

**Detailed response to interactive comments by Anonymous Referee #1 on: “Transport and retention of phosphorus in surface water in an urban slum area” by P. M. Nyenje et al., hessd-10-10277-2013**

**GENERAL COMMENTS**

RC 1.1 The authors present a study that is potentially interesting for a wide audience. Unfortunately, the paper lacks some substantial data in support of the argumentation. The text is also repeatedly unclear in its meaning.

Reply: We thank Referee #1 very much for his/her constructive comments and suggestions. We do acknowledge that some of our interpretations were not supported by data. We have therefore provided additional data in the revised manuscript to support our findings. For example we have included data on saturation indices of phosphate minerals for all the events sampled at the catchment outlet. We also included data on two more rain events that we collected at two locations upstream of the catchment.

We also improved the clarity and coherence of the text. The title was also slightly revised so that it is more informative: *Phosphorus transport and retention in a channel draining an urban tropical catchment with informal settlements*.

**MAJOR COMMENTS**

RC 1.2 The paper lacks proper data about the sediment chemistry and its interpretation. The text is generally unclear about sorption versus precipitation/dissolution control on PO<sub>4</sub>, partly due to lack of data and partly due to sound interpretation. A first shortcoming is that no data about the carbonate content of the sediments is presented, which might be estimated from the 0.43 M HNO<sub>3</sub> extraction or not. From such data, sorption intensities for PO<sub>4</sub> may be estimated using literature values. This could make it plausible or not whether sorption to Ca-carbonates is important.

Reply: Unfortunately, we did not determine the carbonate content in the sediment. Additionally, data on the mineralogy of the sediments in the channels draining the studied catchment or the neighboring catchments is currently not available. However, we have provided other additional information to augment our interpretations. In the revised manuscript, we have included data on the geochemical speciation calculations (using the PHREEQC code), which can provide insights as to whether sorption onto calcite precipitates took place or not. Indeed, our results showed that calcite was near saturation levels and it was likely controlling the concentrations of o-PO<sub>4</sub> in surface water by adsorption of P to calcite precipitates. Our revised manuscript is now much clearer about sorption versus precipitation/dissolution control on PO<sub>4</sub> than the first version.

We also want to clarify that we did not mean that PO<sub>4</sub> was adsorbed to calcite in the sediments. No calcite minerals have been reported in the study area in the past. In addition, the geology of the studied area is characterized by Precambrian rocks predominantly consisting of granite and gneiss and therefore there are no carbonate mineral bearing rocks in the geological formation of the studied catchment area. The only possible source of calcite in the sediment was by mineral precipitation from the

water column.

In the revised version of the manuscript, we have used data from geochemical speciation and the sediment analyses to provide better interpretation of the processes responsible for the retention of P in the bed sediment. We do acknowledge that this was not clear in the first version of the manuscript.

RC 1.3 Second, no aqueous speciation is performed using the water analyses so nothing is proven with respect to the likelihood of Ca-phosphate dissolution or precipitation.

Reply: As mentioned above (reply to RC 1.1 and RC 1.2), we have now performed aqueous speciation calculations using the PHREEQC model code. The results of this calculation have been provided in the results in the revised manuscript. The implications of the results are further discussed in the discussion section. Indeed, our results showed that calcite was near saturation levels, which suggested that it had potential to regulate P by co-precipitation. Other phosphate minerals like vivianite, strengite, hydroxyapatite or  $\text{MnHPO}_4$  were either under-saturated or over saturated implying that they were either not present or not reactive. With these data, we have now provided better interpretations of our findings in the revised manuscript.

RC 1.4 Third, ratios between  $\text{PO}_4$  extracted and Fe, Al or Mn should be inferred and whether these can be interpreted as Fe-hydroxyphosphates, etc. or sorption to oxides. Here, notice should be made about literature data on sorption capacities.

