil.eng.monash.edu.au/centres/crcch/