Phosphorus behaviour in a river during periods of drought and rain

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The behaviour of phosphorus forms and loads under conditions of drought and rainfall and based on real measurements was studied in the Timbú River Basin, an important water source in the metropolitan region of Curitiba, Paraná State, Brazil. Quantitative and qualitative chronosequential analyses were performed in different points of the river during a period of drought and every 5–10 min before, during and after rainfall in the basin. The main results showed that the phosphorus load at the river mouth during drought periods was 2.8 kg/d, five times lower than the normal flow of 8.8 kg/d. At its peak during medium rainfall, the load reached 175.3 kg/d, highlighting the significant influence of diffuse loads in the catchment area. The parameters total phosphorus and reactive phosphorus differed based on river compartments and land uses, mainly urban, agricultural and preserved areas. Therefore, basin action plans must consider varying weather conditions, including both drought and rainy periods, and implement long-term monitoring programmes.

Introduction

The region of Curitiba, Brazil, has very low water availability ($550 \text{ m}^3/\text{year}$ per inhabitant), with the only available sources coming from nearby river springs, thus requiring the need for water reservoirs. Water availability is one of the most crucial factors in the development of the region. However, this concern has been disregarded and population growth has accelerated environmental degradation.

The integrated water supply system of Curitiba provides 9495 l/s of treated water to about three million inhabitants (Sanepar, 2013). The Iraí and Iguaçu systems, which make up approximately 62% of this water supply, feed three of the four reservoirs operating in the region: Piraquara I, Piraquara II and Iraí (Sanepar, 2013). Lake Iraí is the largest and the most fragile, particularly in relation to eutrophication risk. The Timbú River Basin is one of the main tributaries of Lake Iraí, which contributes *c.* 93% of the phosphorus (P) pollution to the reservoir (Bollmann *et al.*, 2005). Consequently, frequent macrophyte and cyanobacteria blooms have been observed in the ecosystem.

The importance of dissolved and particulate loads carried to waterbodies has been widely recognised for both natural and anthropogenic sources of pollution (Behrendt and Bachor, 1998; Danelon *et al.*, 1991; Jambers *et al.*, 1999; Kruawal *et al.*, 2005; Rietzler *et al.*, 2001). However, although non-point source pollution generally makes up the main fraction of the total phosphorus (TP) load, not only is this source of pollution difficult to measure and locate, but it is often underestimated or disregarded. The principal path of transport for non-point sources is rainfall due to the solubilisation and movement of nutrients to watercourses. Point loads, on the other hand, are mainly the result of urban occupation and the consequent irregular waste water

connections or release of untreated sewage in areas where there is no sewage system (Bollmann *et al.*, 2005).

As rainwater promotes the drag of particulate and dissolved materials, the evaluation of diffuse nutrient inputs must consider weather conditions and in particular the quantity and intensity of rainfall before, during and after events. Rainfall intensity, along with the chemical and physical properties of soil (texture, structure, moisture, cation-exchange capacity) and soil coverage, determines the magnitude and strength of the surface particle drag forces (Erpul *et al.*, 2003; Sharpley and Halvorson, 1994; Sharpley *et al.*, 1981). Thus, knowing about phosphorus inputs into the river and how it works, taking into consideration flows and weather circumstances, is quite important for basin and reservoir management.

The purpose of this study was to evaluate the behaviours of different forms of phosphorus concentrations and loads in waterbodies under varying weather conditions, mainly drought and rain events. To achieve this, water quality and flow at various points throughout the Timbú River Basin were assessed. Special attention was given to the relationship between concentration and flow, resulting in the TP load into the reservoir.

Materials and methods

Study area

The Timbú River Basin is a small basin (26 km^2) located in the metropolitan region of Curitiba, Paraná State, southern Brazil ($49^\circ 35'$ west and $25^\circ 46'$ south; see Figure 1).

The geological source material comes from Tertiary and Quaternary Periods. The predominant geological formation in the

Figure 1. Location of the Timbú River Basin, Metropolitan Region of Curitiba, southern Brazil

area is the Guabirotuba Formation (Bigarella and Salamuni, 1962), which forms part of the sedimentary basin of Curitiba and contains montmorillonite and arkose with carbonate interlayers (Becker, 1982; Bigarella and Salamuni, 1962). These sedimentary units are deposited in erosive discordance on the basement rock layer (Salamuni *et al.*, 1999). The weathering of substrate has resulted in a kaolinite aluminium silicate group, as well as iron oxides, hydroxides and oxyhydroxides. Clay fractions, in particular kaolinite and smectite, are prevalent, and oxyhydroxides, such as gibbsite and haematite, have also been identified (Fortin *et al.*, 1989).