Reply: We have now calculated the molar ratios of Fe and P and we are able to infer whether Fe-bound P was Fe-phosphates or P adsorbed to iron oxides. We have also included the results of two additional bed sediment samples we collected. A molar ratio of  $\text{Fe/P} = 2$  suggests that Fe-bound P was due to precipitation of Fe-phosphates (vivianite or strengite). Higher molar ratios in the sediment ( $\text{Fe/P} > 4$ ) generally suggest that Fe-bound P was due to the adsorption of P to Fe-oxides (Gunnars et al., 2002). We used this explanation and the  $\text{Fe/P}$  molar ratios calculated to conclude whether  $\text{PO}_4$  extracted was due to mineral precipitation or sorption. The following paragraph was added in the revised manuscript:

*"Nutrient ratios are also often used to predict whether the deposited sediment P is produced by adsorption or precipitation reactions or both. A molar ratio of  $\text{Fe/P} \cong 2$  (range = 1.5 - 2.5) suggests that Fe-bound P in the sediment was produced by the precipitation of Fe-phosphates such as vivianite and strengite whereas higher ratios ( $\text{Fe/P} = 3.3 - 9.7$ ) suggest that it was produced by the adsorption of P to Fe-oxides (e.g. Cooke et al., 1992; Gunnars et al., 2002; Clark et al., 1997). For Ca, the limiting Ca:P ratio for mineral precipitation is about 1.7 (Freeman and Rowell, 1981). In our study, both the Fe:P and Ca:P molar ratios in the sediment were too high ( $> 3.6$  for Fe:P and  $> 5.2$  for Ca:P; Table 3) to argue that the precipitation of Fe and Ca phosphates took place. Instead, these high ratios confirm that sediment inorganic P was produced by the adsorption of P to calcite and Fe oxides. These revelations are in agreement with our earlier arguments from mineral saturation indices that the adsorption of P to calcite and*

*Fe-oxides regulated P transport in the studied drains."*

We also added literature data on metal:nutrient ratios from other studies to provide a comparative assessment of our results. This information is provided in the revised manuscript in the "discussion section".

RC 1.5 Last, ratios between organic carbon and organic P should be calculated and compared to literature values.

Reply: One of the ways phosphorus can be released from the bed sediments is by mineralization of organic P (decomposing organic matter). The C:P ratio determines whether there is net mineralisation or net immobilisation. Usually, when the C:P ratio < 200, then net mobilisation is said to occur (Stevenson, 1986). We have now computed the Organic C: Organic P ratios based on the data we collected and we have compared our results with literature values (provided in the discussion section) to provide better interpretations as to whether P was released from the bed sediment or not.

The following paragraph was added in the revised manuscript in the discussion section:

*"Metal/nutrient and C/P molar ratios are often used to indicate P release by dissolution of metal bound P and mineralization of organic P respectively. Fe:P (and Ca:P) ratios < 2 indicate a tendency for PO<sub>4</sub> release from bed sediment (Jensen et al., 1992). Table 3 shows that Fe:P ratios in the water column in our study were very low (< 2) whereas Ca:P ratios were very high (up to 17) indicating that P was potentially released from Fe-bound P in the sediment by desorption. On the other hand, P release by mineralization usually occurs when the C:P molar ratio < 200 (Stevenson, 1986). In our study, the C:P ratios of all sediments collected were less than 200 implying that there was a potential for mineralization of P from the organic P retained in the bed sediment."*

RC 1.6 Additionally, the authors claim to present a first study about P chemistry for unsewered settlements. How does the study of Chua et al. (as cited) refer to it. And it would be interesting to discuss the differences and similarities with P studies in sewerred, urban areas or agricultural areas. What are differences or similarities with respect to speciation, flux, load, and concentrations?

Reply In the first version of the manuscript, we hardly compared our findings with literature data. Hence, our work could not be put in the context of what others had done. The study by Chua et al. (2009) for example provides good comparisons regarding the presence of first-flush effects in urban tropical catchments with rural and urban settlements. This study (Chua et al., 2009), however, did not investigate the geochemical processes governing P transport. In the revised version of the manuscript, we have done a much better search and discussion of previous works. This has been included in the "introduction" and "discussion" sections of the revised manuscript.

## MINOR COMMENTS

RC 1.7 The text is repeatedly unclear in its meaning. Below is a listing of sentences that are unclear or otherwise incorrect.

Reply We have revised the entire manuscript to make the text clearer. We also corrected other grammatical errors that were present. Much of the text has been rewritten to improve on our explanations and interpretations.

