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NUTRIENT PRECIPITATION IN THE NORTHERN PART OF LAKE TANGANYIKA

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PREFACE

The Research for the Management of the Fisheries on Lake Tanganyika project (LTR) became fully operational in January 1992. It is executed by the Food and Agriculture Organization of the United Nations (FAO) and funded by the Finnish International Development Agency (FINNIDA) and the Arab Gulf Program for the United Nations Development Organization (AGFUND).

LTR’s objective is the determination of the biological basis for fish production on Lake Tanganyika, in order to permit the formulation of a coherent lake-wide fisheries management policy for the four riparian States (Burundi, Tanzania, D.R. of Congo and Zambia).

Particular attention is given to the reinforcement of the skills and physical facilities of the fisheries research units in all four beneficiary countries as well as to the build-up of effective coordination mechanisms to ensure full collaboration between the Governments concerned.

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SUMMARY

Analyses of rainwater collected during the rainy season of October 1994 to June 1995 showed that rainwater can contain considerable amounts of Nitrogen and Phosphorus. Concentrations of Nitrogen showed the strongest positive correlation with the rainwater turbidity.

Most values for the parameters measured decrease in course of the rainy season and in course of a shower. These findings were hardly ever incorporated in earlier published material about rainwater chemistry.

It is suggested that for areas around Lake Tanganyika, biomass burning and soil exposure (agriculture, deforestation) are the largest contributors to atmospheric loading of Nitrogen and Phosphorus, and are the dominant factors influencing rainwater chemistry.

The monthly depositions of nutrients were positive correlated with the monthly amount of rain fallen. It is suggested that for Lake Tanganyika the months with the highest amount of rain are periods of significant external nutrient loading, which could induce phytoplankton growth.

Precipitation of rain and dust is likely one of the most important abiological source of nitrogen in Lake Tanganyika.

1 INTRODUCTION

In the past, study on the influx of nutrients trough precipitation to various ecosystems has been underestimated or even neglected when determining nutrient balances.

Recently, an increasing concern over acid deposition and its effect on ecosystem functioning has resulted in an increasing number of studies on the chemical composition of precipitation, especially in the more industrialised countries.

Through these studies it has become clear that atmospheric input can account for a significant proportion of the nutrient flux into lakes (Schindler *et al.,* 1976; Galbally and Gillett, 1988; Pedrozo *et al.,* 1993), terrestrial ecosystems (Lindberg *et al.,* 1986; Franzen *et al.,* 1994) and marine environments (Caddy and Bakun, 1994; Kubilay and Saydam, 1995) directly enhancing biological activity and influencing algal and fish production.

Furthermore, it has become clear that also non-industrial activities can have a large impact on atmospheric chemistry in other regions of the world. In particular vegetation burning and deforestation in the tropics has been shown to greatly increase flux rates of C, N, S and K trough the atmosphere (Lewis 1981, Galbally and Gillett, 1988).

Data on precipitation chemistry in Africa is limited to a small number of studies. However, through these studies it has become clear that in some regions there have been apparent changes in the chemical composition of precipitation during the last few decades, possibly due to intensified anthropogenic activities (Bootsma *et al.,* 1996).

Here we present data on the chemical composition of rain in the Northern part of Lake Tanganyika, with the objectives of: 1) determining the chemical composition of precipitation throughout the rainy season of 1994-1995 and during a shower, 2) estimating the total amount nutrients deposited during one year and 3) assessing the importance of atmospheric deposition as a nutrient source to the Great Rift Lake Tanganyika.

2 METHODOLOGY

Rain water samples were collected during the 1994-1995 rainy season, just outside LTR’s headquarters in Bujumbura, Burundi (Figure 1).

Samples were collected by four intersected polyethylene pipes (13 cm wide) with a rain water catching surface of about 1.5 m^2, which were slightly sloped towards a central positioned collecting bucket. At the start of each precipitation event and before any rainwater was collected the whole installation was cleaned, acid washed twice (HCL 4%) and rinsed three times with deionized water. Soon as enough rainwater was collected in the bucket it was transferred to a polyethylene flask and brought back to the laboratory for immediate analyses of the most basic parameters. During rainwater collecting the installation was closely monitored. In case of leaves and insects settling down on the collector they were instantly removed.

Most emphasis was put on parameters NH4—N, N03-N, Turbidity, Temperature, Conductivity, pH and Soluble reactive Phosphate (SRP), while occasionally also analyses on parameters like SiO_2-Si, SO_4-S, Chloride (CL), Alkalinity, Total hardness (as in $CaCO_3$), Calcium (CA), Total Dissolved Phosphate (TDP) and Total Phosphate (TP) were carried out.

Because of our rainwater collector (rainwater catching area of circa 1.5 m^2) sufficient quantities of rain water could be collected relatively fast allowing time series of measurements on the above mentioned parameters during one shower.

The sampling procedures followed and analytical methods used were the same as those described Langenberg (1996) and Plisnier (1996)

3 RESULTS

3.1 Parameters measured

An overview of all the data collected during this study are presented in Appendix 1.

Since this study was originally not incorporated in our regular Scientific Sampling Programme (SSP), only limited time was available. As a result most emphasis was put on the determinations of Turbidity, pH, NH4-N, N03-N and Conductivity, as these are fast and relatively easy to measure.

During the second part of the rainy season more time series of nutrient analyses were carried out, since it became clear from several time series from the first half of the rainy season that rainwater compositions can change drastically during a shower.

Please note that the results described in the following sections 3.1.1 up to 3.2 are based on results from measurements made on the first rain water sample taken after the start of a shower.

3.1.1 Nitrogen and Turbidity

The results of the Turbidity and Nitrogen compounds measurements are presented in Figure 2 and in Appendix 1.

While NH4—N concentrations in rainwater were on the average around 1 mg/l (average of 0.99 mg/l and ranging between 0.17 to 2.09 mg/l) the N03-N concentrations were about one fifth of the NH4-N concentrations (average of 0.2 mg/l and ranging between 0.0.6 and 0.4 mg/l).

The results show a positive relation between concentrations of NH4-N and N03-N with the Turbidity in rainwater. Generally, higher values of Turbidity were accompanied by higher values of both NH4-N and N03—N.

3.1.2 pH and Conductivity

The results of the pH and Conductivity measurements are presented in Appendix 1 and in Figure 3a. Results of the measurements showed that the pH of rainwater is generally around 7 (neutral) ranging from 8.56 to 4.96. Conductivity ranged between 83 and 7 NTU but values were on the average 5.44 NTU.

Figure 3b shows the relation between pH, Conductivity and Turbidity (Data of 16/2/1996 was not included). High values of Turbidity were normally accompanied by higher values of pH and Conductivity. Nevertheless at lower values of

Turbidity, pH and Conductivity values were ranging from low to average values indicating a less clear relation between these parameters.

3.1.3 Phosphorus

Due to the analytical difficulties and the fact that analyses on Total Phosphate (TP), Total Dissolved Phosphate (TDP) and Soluble Reactive Phosphate (SRP) are time consuming (See Langenberg, 1996 and Plisnier, 1996), little emphasis was put on these parameters.

The results found are presented in Appendix 1 and in Figures 4a.