The elevation varies from 895 to 990 m above sea level (asl), creating 95 m of total vertical distance between the farthest spring and the river mouth. The region includes a range of landscapes and land reliefs, from flat to strongly undulating terrain (see Figures 2(a) and 2(b)).

The main land uses are (a) natural and planted forests, (b) fields and agriculture and (c) urban areas (Figure 2(c)). There are several small farms in the area surrounding both streams. While

mining and poultry farming no longer occur in the basin, temporary crops and vegetables are often planted on the left side of the catchment area, which demand large amounts of phosphate (PO_4^{3-}) fertilisers (in particular corn and grass crops). The right side of the catchment is relatively well preserved. Exotic *Pinus* sp. plantations and bare soil areas are not extensive. Urban areas, concentrated in the lower third on the right side of the basin, are significant and promote greater amounts of run-off due to soil sealing (Figure 2).

According to Lima (2005), the Timbú River Basin has ten different soil types, taking into account the fourth hierarchic level (Embrapa, 1999), which can be found in isolation or associated with others typologies. The main soil type is clay-rich, composed of aluminium humic cambisol (inceptisol) and dystrophic humic cambisol (inceptisol) (Table 1), and occupies 35% of the total area (Figure 2).

The Timbú River is composed of two main unnamed streams, which run across two-thirds of the basin, resulting in an average flow across the mouth of the Timbú River of *c.* 0.430 m³/s (SGP, 2000).

Figure 2. (a) Altitude, (b) terrain, (c) land use and (d) soils of the Timbú River Basin, southern Brazil

Experimental and statistical procedures

The evaluation of phosphorus behaviour in the Timbú River was carried out during three distinct situations throughout 2006: (a) period of drought, (b) light rain (drizzle – 4.9 mm) and (c) medium rain (16.8 mm). The sampling sites were defined based on land use, drainage, elevation and how well the site represents upstream land use (see Figure 3). The phosphate series analysed were TP, dissolved phosphorus ($P_{\text{dissolved}}$), reactive phosphorus (P_{reactive}) and dissolved reactive phosphorus ($P_{\text{reactive dissolved}}$) (essentially orthophosphate).

- Situation 1: 12 d without rain events before sampling. The river was partitioned into 34 sampling points (Figure 3). All samples were obtained in 1 d.
- Situations 2 and 3: light rain (drizzle) of low intensity (4.9 mm) and rain of medium intensity (16.8 mm). For both situations, chronosequential water samples were taken simultaneously at four different points (Figure 3), as follows
 - (i) 27BU (before urbanisation): area with good agricultural management practices, forest relatively well preserved,

Table 1. Main features related to phosphorus behaviour in the Timbú River Basin, southern Brazil

Item	Information
Morphometric	
Total area basin: km ²	26
Greatest length – waterway: km	10.6
Mouth width: m	5.85
Altitude: m asl	885–990
Land relief	Flat to undulating
Hydrological	
Number of main streams	2
Mean depth: m	0.35
Mean flow: m ³ /s	0.43
Mean velocity: m/s	0.22
Weather ^a	
Köppen climate zone	Humid temperate
Annual mean temperature: ^a °C	17
Mean minimum temperature – coldest months: ^a °C	8–10
Mean maximum temperature – hottest months: ^a °C	23–27
Last 20 years' annual average precipitation: mm	1800
Annual average precipitation: ^a mm	1602
Mean rainiest month – January: ^a mm	174
Mean driest month – April: ^a mm	55
Mean highest intensity rain – March: ^a mm/h	2.15
Lithopedological	
Soil: %	Ten types (main inceptisol – 35)
Geology	Mudstone, arkoses and alluvial deposits
Urban areas: %	30.7
Vegetation	
Forest: main composition	Myrtaceae and Fabaceae (montane – mixed rainforest)
Riparian forest: %	39
Missing or damaged forest: %	61

^a Period 2000–2007

non-intense land use; located between right stream sources and the beginning of urban area

- (ii) 80AU (after urbanisation): area with intense urban land use; located between point BU and the beginning of river mouth (MR)
- (iii) 12IA (intensive agriculture): area with extensive agricultural use with poor management practices; located between left stream sources and the beginning of point MR
- (iv) 52MR (river mouth): area that receives all loads from the basin; located between points AU and IA and represents a reservoir/river intersection zone.