RC 1.8 p.1/l.17-18 transport to what and wherein?  
*Original text (in the Abstract): The transport of excessive phosphorus (P) discharged from unsewered informal settlements (slums) due to poor on-site sanitation is largely unknown.*

Reply: To improve clarity, we revised the sentence as follows:  
*"Urban catchments in sub-Saharan Africa (SSA) are increasing becoming a major source of phosphorus (P) to downstream ecosystems. This is primarily due to large inputs of untreated wastewater to urban drainage channels, especially in informal settlements (or slums)."*

RC 1.9 p.1/l.25-27 proof?  
*Original text: We found that P inputs in the catchment originated mainly from domestic wastewater as evidenced by high concentrations of Cl (36 -144 mg/L), HCO<sub>3</sub> and other cations in the channels*

Reply: The presence of high concentrations of Cl, HCO<sub>3</sub> and cations in groundwater and surface water has been used in past studies to indicate the influence of domestic wastewater pollution (e.g. Dejwakh et al., 2012; Schmidt, 1973, Ptacek et al., 1998, Appelo and Postma, 2007; Yang et al. 1999 etc). Indeed Cl is considered an important tracer of wastewater influence in urban areas. In our study, we found very high concentrations of Cl (36-144 mg/L or 1 - 4 mmol/L), HCO<sub>3</sub> (538 mg/L) and cations. It was on this basis that we concluded that wastewater effluents were the main source of P in the channel. In the revised manuscript, we have provided a better explanation regarding the source of P in the studied catchment. We added a sub-section in the discussion section regarding the source of P. Note that during the re-organization of our manuscript, this text and the corresponding explanations were removed from the abstract and incorporated in the body text.

RC 1.10 p.2/l.4 meaning of "strong flush"  
*Original text: High flows exhibited a strong flush of PP and SS implying that part of P retained was frequently flushed out of the catchment by surface erosion and re-suspension of bed sediment.*

p.2/l.7 what is slowly?  
*Original text: Our findings suggest that P accumulated in the channel bed during low flows and then was slowly released into surface water.*

Reply: p.2/l.4 : This phrase was ambiguous in the context presented and has been removed from the text.

The second statement (p.2/l.7; Abstract) was rephrased as:  
*"We also found that the bed sediments were P-saturated and showed tendency to release P by mineralization and desorption "*

RC 1.11 p.2/l.20 on the one hand: where is on the other hand?

Reply: The entire introduction has been revised to improve the coherence in the text.

RC 1.12 p.3/l.14-17 sentence too long and unclear. ion exchange between which species?

*Original text: P retained in bed sediments can, however, be released back to discharging waters either by mineral dissolution or ion exchange (Olli et al., 2009; Fox et al., 1986) or by breakdown of organic matter (Watts, 2000), hence contributing P loads to downstream ecosystems*

Reply: This sentence was rephrased as follows (in the 'Introduction'):

*Original text: P retained in the bed sediments can also be released back into discharging waters by a number of processes, which generally include (e.g. Fox et al., 1986; Søndergaard et al., 1999; Boers and de Bles, 1991): 1) mineralization of organic phosphorus in the bed sediment 2) increased solubility of phosphate minerals and desorption when external P loads are low and 3) release of Fe-bound P following the reductive dissolution of Fe<sup>3+</sup> to Fe<sup>2+</sup> in anoxic conditions.*

RC 1.13 p.3/l.26-29 contribution to what? discharge → load or flux

*Original text: More specifically, our objectives were to: (i) determine the concentrations of the various forms of P discharged from the urban slum catchment during high and low flow conditions,*

Reply We have rephrased the objectives as follows (Introduction):

- (i) determine the concentrations of the various forms of P discharged from the urban slum catchment during high and low flow conditions,*
- (ii) identify the effect of rainfall runoff on the discharge of P, and*
- (iii) Identify the dominant geochemical mechanisms that are likely controlling the fate of P in these channels.*

RC 1.14 p.4/l.18 what is the buffer against pollutants within the context presented

p.4/l.20 degradation → deterioration

p.4/l.23 survival due to eutrophication?