The results show that in most cases when TP, TDP and SRP were determined at the same time and on the same rainwater sample, the concentrations of TP and TDP were higher than the concentrations of SRP. However, the concentrations of TDP were in many cases also higher than the concentrations of TP and on one occasion even lower than the SRP concentrations. This indicates that probably analytical errors are responsible for at least part of the difference, especially when measuring phosphorus concentrations approaching detection limits.

Figure 4b shows the concentrations of TP, TDP and SRP in relation with Turbidity. Although a possible relation is not clear, lower concentrations for TP, SRP and TDP were found in rain water characterised by very low turbidity values.

3.1.4 Other parameters

The results of the other parameters ($Si0_2$–Si, $S0_4$-S, Alkalinity, Ca^{2+} and Total hardness) measured are presented in Appendix 1.

Since the frequency of analyses carried out on the above mentioned parameters was low and the average results have standard deviations of similar magnitude, little can be said about them.

3.2 Seasonality and temporality

Since the early stages of our study it seemed that there was a relation between the nitrogen compounds and Turbidity in rainwater. In order to find out how rainwater Turbidity and its relation to the other parameters would vary intraannually and throughout a shower, more time series of analyses were carried out.

3.2.1 Seasonality

The turbidity values in rain water throughout the sampling period are presented in Figure 5.

While in the beginning of the rainy season turbidity values > 8 NTU were common, the turbidity values in rainwater collected at the end of the rainy season were characterised by much lower values (on average <2.2 NTU).

It seemed that while the rainy season was progressing the initial values (i.e., turbidity measurements on the first rainwater sample collected after the start of a shower)of turbidity in rainwater tend to decrease towards the end of the rainy season.

In Figure 5, one data point is circled. This concerns data collected on the 16th February 1995. Rainwater collected during that day was characterised by the highest values of Conductivity and Turbidity (respectively 83 μE/cm and 15.5 NTU) found during this study and very high values of NH4-N and N03-N (respectively 1.92 and 0.32 mg/l), while the pH (4.96) was the lowest measured.

3.2.2 During a shower

The results of the turbidity values in rainwater from time series of measurements made during separate showers are presented in Figure 6.

Figure 6 shows that turbidity values in rainwater are higher in the beginning of a shower and tend to decrease to about half the initial value after 10 to 30 minutes. After 30 minutes, turbidity values tend the level out at a value of about 30 to 40 % of their initial value.

3.2.3 Nutrients through wetfall

With the precipitation data (millimeter of rain per month) of our meteorological station situated in Bujumbura harbour at about three kilometers away from the water collector (see Figure 1), an estimation was made of the total amount of Nitrogen and Phosphorus deposited through wetfall. The results are presented in Figure 7 and Figure 9.

Most rain fell in the months November 1994, February and March 1995. High deposition rates of NH4–N were found in the months October 1994, February and March 1995. High deposition rates of N03-N were found in February 1995. High deposition rates of P04-P were found in the months December 1994, February and March 1995 (although it has to be stressed that there was no data available in the month of January and May 1995).
Depositions of Total Phosphate seemed to peak in December 1994 and March 1995 (also here missing data for January and May 1995).

The monthly amounts of nitrogen fallen were positively correlated with the amount of rain fallen per month. This relation was less strong for the phosphorus components.

During the rainy season a total of 462 mg/m^2 NH4–N, 101 mg/m^2 N03-N, 32 mg/m^2 P04-P and 61 mg/m^2 Total Phosphate was deposited through wetfall at the rainwater collecting site. The amounts P04-P and TP deposited through wetfall are bound to be higher due to the fact that two months of data were missing.

3.2.4 Nutrients in the lake

With the data of our regular limnological sampling Figure 8 was drawn for Secchi disk depth and concentrations of Total Dissolved Nitrogen (TDN) and P04-P. It concerns monthly averages calculated from data collected in the upper water layers (surface mixed layers, SML) at a station located at about 20 kilometers away from the rainwater collector into the pelagic zones of lake Tanganyika.

Figure 8 shows that, for concentrations of P04-P, higher values were found in the surface waters during the months December 1994 and February 1995, while in all the other months concentrations of P04-P were close to the detection level.
Monthly average concentrations of TDN at the sampling site in the pelagic were during this study always around 0.6 mg/l, dominated by N03-N. Concentrations of NH4—N were in most cases close to the detection level. For the months October 1994 and March 1995, TDN concentrations of close to 0.9 mg/l were measured.

Secchi disk depth was lowest in the months December 1994 and January 1995 and highest in March 1995.

4 Discussion and Conclusion

In the past, many studies of nutrient cycling through the atmosphere rely on measurements of the wet deposition of these nutrients (the rainfall amount times the nutrient concentration in rainwater) as being the primary information around which an atmospheric nutrient cycle is constructed. Understanding the concept of scavenging efficiency which determines nutrient depositions was the next step; i.e., how rapidly precipitation removes gases or aerosol particles from the atmosphere.

Precipitation scavenging is a complex subject but concerns fundamentally the chemical interaction between aerosols and falling rain drops. Scavenging can be influenced by the height from which the rain falls, the intensity of the rain and whether the subcloud air has been scavenged previously. An in-depth study on scavenging processes with our data was not possible and even nowadays scavenging is an incompletely understood subject (Galbally and Gillett, 1988). Our rainwater analyses show that Turbidity values (solids) decrease and several other parameters change during a shower and in the course of the rainy season, largely depending on local scavenging which could result in different wash out times of chemicals and particles.

Four basic processes introduce nitrogen compounds into the tropical atmosphere: emissions from soil bacterial processes (denitrification and nitrification can both lead to the production of NOx); lightning (fast formation of NOx); combustion of fossil fuels and biomass (producing NOx, NH3, etc.); and ammonia volatilization (from animal and human excreta, soil and senescing vegetation) . Whereas N03 is normally associated with particulate material where it is associated with sea salt or soil dust, NH4—N can bind with other chemicals to much smaller particles (Galbally and Gillett, 1988)

In figure 7 we calculated the total wet deposition of NH4-N, N03-N, P04-P and TP. In order to calculate the total amount of these nutrients precipitating on a yearly basis we must know the amount of nutrients precipitated by dryfall. Information on nutrient precipitation through dryfall is very scarce. Nevertheless, Bootsma *et al.* (1996) and Galbally and Gillett (1988) suggested that the amount of nutrients precipitated through dryfall to be nearly the same as through wetfall on a daily basis. In Bujumbura, on average, there are about 6 times more “dry days” than rainy days, which would mean that the values given in figure 7 could be multiplied by a factor 7, resulting in the following total yearly amount of precipitated nutrients: NH4-N (3.2 gm^{-2} yr^{-1}),N03-N (0.7 gm^{-2} yr^{-1}), P04—P (0.27 gm^{-2} yr^{-1}) and Total Phosphate (0.51 gm^{-2} yr^{-1}) . The latter two total amounts were calculated by using average monthly wet depositions for a period of two months (January and May 1995) during which no phosphorus analyses were carried out.