The chronosequential sampling under low-intensity rainfall (4.9 mm) resulted in seven samples at point 27BU over 82 min and four samples at points 80AU, 12IA and 52MR, over 136, 143 and 156 min, respectively.

Under medium-intensity rainfall (16.8 mm), 11 samples were taken for each of the four points as follows: the first ten samples were taken before, during and after rainfall over a period of 90 min at 27BU, 121 min at 80AU and 12IA and 107 min at MR. The 11th sample was taken 14 h after the tenth sample to determine if water quality returned to pre-rain conditions.

The flow rates were measured concomitantly with sample taking. Because of different morphometric characteristics at each point, different methods were used to determine the flow, as follows: 27BU – California method, case of horizontal ducts; 80AU and 12IA – hydrometric reel; 52MR – estimated by Manning's equation, uniform and constant flow.

Scatter plots were used to demonstrate the behaviour of the parameters, and Pearson's correlation coefficient (*r*) was used to detect the relationships between phosphorus forms and flows.

Results and discussion

Reportedly, weather phenomena are more intense over the past decades, particularly due to climate changes. Rainfall and drought events have behaved differently and are more severe than they have been historically (Unesco, 2015, 2016). A recent study by Ayanlade *et al.* (2018) has shown a very high spatial variability between stations, temporal variability, and, in consequence, there are several anomalies in rainfall in recent years. Thus, understanding the behaviour of the river basin plays a vital role in managing and protecting the ecosystem.

As expected, there were relevant differences among all three scenarios analysed. Under the drought condition a phosphorus concentration effect was observed, whereas during rainfall the effects of both the phosphorus concentration and the behaviour of the river basin were observed.

Response managers should follow the monitoring of these different conditions. Water quality monitoring programmes and databases play a crucial function in defining activities across the basin, principally in anticipating potential problems.

Drought period

As expected, water flows in the basin and their loads were markedly lower than normal during periods of drought. In this situation, artificially released effluents become determinants in water quality patterns and are also easier to detect. This corroborates with the statement that base flow concentrations (or at non-high-flow events) are most ecologically relevant to analysing flowing waters (Stamm *et al.*, 2014). High TP concentrations were found at sampling points with low flow levels, most of which occur in tributary channels, such as 26

Figure 3. Sampling stations: drought period (yellow) and rainy period (white) in the Timbú River Basin, southern Brazil

(BU, although it has a village upstream) and 28, 47, 49, 50 and 51 (all AU) (Figure 4). Among low-flow sampling points, only 25 (BU) and 48 (AU) had a low TP content. High TP concentrations are expected from waterways with reduced flow in urban areas.

A considerable number of these points also had high concentrations of P_{reactive} , except 44 (AU) and 50 (AU) ($r = 0.84$; $p \leq 0.05$; for $TP \times P_{\text{reactive}}$). The correlation coefficients between flow and TP concentration ($r = 0.14$; $p \leq 0.05$) and flow and P_{reactive} ($r = -0.24$; $p \leq 0.05$) indicate that the highest concentrations are not directly correlated with greater flow. Point 12IA, further downstream on the left tributary, had a TP concentration ($50 \mu\text{g/l}$) significantly lower than that of point 29 (AU), located downstream on the main axis of the right tributary ($1160 \mu\text{g/l}$), which is affected by the first large urban area (pollution from the Eugénia Maria housing estate). Before this housing complex, a considerably lower TP concentration ($30 \mu\text{g/l}$) was observed. The first point after confluence (40AU) presented $380 \mu\text{g TP/l}$. Thus, the 1 km distance between points 29 (AU) and

40 (AU) reduced TP concentrations due to TP dilution and purification processes probably resulting from greater flow and the presence of iron (III) (Fe^{3+}) and aluminium (Al^{3+}) oxyhydroxides and/or biological utilisation (Stamm *et al.*, 2014).