*Original text: Lubigi swamp is one of the largest wetlands in Kampala city and provides a good buffer against floods and pollutants from informal settlements and industries in the catchment. However, increasing degradation and pollution are affecting the ability of Lubigi swamp to buffer nutrients and other pollutants from upstream areas (e.g. Natumanya et al., 2010; Okiror et al., 2009). A similar*

*problem is faced with other wetlands in Kampala, hence threatening the survival of vital ecosystems like Lake Victoria due to eutrophication (Kansiime et al., 2005; Kansiime and Nalubega, 1999; Kelderman et al., 2007),*

We revised the whole paragraph to make it clearer. The revised version (in the section 'Catchment description') now reads as follows:

*"Lubigi swamp is one of the largest wetland in Kampala city and, like many other wetlands in Uganda, it performs a number of important functions such as the retention of the nutrients derived from urban catchments via drainage channels (e.g. Natumanya et al., 2010; Okiror et al., 2009). However, most wetlands in Uganda are being degraded due to extensive encroachment for agricultural activities and infrastructure development. This has hampered their ability to retain nutrients, hence resulting in deterioration of adjacent water bodies such as Lake Victoria due to eutrophication (Kansiime et al., 2005; Kansiime and Nalubega, 1999; Kelderman et al., 2007; Kyambadde et al., 2005; Mugisha et al., 2007)."*

RC 1.14 p.4/l.27 spring water aquifers?

*Original text (catchment description): The regolith soils and fractured rocks are important spring water aquifers in the catchment, which also form head waters of secondary drainage channels*

Reply We have rephrased this sentence to read as follows:

*"The saturated regolith is an important aquifer containing shallow groundwater flow systems that usually discharge as springs in the valleys of the catchment (Flynn et al., 2012; Taylor and Howard, 1998). These springs generally form the upper reaches or headwaters of the secondary channels (Nyenje et al., 2013a)"*

RC 1.15 p.5/l.26 why has SO<sub>4</sub> and total-N not been measured? these compounds are crucial within the context presented.

Reply In the context presented total N was not important because our focus was on phosphorus. Total N also does not affect redox processes, which can otherwise influence the fate of P. Therefore total N was not measured. Sulphate (SO<sub>4</sub>) was measured but this data was not presented in the first version of the manuscript. SO<sub>4</sub> may, however, be important in calculating the saturation indices and also in understanding the redox environment. In the revised manuscript, SO<sub>4</sub> data and the calculations for geochemical speciation using the PHREEQC code have been included.

RC 1.16 p.6/l.22-30 this procedure is somewhat clumsy and I wonder about the error in SS, when subtracting two values from each other

*Original text (methodology): Total dissolved solids (TDS) were not directly measured but estimated by multiplying the electrical conductivity (EC) with a conversion factor of 0.56. The conversion factor was calculated from a linear relationship ( $n = 31$ ,  $r^2 = 0.99$ ) of a series of TDS and corresponding EC values, which were measured during background water quality sampling. The factor we*

*used was within acceptable limits (0.55 - 0.7; APHA/AWWA/WEF, 2005). Total suspended solids (SS) were then calculated as the difference between TS and TDS concentrations*

Reply: For samples collected at the outlet of the catchment, we were unable to determine the total suspended solids directly during the rain events. This is because the samples were very turbid and frequently clogged the filter paper (0.45µm Whatman filter). This made it difficult to determine TSS directly as we did for other samples collected upstream. However, estimating TSS as the difference between TS and TDS is an alternative procedure recommended in standard methods for water and wastewater analysis (APHA/AWWA/WEF, 2005) and in the current version (APHA/AWWA/WEF, 2012).

We have slightly revised this section (see below) to inform the reader the reasons for the choice of the method used.

*"Suspended solids (SS) were calculated as the difference between TS and TDS. Total solids (TS) were determined by evaporating an unfiltered sample in an oven at 105 °C for 24hrs, and then determining the mass of the dry residue per liter of sample, whereas TDS were determined using the same method as TS but on samples filtered using Whatman GF/C filters (APHA/AWWA/WEF, 2005). Samples collected at locations B1 and B4 were very turbid and frequently clogged the filter papers. For these samples, SS were calculated as the difference between TS and TDS estimated from EC as recommended in APHA/AWWA/WEF (2005) in such situations. Here, TDS were estimated from EC using a conversion factor of 0.56, which was computed from a series of TDS and EC values measured during our initial samplings. The factor we used was within acceptable limits (0.55 - 0.7; APHA/AWWA/WEF, 2005)."*

RC 1.17 p.7/l.31 (and p.8/l.6-7) was IP really measured or just calculated as sum of Ca-P and Fe/Al-P. The latter appears to me.