These total amounts are calculated in a rather crude way. As shown in figure 6, turbidity values (and probable related nutrient concentrations) level out during a shower to about 40% of their initial value at the beginning of the shower. Furthermore is to be expected that during dry days, within the rainy season, less nutrients will precipitate due to the reason that the atmosphere has recently been scavenged. As indicated before, scavenging or the “washing out” of nutrients depends on factors like: seasonality, locality, duration of a shower (in Bujumbura, Burundi rarely longer than 80 minutes), quantity of rain fallen during a shower, rain intensity, cloud structure and origin. How important locality can affect precipitation was shown by Kotilainen *et al*. (1995) . They found huge differences in the amount of rainwater fallen within a few kilometers. Our results have shown that monthly nutrient depositions largely depend on the amount of rain fallen that month and that the rainy season of 1994-1995, with only 512 mm of precipitation, was a rather meager one compared to an normal amount of around 850 mm and more.

It has to be said that most of the above mentioned factors influencing or determining the scavenging are known only from areas around Lake Tanganyika. I.e., we have no knowledge on rain quantities or atmospheric depositions on Lake Tanganyika itself.

Our results show that also in less industrialised regions acidic precipitation can occur (see Appendix 1.). Acidic precipitation in industrialised regions like Europe is primarily the result of combustion processes like fuel burning (Home and Goldman, 1994) while a low pH and the relatively high concentrations of NO3-N and NH4-N in tropical rain probably result from the production of nitric and sulfuric acids as a result of biomass burning (Lewis, 1981; Crutzen and Andreae, 1990; Carvalho *et al.,* 1995). As in much of Africa, biomass burning is widespread in countries like Tanzania, South of D. R. Congo and Zambia, directly increasing the flux of atmospheric nutrients and greatly decreasing the air visibility. In these countries, most burning is done from halfway to the just before the end of the dry season when fires become uncontrollable. This could explain the high deposition rates of at least some rain constituents at the beginning of the rainy season and lower deposition rates in the course of the rainy season when there is atmospheric wash—out and of course reduced burning.

The higher pH values found during our study indicate the presence of alkali. From studies in Malawi (Bootsma *et al.,* 1996) it appeared that alkalinity can be attributed entirely to

$Ca(HCO_3)_2$. This could explain The higher pH values in the beginning of the rainy season where the $CaCO_3$ concentrations in the form of dust particles are still sufficient to buffer high atmospheric fluxes of acid, whereas towards the end of the rainy season they could become insufficient resulting in a lower rainwater pH.

Although Ca^{2+} can be found as biogenically produced aerosols, it is often considered to be indicative of a soil source (Bootsma et *al.,* 1996). The little data we collected during this study suggest that the relatively high concentrations of Ca^{2+} found in this study are probably originating as soil particles. Bootsma and Hecky (1996) suggested a relation between the degree of soil exposure and the deposition rate of Ca^{2+}, and concluded that Ca^{2+} but also Mg^{2+} and probably Si are controlled primarily by soil exposure and wind direction, i.e., by production and transport mechanisms.

Factor analyses carried out by Bootsma et *al.* (1996) showed that TDP and SRP were grouped, which could indicate a common source. Although the release of aerosols by vegetation may also be a potential P source (Galbally and Gillett, 1988), soil exposure from deforestation and agriculture has been suggested as a possible cause of increased P deposition in Uganda (Bootsma and Hecky, 1993). Our results also show a probable relation between TP and SRP, but further studies are needed to determine the relative importance of soil exposure, vegetation and biomass burning in releasing different phosphorus compounds into the atmosphere.

Assessing the importance of atmospheric deposition as a potential nutrient source for lake Tanganyika needs understanding of the importance of the different fluxes of nutrients to the surface waters of lake Tanganyika. Nutrient sources for the productive layer of lake Tanganyika mainly include, riverine input, upward flux from the hypolimnion, atmospheric deposition, and *in situ* N fixation.

The limnological results from SSP's third year, in which both littoral and pelagic zones were studied, indicated that there was hardly any substantial difference in nutrient and chlorophyll *a* concentrations between coastal and pelagic zones. This suggests that the shoreline has little bearing on nutrient input or any related increase in phytoplankton biomass (Langenberg, *in prep.).* This was also confirmed by studies in lake Malawi (Patterson and Kachinjika, 1995). Thus, suggesting that the main nutrient inputs into the pelagic zones are limited to internal loading and precipitation. Although the nitrogen fixating bluegreens like *Anabaena* sp., which can manifest themselves in large blooms in Lake Tanganyika, could be an additional source of nitrogen, earlier studies have shown that during the rainy season these nitrogen fixating cyanobacteria are rarely abundant in the phytoplankton of Lake Tanganyika (Hecky and Kling, 1981)

Earlier research from our SSP has clearly shown that seiche activity affects the internal nutrient loading and consequently chlorophyll *a* concentrations and secondary production, indicating that the productivity of Lake Tanganyika is determined to a large extent by wind-driven processes (Langenberg, 1996). Upwelling of N and P into the surface mixed layers (SML) are most clearly at the end of the year in Bujumbura around October and November. Problems arise when trying to quantify these influxes of nutrients from vertical nutrient profiles alone.

Our limnological sampling showed that there were also increased concentrations of P and N and substantial concentrations of chlorophyll *a* in the SML around December, February and March (Sampling year 1995-1996) which partly corresponded with the findings in the sampling year of 1993–1994 (Plisnier et *al,* 1996) . These increases are difficult to explain as being the result of some wind-driven intrusion from deeper nutrient rich hypolimnion waters, since during these periods mentioned above, the wind force has already decreased and the clear defined thermocline, acting as a barrier between epi- and hypolimnion, is situated much deeper. This could indicate periods of external loading from rainfall. Patterson and Kachinjika (1995) found a similar pattern in Lake Malawi during the wet season and also suggested that these indicate periods of external nutrient loading from rainfall.

In order to determine the relative importance of nutrient precipitation to the Lake Tanganyika nutrient budget, calculated wet deposition rates of N and P were compared to the measured changes in nutrient concentrations in the SML of the lake (Figure 8 and 9)

Concentrations of P04-P in the SML where on the average close to detection levels except for the months December and January. It was also in these months that P04-P depositions peaked. The relation between concentrations of TDN in the SML and deposited TDN was less clear.

It is too simple to conclude that these depositions directly could lead to such an increase in SML concentrations of P and N. For example, if in December and January around 20 mg P m^{-2} is deposited at the surface this would mean a concentration increase of about $2 \mu g l^{-1}$ in the upper 10 meters of water, which will not be measured with our methods used. Furthermore is it hard to predict the biological reaction (speed of nutrient uptake, recycling, etc.) of organisms in the SML in case of external nutrient loading. Nevertheless, on one occasion a limnological sampling was carried out on a rainy day (13/12/1994), and the high surface concentrations of P and N found that day in the lake were similar to those found in rainwater, indicating that rainfall directly onto the lake surface can be a significant factor in nutrient loading.

Generally, rain chemistry is closely linked to soil exposure, deforestation, agricultural activities and animal and human excreta. The lack of knowledge on rain chemistry and quantity in parts of Africa and the important role of atmospheric deposition in lake nutrient cycles, are strong reasons to establish deposition monitoring programs on Lake Tanganyika and other African lakes.