All sampled points after confluence maintained high TP values, even with increased flow, which suggests that the increased flow cannot dilute or sink the loads coming into the river. The Paulista housing estate (points 41–49) contributes significant loads to the river mouth point (52MR) despite its high level of sanitation of greater than 80% (Sanepar, unpublished data). Small amounts of untreated sewage can lead to considerable phosphorus loads as a result of their high phosphorus concentrations.

Light rain (drizzle – 4.9 mm)

In the second stage of this study, light-rain conditions were evaluated: 4.9 mm at point 27BU, 1 mm at points 12IA and 80AU and 0 mm at the river mouth region 52MR. This event did not produce significant changes to water flow throughout the period of rain (about 73 min) (Figure 5).

Figure 4. TP and P_{reactive} concentration in Timbú River Basin during the drought period. Note: connected points belong to the main stream waterway

Figure 5. TP, P_{reactive} , $P_{\text{dissolved}}$ and $P_{\text{reactive dissolved}}$ concentrations, mean TP loads and rainfall for four sampling stations in the Timbú River Basin during light-rain conditions (4-9 mm)

The behaviour of the phosphorus forms was relatively homogeneous. However, all phosphorus forms observed at 80AU (anthropogenic influence) had higher values at 143 min (0.190 mg/l) than the previous sample times. This increase can be related to rain in the basin and to the movement of the water flow upstream (from point 27BU), causing the transport of suspended particulates and sediment (Figure 5). Before the observed rain effects at points 80AU and 52MR, the influence of land use was clear in all measured phosphorus forms, with the highest '0 min' value found after urbanisation 80AU (Figure 5). The 4.9 mm precipitation that occurred in the region of point 27BU did not influence phosphorus concentrations, which is likely the result of a lack of precipitation upstream. The phosphorus contributions are therefore essentially diffuse. Similarly, the 1 mm rain did not result in considerable changes in phosphorus concentrations at 12IA, which, like 27BU, receives loads primarily in diffuse form (see Figure 5).

The reactive orthophosphate values (between 0.01 and 0.90 mg phosphorus/l; Figure 5) are in the same range as those found by Ramanathan *et al.* (1999) of 0.016–0.767 mg phosphate/l ($\chi = 0.280$ mg phosphate/l). The authors associated their observed values to the anthropogenic and agricultural influences in the basin, in particular the use of the diammonium phosphate fertiliser, among other contributions. Sharpley and Halvorson (1994) found run-off values around 0.009 mg phosphorus/l in forests and 0.071 mg phosphorus/l in agricultural areas. A similar average (0.056 mg phosphorus/l; from 0.032 to 0.375 mg phosphorus/l) was reported by Defew *et al.* (2013) in a stream of an intensively farmed catchment.

The highest TP loads were observed at points 12IA and 52MR, in contrast to expectations that point 80AU would be higher. The results showed that under drought periods, flow has a greater influence on

loads than concentrations. The drag of phosphorus depends on rain events; therefore, the decreased TP load at the river mouth (point 52MR) is due to an absence of rain in this zone (Figure 5).

Medium rain (16.8 mm)

For this condition, the amount of rain varied according to sample points, as follows: 27BU = 16.8 mm; 12IA = 15 mm; 80AU = 15 mm; and 52MR = 15.7 mm (Figure 6).

The flow at point 80AU had a much greater increase than at point 12IA. Despite similar initial flows, the differences between the observed peaks at the points after urbanisation and after intensive agriculture (0.575 and 0.283 m³/s) suggest that the impermeability in the 80AU subbasin is very high, leading to pronounced run-off. The river mouth point (52MR) reached 2.229 m³/s, which is ten times greater than the initial flow (Figure 6).

Unlike the observed drought or the light-rain conditions, the period of medium rainfall not only showed greater run-off from urban areas but also showed increased TP concentrations and consequently loads (Figure 7). This increase is likely due to problems in municipal sanitation, because of either a lack of an appropriate sewer system or pipe structural problems, thus further deteriorating the quality of the waterbody.

The behaviour of phosphorus concentration was different among the sample points. At point 80AU, a greater influence of run-off was observed than at the other points. Clearly, at this point, the TP load peak (Figure 6), as well as TP concentration peak (Figure 7), is related to the hydric increment at 47 min. TP concentration

increased again at 95 min, even after the rain in the basin ended. Considering that both load and flow decreased, this late increase is likely related to the drag of some rich source of this element.