Reply: IP was measured and the procedure we used is described in the section "sequential extraction of phosphorus species from selected sediments". However, during the analysis, we did not use the measured IP. Instead IP was calculated as the sum of Ca-P and Fe/Al-P because we found this approach more representative of the content of inorganic P in the sediment. In the revised manuscript, however, we have compared the values of IP measured with the sum of Ca-P and Fe/Al-P. The following phrase was added in the results section:

*"The measured IP contents (not shown) were close to the calculated values (sum of Ca-P and Fe-P) except for suspended sediments."*

RC 1.18 p.7/l.32 when and where were the samples dried? Immediately after sampling in Uganda, or in the Netherlands. What might be the implication of shifts in the speciation due to e.g. reductive dissolution of Fe-oxides. Can this be excluded?

Reply All sediment samples were dried in Uganda immediately after sampling. Afterwards, they were kept in water tight polyethylene bags until analysis. We are sorry that this was not highlighted in the methodology

We therefore revised the methodology by including the following phrase under the section 'Sediment sampling and analysis':

*"At the Public Health and Environmental Engineering Laboratory, Makerere University-Uganda, the sediments were air-dried for two weeks. All samples were then sieved using a 2 mm sieve, kept in plastic bags and then transported to UNESCO-IHE, The Netherlands, for analysis."*

RC 1.19 p.8/l.14 these P concentrations are huge. What were the remaining concentrations in the incubations and how do they compare to the field data?

*Original text: Thereto, 25 mg of sediment samples were accurately weighed and mixed with 500 ml of 0.01 M CaCl<sub>2</sub> solution of varying initial P concentrations of 0, 20, 40, 80, 100 and 250 mg/L.*

Reply: The P solutions used ranged from 0 to 250 mg P/L. These solutions were prepared using KH<sub>2</sub>PO<sub>4</sub>. These concentrations, although much higher than those present in the channel ( $\cong$  0.4 mg P/L), were needed to establish the maximum adsorption capacity of the sediments. In our initial trial experiments, we first used P solutions ranging from 0 - 50 mgP/L. However, with these concentrations, we did not detect any phosphate ions in solution at the end of the experimental period, which necessitated us to use higher P solutions.

RC 1.20 p.9/l.7 and further these concentrations are no background concentration that refer to a natural condition.

Reply The concentrations measured represent existing conditions and these may indeed not refer to background conditions. This section has been revised to indicate current hydrochemical conditions. Results are therefore present as "the hydrochemistry of drainage channels"

RC 1.21 p.9/l.10+15 notice that Ca is about the same. Calculate saturation state with respect to carbonates, etc. from the data.

Reply: Ca concentrations in the tertiary drain were 2 times higher than in the main drain (Refer to Table 1). However, as recommended, we have calculated the saturation state with respect to carbonates. Table 1 has been revised and it has more hydrochemical parameters. Results are also presented as ranges and means of baseflow concentrations.

RC 1.22 p.9/l.17 low Fe and Mn does not mean not strongly reducing. Under sulphide conditions, Fe and Mn are rather insoluble but it is strongly reducing.

*Original text: Fe and Mn concentrations were also low, which showed that surface water was not strongly reducing*

Reply: We have removed this statement because under certain conditions, e.g. in presence of SO<sub>4</sub>, Fe may precipitate as FeS making it insoluble. However, our results generally showed that the drainage channels were Mn-reducing as explained in the section "hydrochemistry of drainage



channels". The revised text is shown below.

*"The channels were generally anoxic and characterized by low concentrations of dissolved oxygen ( $DO < 1$  mg/L; Table 1) in both the primary and the tertiary channel. Consequently, the concentrations of  $NO_3-N$  were low ( $< 1.6$  mg/L) while  $NH_3-N$  concentrations were high (mean of 10.4 mg/L in the primary channel and 32.4 mg/L in the tertiary channel). With regard to redox sensitive elements, Fe concentrations were very low (mean  $< 0.2$  mg/L) whereas  $SO_4$  concentrations were high (about 10 mg/L; Table 1). The Mn concentrations, although also low, were relatively higher than Fe concentrations (mean values = 0.4 - 0.6 mg/L). Hence, the redox status of the surface water was likely Mn-reducing."*

RC 1.23 p.9/l.27 very flashy response meaning? and of course base flows are relatively constant

*Original text: High flows in Nsooba channel were characterized by a very flashy response whereas base flows were relatively constant with an average discharge of  $0.22$  m<sup>3</sup>/s (Fig. 2).*

Reply This sentence has been removed because this information was not useful in the context provided.