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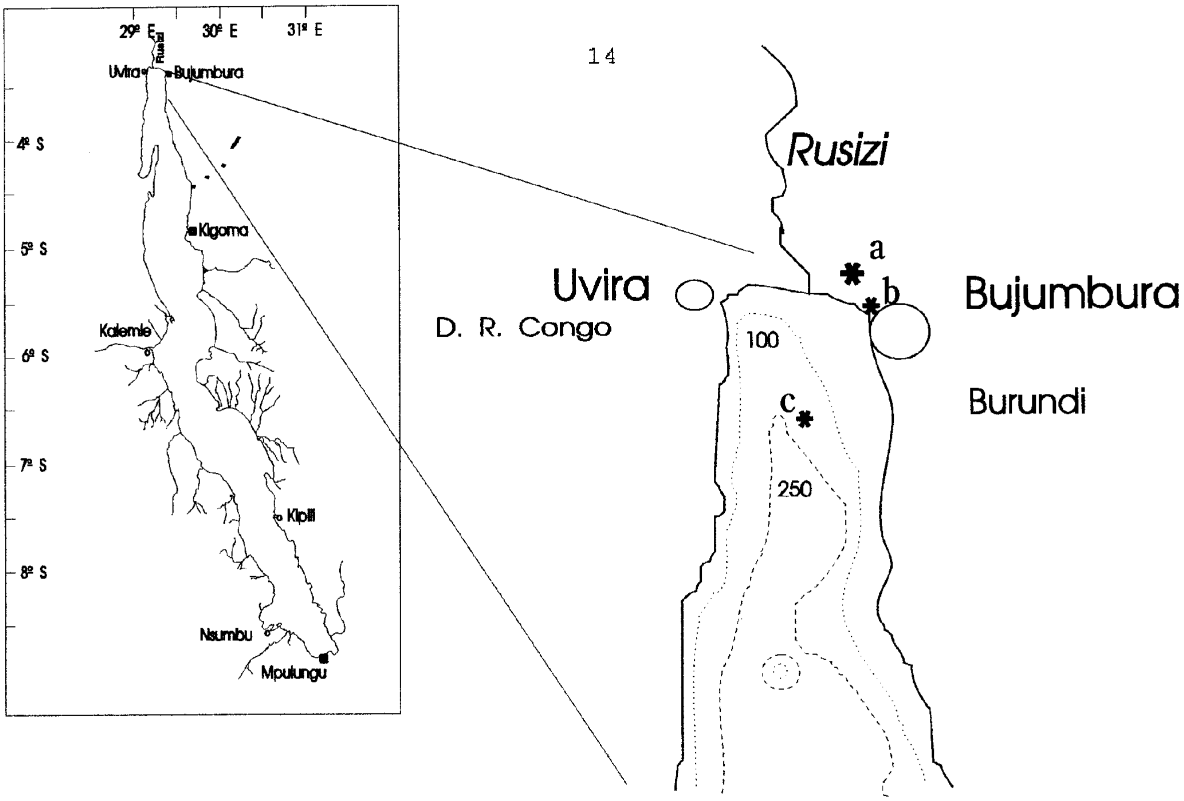

Figure 1. Bujumbura at the Northern part of Lake Tanganyika. Indicated are the rain water collecting site (a). our automatic meteo station (b) and the pelagic limnological sampling site (c) of our regular Scientific Sampling Programme (SSP). Also indicated are the 100 and 250 meter isobaths.

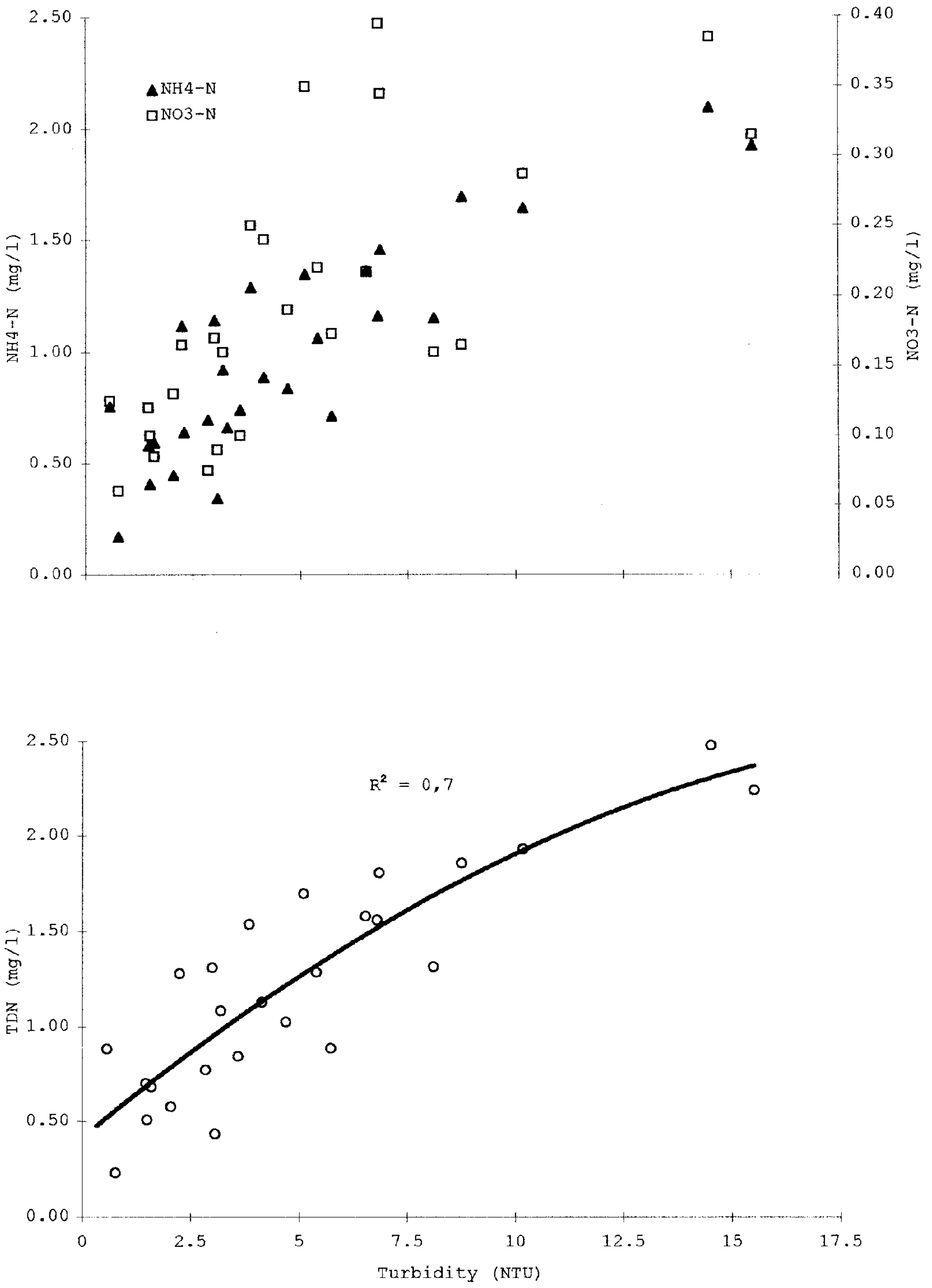

Figure 2. Concentrations of NH4-N and NO3-N (upper graph), and Total Dissolved Nitrogen (TDN = NH4-N +NO3-N +NO2-N) versus rainwater Turbidity (NTU), during the period from October 1994 to July 1995. Trendline trough data with R^2 = 0,7 is shown in lower graph.