The differences in TP concentration peaks (as well as TP loads) between neighbouring points 80AU and 12IA, which have similar drainage areas, confirm the influence of different land uses. Point 80AU apparently indicates a high level of soil sealing, while 12IA likely shows greater field roughness and consequently higher levels of infiltration (Figures 6 and 7). While TP concentrations observed at 80AU and 52MR were high before the rainfall, during the event, the values increased considerably, particularly in the region downstream of urbanisation. As such, these values depend largely on land management. In a similar study, 31% of the TP loads were attributed to eroded material from crops, 30% from domestic sewage, 12% from inappropriate agricultural use, 10% treated rainwater, 10% industrial effluents and 7% other sources, such as urban drainage, groundwater and rainfall (Umweltbundesamt, 1997: pp. 234–236).

The agricultural regions (27BU and 12IA) showed P_{reactive} concentrations higher than $P_{\text{dissolved}}$, even during rainfall. The urbanised subbasins (80AU and 52MR) presented the opposite; dissolved phosphorus forms were observed at the beginning and during rainfall and were exceeded only by reactive forms after the rain had influenced the flow. Low-molecular-weight organic compounds containing phosphorus, such as amino acids and other substances from urban sources, can promote an increase in $P_{\text{dissolved}}$ concentrations before rain. Under light-rain conditions (4.9 mm), when the effects of run-off were not pronounced, higher concentrations of the dissolved forms were also found instead of

Figure 6. Rainfall, flow and TP load at four sampling stations in the Timbú River Basin during medium-rain conditions (15–16.8 mm)

Figure 7. TP, $P_{\text{dissolved}}$, P_{reactive} and $P_{\text{reactive dissolved}}$ concentrations at four sampling stations in the Timbú River Basin during medium rainfall (16.8 mm). Flow is shown in Figure 6

reactive phosphorus forms. An increase in P_{reactive} was detected only with an increase in flow at 47 min (peak at 95 min; 0.37 mg/l). Therefore, the run-off was responsible for the reactive forms, which were negligible in the absence of diffuse pollution. The P_{reactive} concentration at 80AU after 14 h decreased to 0.08 mg/l and $P_{\text{dissolved}}$ to 0.04 mg/l, supporting the aforementioned statement. The reactive phosphorus forms are immediately available for phytoplankton and aquatic macrophyte uptake. P_{reactive} and $P_{\text{dissolved}}$ present similar behaviours in all regions, suggesting a relative equilibrium between phosphorus from particulate and solubilised materials.

At points 27BU and 12IA, TP concentrations were considerably higher than dissolved and reactive forms (Figure 7). This suggests that a large proportion of TP found was in organic form, with predominantly non-soluble molecules, or as attached to clay materials. Higher increments observed for phosphorus in water can be attributed to its significant fixation with aluminosilicates (Mackenthun *et al.*, 1964). From this, phosphorus could come from the dragging of organic particulates, litter, agricultural crop residue or organic waste from farm activities such as fishing, while the source of mineral inputs can be fertilisers and aluminosilicates.

At point 52MR, rainfall had little influence on the observed phosphorus forms, confirming that with greater river flow, a greater amount of rainfall is required to bring about significant changes to normal phosphorus levels (Figure 7).

TP load behaviour

Generally, increases in flow result in increases in TP loads. In addition, when a particular segment of the river is measured during a rainfall event, the dragging potential of particulate materials by run-off and the solubilisation potential of chemical

elements are the determining factors in higher or lower loads. Obviously, both transport and solubilisation processes depend on morphological, physical, chemical and biological features.

During the observed drought condition, TP load at 52MR was 2.8 kg/d, for an estimated flow of 0.185 m³/s (Figure 4). This load can be considered low, as was the water flow, which was four times lower than the average flow reported in the publication by the State Government of Paraná (SGP, 2000) of 0.430 m³/s. The maximum TP load for the maintenance of a mesotrophic state in the Iraí Lake is limited to 18.7 kg/d (Franz *et al.*, 2007). However, the results of another study (Gobbi, personal communication) suggested that the TP load should be less than 2.3 kg/d for the maintenance of a mesotrophic state.

Under conditions of low-level rainfall (drizzle of 4.9 mm), the increased flow led to an increased TP, reaching 6.01 kg/d, 214% higher than the drought load observed at point 52MR (Figure 5). During this event, the highest TP load (7.37 kg/d) was observed before the river mouth (point 80AU). This is likely due to the location of the sampling point, which is downstream of pollution inputs from an urban area, where infiltration is reduced and run-off is increased, and downstream of point 27 (IA), where the highest amount of rainfall occurred.