RC 1.24 p.10/l.14-16 clumsy phrasing

*Original text: The mean contribution of PP to TP increased to 87% from 56% whereas that of  $PO_4-P$  was only 9.7% down from 31% of the base flow.  $NO_3-N$  concentrations were lower during E1 compared to base flow conditions implying that dilution was likely taking place.*

Reply: This sentence was not structured properly and has been revised (in the section 'results') as follows:

*"In all rainfall events, there was a simultaneous increase in concentrations of TP and PP (and SS as well) with peak concentrations almost coinciding with the peak discharge of the rainfall-runoff hydrographs (Figs. 3 - 5). Thereafter, base flow concentrations were restored. At the catchment outlet, B1, about 8.6 mm (intensity of 14 mm/h) fell during the first event (28-29 June 2010) producing a peak discharge of  $6.7$  m<sup>3</sup>/s. Subsequently, there was an increase in concentrations of TP and PP and concentration peaks of 4 mg/L for TP and 3.66 mg/L for PP (about 92% of TP) were realized (Fig. 3b)."*

RC 1.25 p.11/l.12 what is a sandy clay loam?

Reply: Sandy clay loam is a type of sandy loam soils, which has more than 52% sand and at least 20 - 35% of clay according to the USDA soil classification system. However, we have opted not to limit ourselves to a specific type of soil classification. We have therefore revised the text as follows:

*"Table 2 presents the results of the soil analyses. The bed sediments had very high values for sand content (from 63 - 83%) and low values for silt content (5 - 11%). Suspended sediments, however, had a high silt content (56%) and low sand and clay contents ( $< 23\%$  each)."*

RC 1.26 p.11/l.15 what about Al or Si as major cations? Remark that it holds for the 0.43 M HNO<sub>3</sub> extraction.

Reply We did not determine Al and Si content in the soil due to analytical limitations. However, as recommended, we have revised this sentence as follows:

*"Based on the 0.43 M HNO<sub>3</sub> extraction we performed, Ca was the dominant cation followed by Fe and then Mn."*

RC 1.27 p.12/l.5-10 text unclear

*Original text: The Maximum P ( $S_{max}$ ) that can be sorbed on the sediments ranged from 820 - 2350 mg/Kg with deeper sediments having the highest sorption potential ( $S_{max} = 2350$  mg/Kg; Fig.5). Shallow sediments had lower values of  $S_{max}$  than the deeper sediments (e.g.  $S_{max} = 1550$  mg/Kg for shallow sediments in Nsooba channel and 850 mg/Kg in the tertiary drain; Fig. 5). This suggested that shallow sediments had a lower sorption potential than the deep sediments. The Nsooba and the tertiary drainage channel system (results of Fig. 3, Fig. 4 and Fig. 5) plotted above the sorption isotherms (see Fig. 6) suggesting that the sediments were less likely to sorb P.*

Reply: This text has been revised as follows:

*"The maximum sorption capacity ( $S_{max}$ ) of the sediments ranged from 820 - 2350 mg/Kg (Fig. 8). Deeper sediments had the highest sorption capacity ( $S_{max} = 2350$  mg/Kg) whereas shallow sediments had lower sorption capacities ( $S_{max} = 1550$  mg/Kg in Nsooba sediment and  $S_{max} = 850$  mg/Kg in the tertiary drain). From Fig. 8, the predicted amount of P sorbed to the sediment based on the measured PO<sub>4</sub>-P concentrations (0.11 - 3.3 mg/L; Table 1) was about 0.02 mg/g (or 20 mg/Kg), which is much less than the sum of the inorganic and the Bray-2 extractable P (1.15 - 1.29 mg/g; Fig. 5). Hence, the sediments were likely P saturated."*