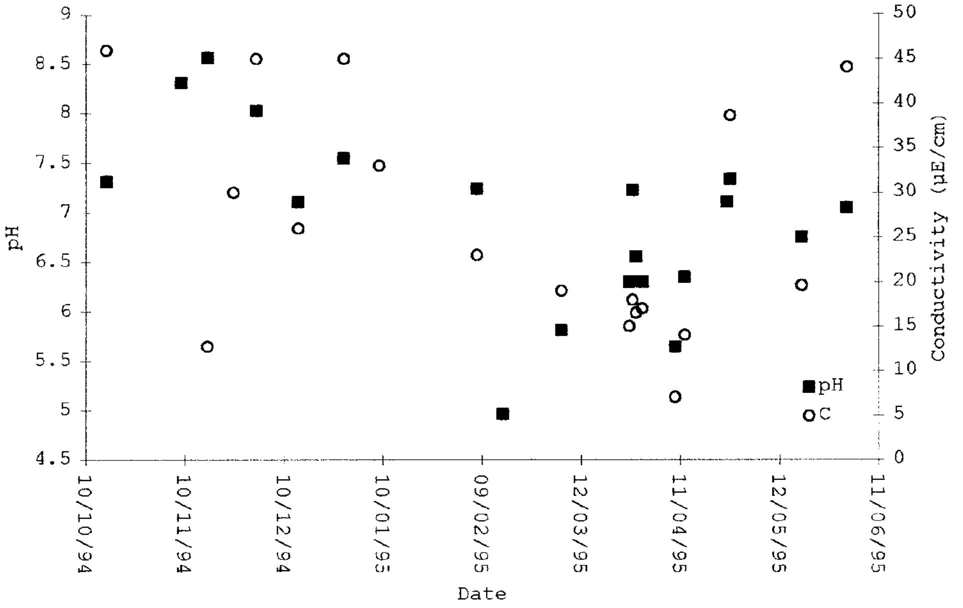

Figure 3a. pH and Conductivity values troughout the sampling period. Note that data of 16-02-96 are not included in this graph.

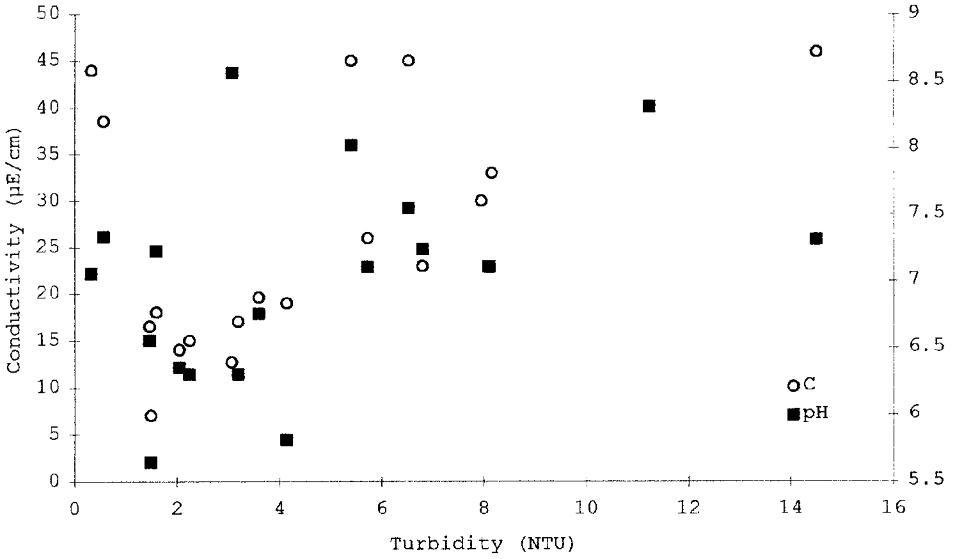

Figure 3b. pH and Conductivity values versus Turbididty. Note that data of 16-02-96 are not included in this graph.

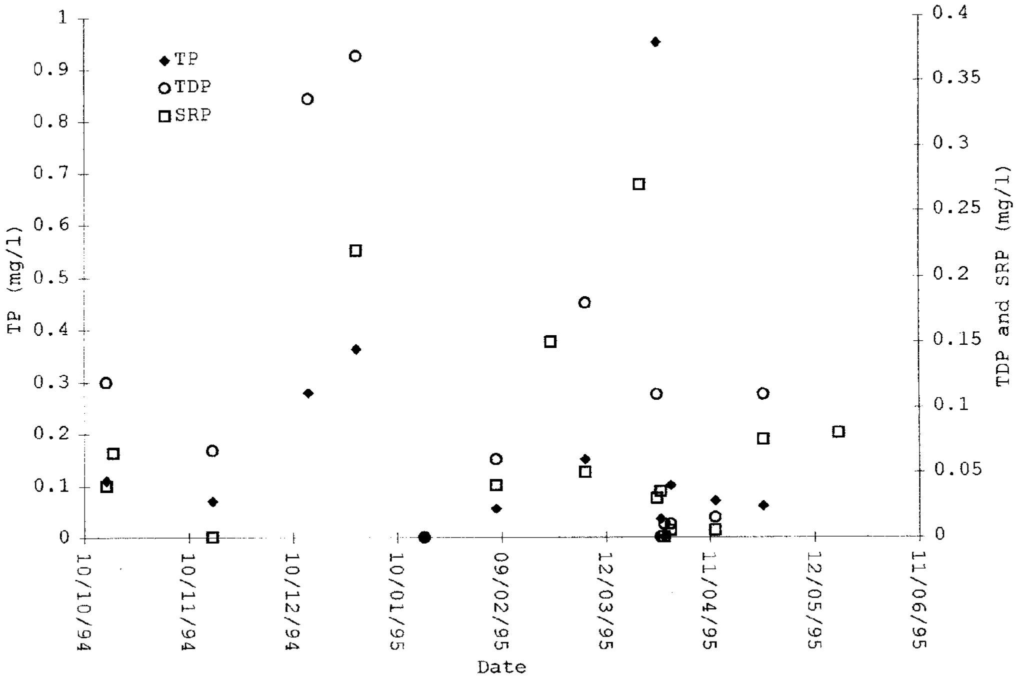

Figure 4a. Total Phosphate (TP), Total dissolved Phosphate (TDP) and Soluble Reactive Phosphate (SRP) values throughout the sampling period.