During medium-rainfall conditions (16.8 mm), significant variations in TP loads did not occur at points 27BU and 12IA (both influenced by agriculture and livestock) (Figure 6), except for a slight peak at 56 min at point 12IA. Therefore, agricultural land use with pastures and riparian forest delayed and retained possible TP loads. Additionally, the points within urbanised areas had flow and TP concentration peaks earlier and with greater intensities.

At 47 min, point 80AU showed an increase in TP concentration, which is likely related to the incoming of run-off causing a load peak. Later, even with increased flow (55–66 min), the load intensity decreased, suggesting that the wetting front was responsible for the greater phosphorus load.

Point 52MR is the last point in the Timbú River waterway and can be considered the most representative point for measuring total load inputs from the basin to the reservoir. The variation in flow caused by the medium rainfall (16.8 mm) was considerable. Before the rain, TP load was 8.8 kg/d, and during flow peak, it reached up to 175.3 kg/d; 14 h after rainfall, the load regressed to 12.2 kg/d, slightly higher than pre-event levels. These values highlight the importance of rainfall events for phosphorus loads, even in drizzle conditions (low-intensity precipitation). Clearly, samples taken for monitoring water quality must consider pluviometric variables, since the rain events vary significantly and there are uncertainties associated with weather conditions. In these episodic events, phosphorus load metrics assume greater ecological relevance to help management of the downstream standing waters (Stamm *et al.*, 2014). If regulatory authorities cannot increase sampling frequency due to financial or resource constraints, it is recommended to focus in high-flow events during their sampling programmes (Defew *et al.*, 2013).

The estimated TP load from Timbú River throughout 2006 (10 453 kg; Figure 8) were similar to those estimated for the four main reservoir tributaries (including the Timbú River) from 2009 to 2012 as follows: 10 425, 10 623, 9098 and 9387 kg TP/year (Carneiro, unpublished data). This considerable contribution from a single tributary indicates that although improvements in the sanitation system have been undertaken, they are insufficient to solve the problem.

Although medium rain occurred only during 53 d of the year, this condition seems to contribute the largest TP loads throughout the

year (80.8% of inputs). The frequent drizzle conditions (222 d) represent 17% of loads, while drought (90 d) represents only 2.2% of TP inputs (Figure 8).

It is important to highlight that the estimates of catchment discharge and nutrient loads are subject to aleatory and epistemic uncertainties (Hollaway *et al.*, 2018). So, for a broad monitoring quality programme and calibration models, these aspects cannot be neglected.

Conclusions

From quantitative and qualitative chronosequential analysis at different points along the Timbú River – an important tributary of Iraí reservoir – the behaviour of phosphorus concentrations and loads was assessed, taking into account drought and rainfall conditions and based on real measurements.

The analysis of distinct phosphorus forms enabled to distinguish environments related to land use. The water-quality assessment considering different land uses showed that agriculture and urbanised areas provide greater phosphorus inputs compared to forest well-preserved areas. In river and streams with adjacent urbanised areas, considerably higher levels of TP and P_{reactive} were found, independently of rain or drought conditions.

The TP load peaks occurred after the increasing of flow over the points 12IA (intensive agriculture) and 52MR (river mouth), suggesting that the greatest loads came from upstream and, mainly, the preponderant weight of flow in the total load.

At the mouth of the river (52MR), a TP load of 2.8 kg/d was observed in drought conditions. During periods of annual average flow, TP loads of 8.8 kg TP/d can be expected. During rainfall of 16.8 mm, the load reached a maximum of 175.3 kg TP/d (20 times greater), underscoring the influence of diffuse pollution on

Figure 8. TP loads from the Timbú River to Iraí Reservoir in three different weather conditions during 2006: drought, light rain (drizzle – 4.9 mm) and medium rain (16.8 mm)

river water quality. The total phosphorus load should be less than 2.3 kg/d to avoid eutrophication processes in the lake.

The variability in water quality during the presence or absence of rainfall in the basin indicates that management strategies must be based on monitoring programmes in order to account for such wide fluctuations. Furthermore, these programmes should take into account the uncertainties associated with rain events and observational data.

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