RC 1.28 p.12/l.28-30 scientifically meaningless sentence

*Original text: Most P in the sediment was inorganic associated mostly with Ca and Fe/Al oxides. although organic P was also relatively high*

Reply: This text was revised as follows:

*"Fractionation analyses also showed that the P retained in the bed sediment was largely inorganic accounting for 64 - 80 % of the total sediment P."*

RC 1.29 p.14/l.2 remarkable conclusion when you fear that you have missed the real peaks

Reply We had limited data on rainfall events (only 2 events) at the catchment outlet due to logistic reasons. However, we have presented two more rain events in the revised manuscript, which we collected at two locations upstream of the studied catchment. With this additional information, we are able to conclude that there was indeed flushing of phosphorus mainly in particulate form. However, our data was not intense enough during peak flows for us to conclude that first-flush effects were present or not. We therefore recommended that future studies involving high frequency

monitoring during rain events be undertaken to investigate the presence of first-flush effects and to compare the results with similar other studies.

RC 1.30 p.14/l.20 to p.15/l.9 this interpretation is not sound at all

Reply In this section, we were trying to explain that desorption was taking place basing on the saturation state of the sediment. The release of P from bed sediments can, however, be better explained using nutrient and metal ratios (Fe/P, Ca/P and Organic carbon: organic P). We have revised this section accordingly taking into account the P saturation state of the sediment and the nutrient and metal molar ratios.

We added this paragraph in the discussion section under the sub-section 'P release'.

*"Metal/nutrient and C/P molar ratios are often used to indicate P release by dissolution of metal bound P and mineralization of organic P respectively. Fe:P (and Ca:P) ratios < 2 indicate a tendency for PO<sub>4</sub> release from bed sediment (Jensen et al., 1992). Table 3 shows that Fe:P ratios in the water column in our study were very low (< 2) whereas Ca:P ratios were very high (up to 17) indicating that P was potentially released from Fe-bound P in the sediment by desorption. On the other hand, P release by mineralization usually occurs when the C:P molar ratio < 200 (Stevenson, 1986). In our study, the C:P ratios of all sediments collected were less than 200 implying that there was a potential for mineralization of P from the organic P retained in the bed sediment."*

RC 1.31 p.15/l.10-16 the two concluding findings seem conflicting to me

*Original text (under discussions): Overall, our findings suggest that there were two main sources of P inputs in Nsooba channel (i) external loading from wastewater releases from slums and (ii) internal loading from P released from bed sediments. During storm events, however, suspended sediments and P (in particular PP) increased with magnitude of runoff events suggesting that resuspension of bed sediment and erosion from the urban surface were likely the dominant factors controlling P discharge during high flow events. The transport processes described above are illustrated in Fig. 9.*

Reply This section has been revised after interpreting the results of the saturation indices of phosphate minerals and the nutrient molar ratios. Our revised text (in the discussions) now reads as follows:

*"This study has provided useful insights into the processes regulating the transport of sanitation-related phosphorus in drainage channels in a typical urban slum catchment. We showed that the adsorption of P to Fe-oxides in the sediments and to calcite precipitates in the water column played an important role in limiting P transport to downstream areas. We have also demonstrated the presence of flush-effects and the role of the channel-bed sediments to release phosphorus back into the water column. Knowledge of these processes is crucial in developing process-based water quality models, which can aid policy and decision making regarding strategies to reduce nutrients exported from urban catchments. A complete understanding of these processes, however, requires more research to be carried out in these types of catchments. Future work could focus*

*on using on-site automated samplers and analysers in order to obtain high-resolution data, which allows for improved understanding (at a much higher scale) of the P transport processes and the trends that occur when hydrological conditions changes."*

RC 1.32 p.15/l.18-20 vague and not truly supported by the data

*Original text: The implication of our findings is that even if P loads from slum areas are reduced through sanitation improvements or by removal of slums, it will take time for P in discharging waters to reduce, because P-saturated bed sediments will continue to release P.*

Reply We did not provide sufficient explanation as to whether desorption was taking place. Therefore our conclusion (that the sediments will continue to release P even when external P loads are reduced) was not supported by the data and the explanations we provided. In the revised manuscript, we have provided additional data as explained earlier and we have undertaken a more rigorous analysis of our results in order to provide better interpretations.

## REFERENCES

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