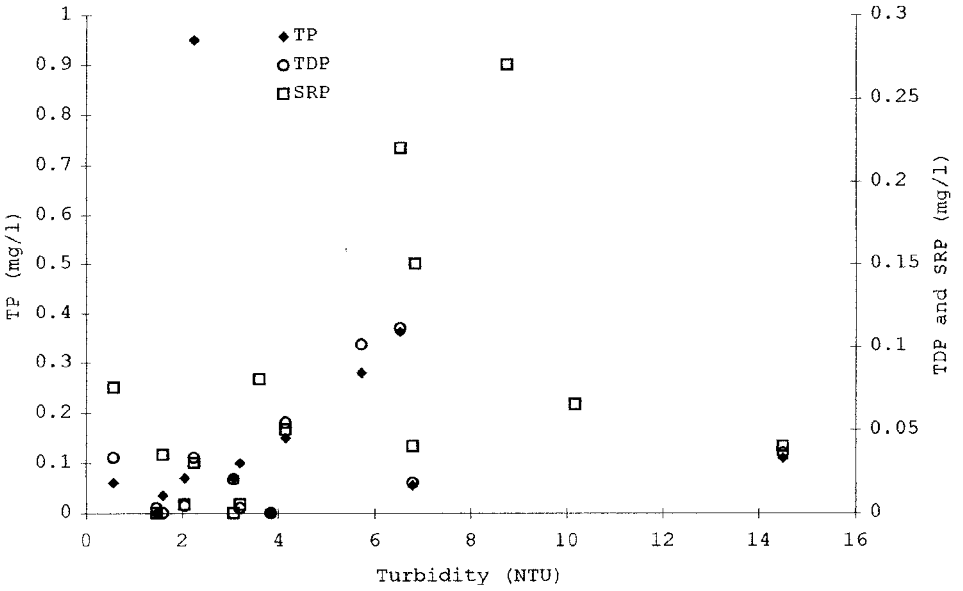

Figure 4b. Total Phosphate (TP), Total dissolved Phosphate (TDP) and Soluble Reactive Phosphate (SRP) values versus Turbididty.

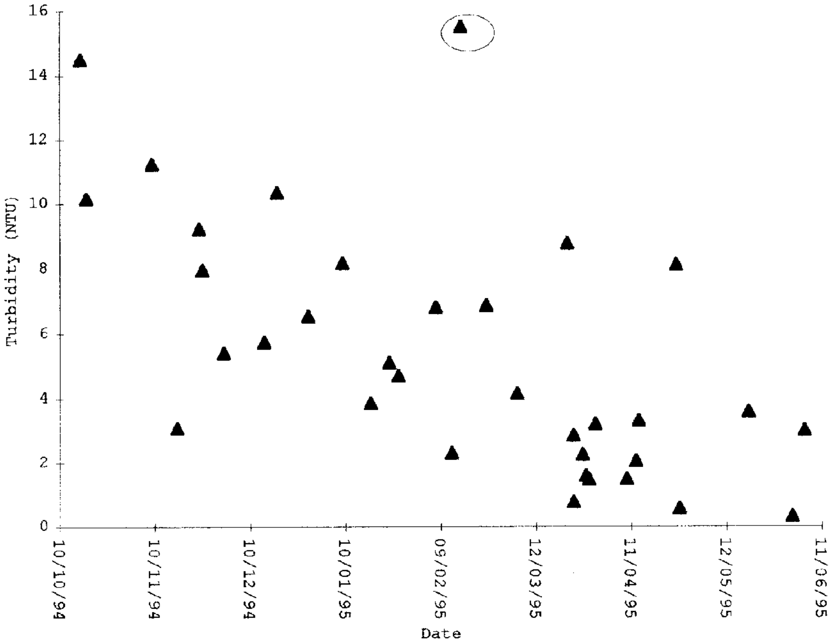

Figure 5 . Turbidity values in rainwater troughout the sampling period. Data from 16-02-95 is circled (see text).

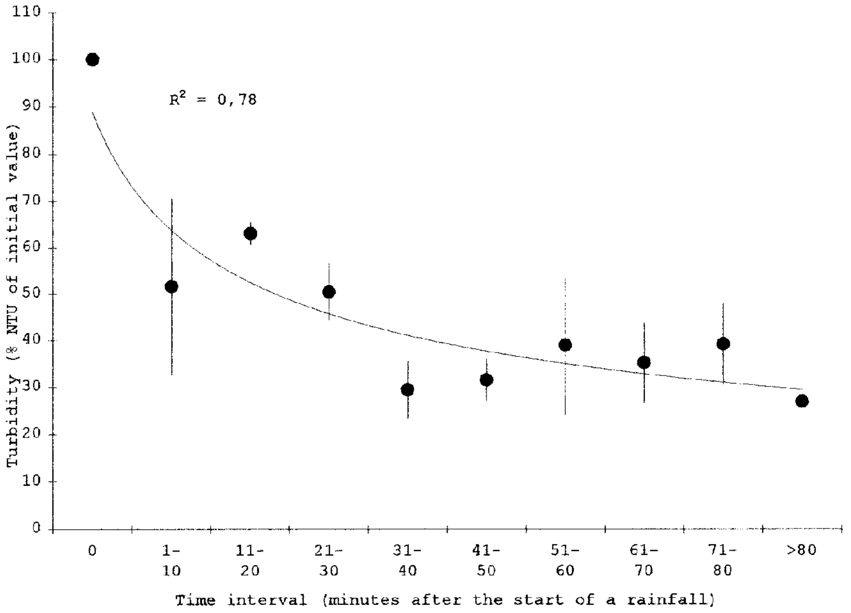

Figure 6 . Turbidity values in rainwater as percentages of their initial value at T=0. Averages and standard deviations are shown). A trendline with $R^2 = 0,78$ is shown.

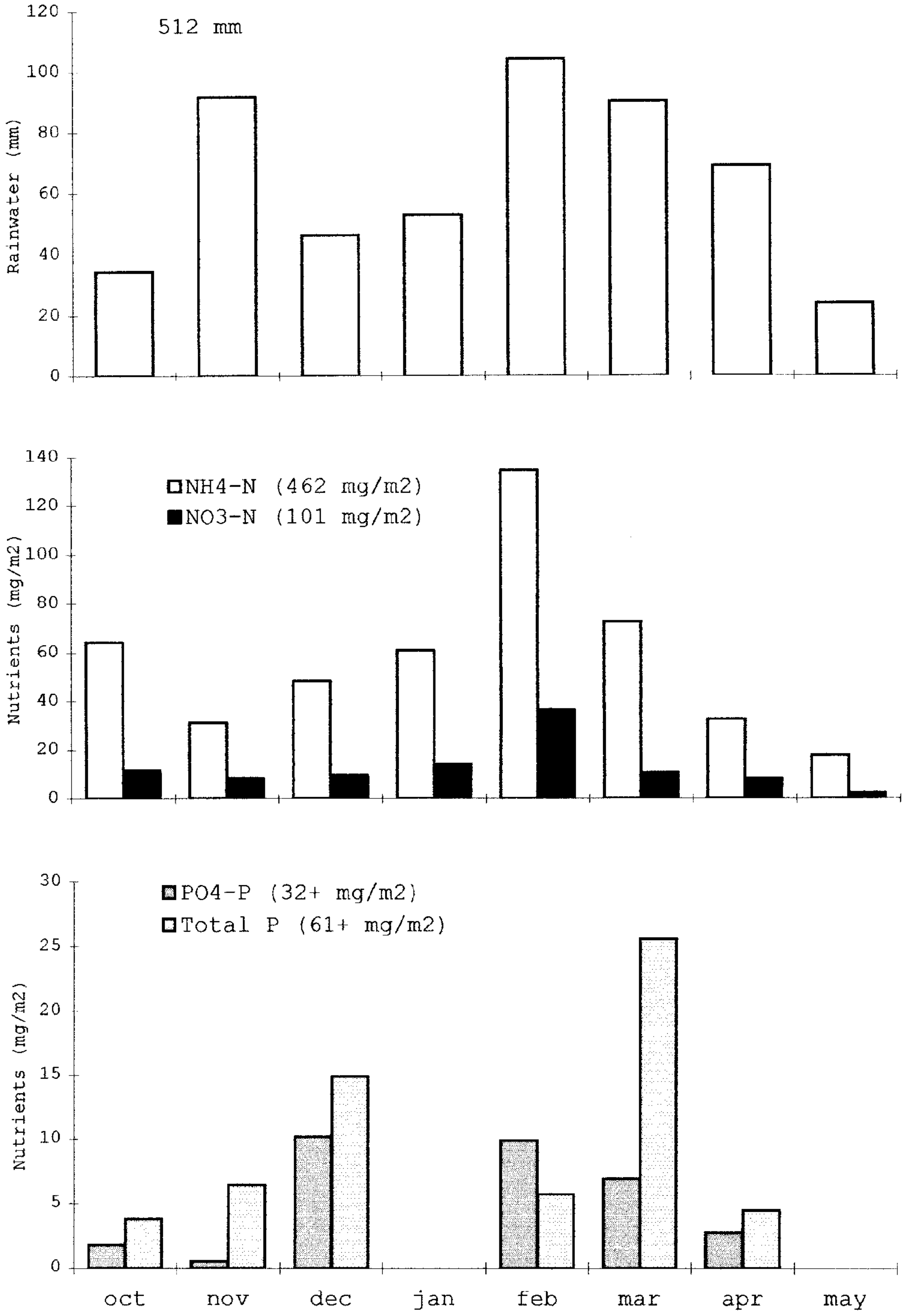

Figure 7. Rainfall and average monthly wet depositions of NH4-N, NO3-N, PO4-P and Total Phosphate. Values for nutrients are all in mg/m2. In the graphs the total calculated amount of rain (mm) and nutrients (mg/m2) is given during the period sampled. Note: the calculated total (+) for PO4-P and Total phosphate are irrespective of two months of data.

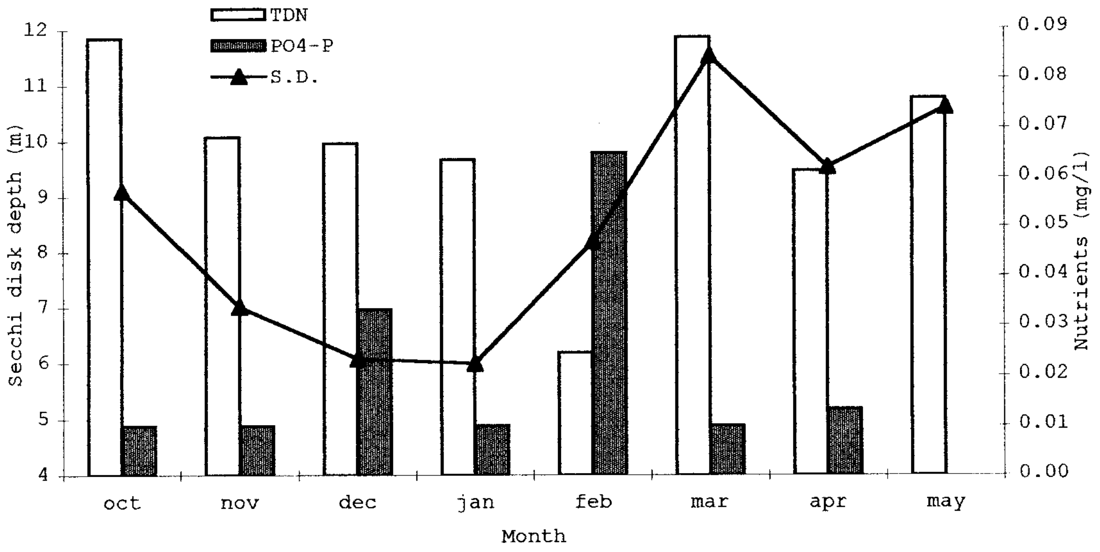

Figure 8. Monthly averages of concentrations of Total Dissolved Nitrogen (NO3-N, NH4-N and NO2-N) and PO4-P and monthly average Secchi Disk depth during the period of October 1994 to June 1996 in the most upper waterlayers of Lake Tanganyika in the vicinity of Bujumbura.

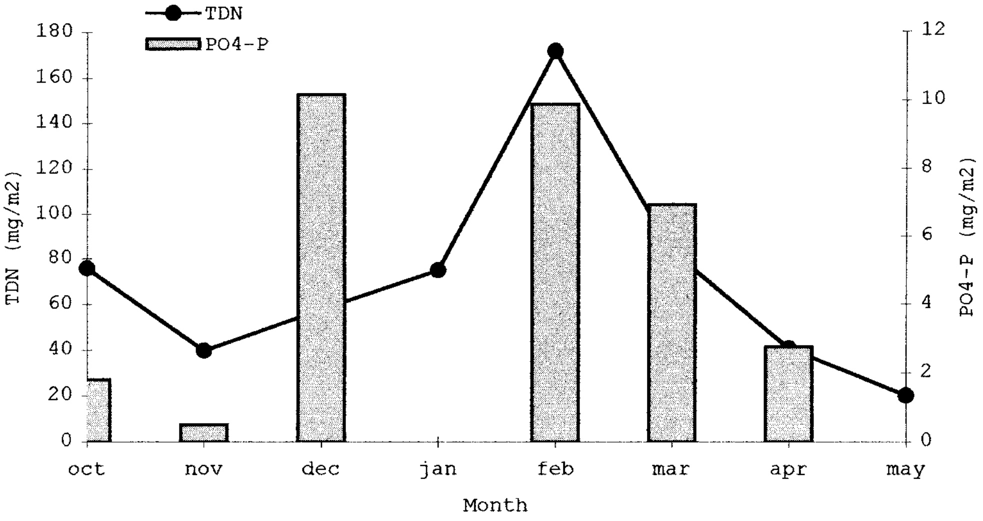

Figure 9. Monthly total wet depositions of PO4-P and TDN (NH4-N, NO3-N and NO2-N) during the period of October 1994 to June 1995. Note concerning PO4-P in the months January and May 1995 no measurements were carried out.

Appendix 1. Overview of all data collected in this study. T= temperature (°C), C= conductivity µS cm $^{-1}$. Total Phosphate (TP), Total Dissolved Phosphate (TDP), Chloride (Cl), Calcium (Ca), Total hardness (T hard), Alkalinity in CaCO3 (T alkal) and all other elements in mg l $^{-1}$.

date	time	T (°C)	C	pH	Turb.	TP	TDP	PO4-P	NH4-N	NO3-N	NO2-N	SiO2-Si	SO4	Cl	Alkal	Ca	T hard
17/10/94	16:00		46	7.31	14.50	0.11	0.12	0.04	2.09	0.39	0.002	0.115	0.5	24.0			
19/10/94					10.17			0.07	1.64	0.29	0.002						
09/11/94	09:30			8.31	11.24												
09/11/94	09:45				7.31												
09/11/94	10:05				3.93												
09/11/94	10:15				3.71												
09/11/94	10:40				2.92												
09/11/94	10:45				4.27												
17/11/94	16:30		13	8.56	3.07	0.07	0.07	0.00	0.34	0.09	0.002						
24/11/94					9.21												
25/11/94			30		7.95												
02/12/94	16:00		45	8.02	5.40				1.06	0.22	0.005						
15/12/94	10:45		26	7.10	5.73	0.28	0.34		0.71	0.17							
15/12/94	11:00				3.55												
15/12/94	11:10				3.09												
15/12/94	11:20				1.32												
15/12/94	11:30				1.55												
19/12/94					10.34												
29/12/94	15:45		45	7.54	6.53	0.36	0.37	0.22	1.36	0.22	0.002						
09/01/95			33		8.15												
18/01/95	14:45				3.85				1.29	0.25	0.001						
18/01/95	03:10				1.89												
18/01/95	03:35				1.12												
18/01/95	03:50				1.27												
18/01/95	03:55				1.35												
18/01/95	04:00				1.19												
24/01/95	16:30				5.10				1.35	0.35							
27/01/95	14:30				4.70				0.84	0.19							
08/02/95	16:00		23	7.24	6.80	0.06	0.06	0.04	1.16	0.40	0.004						
13/02/95	07:50				2.30				0.64								
16/02/95	16:35		83	4.96	15.50				1.92	0.32	0.003						
24/02/95	11:30	19			6.85			0.15	1.46	0.35	0.003	0.055			0.4	4.4	6.8
24/02/95	12:30				1.55				0.50	0.05	0.000	0.014		8.4	0.2	1.1	0.6

date	time	T (°C)	C	pH	Turb.	TP	TDP	SRP	NH4-N	NO3-N	NO2-N	SiO2	SO4	Cl	Alkal	Ca	T hard
06/03/95	16:00	20.8	19	5.81	4.15	0.15	0.18	0.05	0.89	0.24	0.002	0.061		7.0	4.0	18.0	6.3
06/03/95	17:00		12		2.05				0.61	0.03	0.003	0.025		6.0	7.2	15.0	12.4
22/03/95	16:49				8.75			0.27	1.69	0.17	0.001						
24/03/95	09:00				2.85				0.70	0.08	0.002						
24/03/95	15:30				0.77				0.17	0.06							
27/03/95	15:30		15	6.30	2.25	0.95	0.11	0.03	1.12	0.17							
27/03/95			15	6.30	2.25				1.12	0.17							
28/03/95	11:30		18	7.22	1.60	0.04	0.00	0.04	0.60	0.09	0.001	0.038					
28/03/95			18	7.22	1.60				0.60	0.09	0.001						
29/03/95	11:45		17	6.55	1.48	0.00	0.01	0.00	0.58	0.12	0.001						
31/03/95	14:30	18.5	17	6.30	3.20	0.10	0.01	0.01	0.92	0.16	0.002	0.048		6.0		7.1	
31/03/95	15:00	23.1	14	6.20	1.80	0.03	0.00	0.00	0.63	0.07	0.002	0.037		5.0		2.8	
10/04/95	11:00	20.1	7	5.64	1.50				0.41	0.10	0.003	0.016	1.0	8.2	4.0	0.4	1.0
10/04/95	11:05	21.2	7	6.01	0.90				0.31	0.08	0.003		0.5		1.8		
10/04/95	11:15		8		1.00				0.39	0.11							
13/04/95	11:30		14	6.35	2.05	0.07	0.02	0.01	0.45	0.13	0.001		0.5	4.6	0.9	1.7	0.3
14/04/95	08:05				3.30				0.66								
14/04/95	08:15				2.45				1.08								
14/04/95	08:30				1.40				0.11								
14/04/95	08:45				1.00				0.03								
14/04/95	09:05				1.00				0.00								
14/04/95	09:35				0.90				0.33								
26/04/95	11:05			7.10	8.10				1.15	0.16	0.004						
27/04/95	16:10		39	7.33	0.57	0.06	0.11	0.08	0.76	0.13	0.004	0.048					
27/04/95	17:00		46	7.25	0.21	0.06	0.15	0.11	0.75	0.12	0.002	0.112					
19/05/95	08:25		20	6.75	3.60			0.08	0.74	0.10	0.003	0.057					
19/05/95	08:30		6	6.30	1.20			0.02	0.68	0.06	0.002	0.017					
19/05/95	08:35		7	6.34	1.40				0.36								
19/05/95					3.60												
02/06/95			44	7.05	33.00												
06/06/95	14:32				3.00				1.14	0.17							
06/06/95	14:57				1.80				1.40	0.19							
06/06/95	15:11				1.60				0.78	0.12							
06/06/95	15:52				1.40				1.06	0.08							
06/06/95	15:59				1.45				0.94	0.11							

Appendix 2. Basic statistics on all data collected during this study. Abbreviations of parameters are explained in Appendix 1. AVG= average, N= sample size, Stdev= standard deviation, Max= Maximum values measured, Min= minimum value measured. Lower table (B) comprises data from first sample taken after the start of a shower. Upper table (A) comprises data from all the measurements carried out.

A

	T (°C)	**C**	**pH**	**Turb.**	**TP**	**TDP**	**SRP**	**NH4-N**	**NO3-N**	**NO2-N**	**SiO2**	**SO4**	**Cl**	**Alk**	**Ca**	**T hard**
AVG	20.5	24	6.81	3.73	0.17	0.11	0.07	0.84	0.16	0.002	0.049	0.6	8.6	2.6	6.3	4.6
N	6.0	28	26	68	14	14	18	47	39	27	13	4	8	7	8	6
Stdev	1.7	17	0.84	3.03	0.26	0.12	0.08	0.43	0.09	0.001	0.027	0.3	1.5	2.6	6.7	4.8
Max	23.1	83	8.56	15.50	0.95	0.37	0.27	1.92	0.40	0.005	0.112	1.0	8.6	7.2	18.0	12.4
Min	6.0	6	4.96	0.21	0.00	0.00	0.00	0.00	0.03	0.000	0.014	0.5	4.6	0.2	0.4	0.3
Median	20.1	18	6.75	2.28	0.09	0.11	0.05	0.74	0.13	0.002	0.048	0.6	6.5	2.6	6.3	4.8

B

AVG	19.6	29	6.92	5.44	0.19	0.12	0.07	0.99	0.20	0.002	0.055	0.7	10.0	2.3	6.3	3.6
N	4.0	19	19	34	12	12	15	28	26	20	8	3	5	4	5	4
Stdev	1.0	18	0.91	3.89	0.26	0.12	0.08	0.48	0.10	0.001	0.028	0.3	8.0	2.0	7.0	3.4
Max	20.8	83	8.56	15.50	0.95	0.37	0.27	2.09	0.40	0.005	0.115	1.0	24.0	4.0	18.0	6.8
Min	18.5	7	4.96	0.33	0.00	0.00	0.00	0.17	0.06	0.001	0.016	0.5	4.6	0.4	0.4	0.3
Median	19.6	23	7.10	4.43	0.09	0.09	0.04	0.90	0.17	0.002	0.051	0.5	7.0	2.4	4.4	3.7