Hydrology and Earth System Sciences Discussions

Interactive comment on "Impact of phosphorus control measures on in-river phosphorus retention associated with point source pollution" *by* B. O. L. Demars et al.

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Two anonymous referees (R1 and R3) as well as the editor, professor Alberto Montanari, have raised stimulating queries about the paper published in HESSD by Demars et al. (2005). I am addressing the weak points, questions and suggestions below in view of submitting a revised version of the paper to HESS.

1 Reply to anonymous referee 3.

1.1 Typology of diffuse and point sources of the basin.

We only took into account the consented effluents with discharge > 5 m3 day-1. We do not know about the distribution and proportion of P inflows due to septic tank leakages. This was stated both in material and method (p. 41, l. 24-25) and the discussion (p.49, l. 25). These unknown minor effluents were however implicitly included in the

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background loads (B) with diffuse pollution. This can be clearly stated at the beginning of the theory section (p.44, l. 23-24).

Urban runoff would be important to evaluate because they would not be taken into account in the background loads (B). However the River Wensum catchment (down to Costessey Mill) has only small villages and therefore urban run-off were negligible.

River bank erosion is also negligible due to the development of riparian plants such as Glyceria maxima, Phalaris arundinacea, or woodlands along the river channel. Whatever is their importance, these would also be implicitly included in the background loads (B).

1.2 Transport of point sources and remobilisation of in-stream phosphorus

Equation (4) is simply representing how the transport of point sources is altered under changing flow conditions (Q). The underlying dominant processes are net uptake of SRP by the river bed under low flows (see House and Denison 1997, 1998) and mobilisation of river bed sediment under high flows (although those are modest compare to other river systems). See also point 2.3 below.

1.3 Hydrological power law hypothesis

We did not have enough data to test equation (3). However, since submission of the paper we have found more data from the River Bure, adjacent to the River Wensum. The River Bure was previously used in two P budget studies (Moss et al. 1988; Johnes 1996). One stream, unimpacted by point source effluents, the Spixworth Beck, with a catchment area of 40.3 km2, has been monitored weekly during at least two periods (10/1989-10/1990 and 02/1995-02/1996) for which we have recovered the data.

The best fit was achieved with a multiple regression analysis including mean daily discharge Q (m3 s-1) and seasonality W (a categorical descriptor). The new equation for background load is:

(equation 1) $B = a + b_0 Q + b_1 W$

with a intercept, b0 and b1 constants.

From equation (2) of Demars et al. (2005) it follows:

(equation 2) r = (TP - B) / P

with, r observed coefficient of net retention/remobilisation, TP observed TP loads (kg day-1) at the outlet of the catchment, B background TP loads (kg day-1) assessed with equation (1), and P sum of the point source TP loads (kg day-1).

Regression of r against Q was best with a linear equation as follow:

(equation 3) r = c Q + d

with c, d constants.

The hydrological power law hypothesis could therefore not be justified in the light of this revised version. The general results of this revised version were found to be similar. Figures illustrating the regression equations will be provided in the revised manuscript, re-calculations will be performed throughout the entire manuscript, figures 2-5 will be corrected and finally the text will be amended.

1.4 Novelty of the approach.

Previous studies have used interpolation techniques to calculate observed TP loads at the outlet of the catchment (e.g. Moss et al. 1988; Johnes 1996). This technique is underestimating peak flows and prevented to conclude whether the difference between calculated and observed loads represented true retention or missed loads under high flow conditions. Demars et al. (2005) used an extrapolation technique based on the continuous record of discharge Q, similar to what has been suggested in other studies (e.g. Webb et al. 2000). Johnes (1996) introduced a coefficient of retention ('sediment trapping coefficient') to calculate TP load based on river gradient and nutrient concentration. However it was not clear whether the river gradient she used took into account the effect of the weirs (stepped river bed, rather than gradual slope). The novelty in De-

mars et al. (2005) was to introduce explicitly a net retention/remobilisation coefficient (r) based on river discharge (Q). Another novelty was to derive a 'critical flow' function (equation (7)) characterising net retention/remobilisation. The phosphorus mass balance was plotted against the percentage of time flow exceeded. This provides a new approach to assess the impact of nutrient removal under any particular flow, including potential change in 'critical flow' conditions. Finally, errors were propagated and graphed so that the reader can instantaneously have an idea of the uncertainties. These uncertainties are complementary to the coefficient of regression. The text will be amended in the relevant sections.

The approach developed by Demars et al. (2005) will perform best in lowland rivers where background loads are little compare to point source loads and where P storage in the river sediment is only slightly affected during high flows. Both conditions are of general interests since many rivers have been highly polluted by point sources (see e.g. Muscutt and Withers 1996) and most rivers have been engineered all across the lowlands of industrial countries and can potentially have huge TP stores in the sediment (see e.g. Demars and Harper 2002a).

1.6 Other suggestions.

I agree with referee 3 about the management section in the discussion. Alteration will be made in the text. Further comments will be added in the text about reduction of P retention following P treatment. Finally further research will be suggested at the end of the conclusion.

2 Reply to anonymous referee 1.

2.1 P-discharge relationship.

It is not possible to draw general conclusions from Fig 6, p.72 in Demars et al. (2005). First, particulate phosphorus only represent a fraction of the TP loads (20-60% in the River Wensum at Swanton Morley). Second, the phosphorus content of the suspended

particles changes with the concentration of suspended solids (Demars and Harper 2002b, p.27). Finally, there is a tight relationship between TP loads and discharge Q in the River Wensum, r2 = 0.92 (based on 40 samples collected fortnightly at Swanton Morley during 2000-01, including high flow events).

Fig 6, p.72 was presented in the paper to show that the concentration of suspended solids remained low even under high discharge (maximum to about 100 mg L-1) compare to other catchments; see e.g. Kronvang (1992); Evans and Johnes (2004).

2.2 Background P loads

I have shown that a tight relationship exist between TP loads and discharge Q in the River Wensum below the impact of major point sources. The new data from Spixworth Beck (see section 1.3) illustrate that this relationship is not so strong in catchment not impacted by point sources and that other variables are important such as seasonality.

Equation (1) above is assessing relatively well the amount of background TP loads B for the purpose of this study (r2=0.39). A figure will be provided in the revised manuscript. Of course, there is a whole range of factors other than mean daily discharge Q that can alter TP loads in streams, but the data collected by governmental organisation is generally not sufficient to test individual parts of more complicated models.

More intensive monitoring in catchments not impacted by point sources would be necessary to explore the well known effects of timing of peak flows ('first flush effect').

Note that the background P loads are taking into account a whole range of processes because they were based on in-stream samples from catchment not polluted by point sources (refer to the theory section of the paper).

2.3 Elasticity in the retention/remobilisation equation

Referee 1 states that normally one would expect a lag between retention and remobilisation. Referee 1 is thinking in terms of gross retention and gross remobilisation, but our approach has introduced a coefficient of net retention/remobilisation. Elasticity is

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therefore implicitly taken into account. R1 should also refer to the discussion section p.50, l.17-20.

This confusion between gross and net retention/remobilisation also explain point 8 raised by referee 1, where (among other processes) floodplain processes are implicitly taken into account in our coefficient of net retention/remobilisation.

2.4 TP storage in river bed sediment.

Our approach did not take into account the storage of TP in river bed sediment. It implicitly assumed that TP storage is not depleted after high flow events. Peak flows in calcareous rivers are generally not very powerful. There are also many weirs where flow energy is dissipated. And upstream from the weirs, there are impoundments where silt accumulates (up to 0.5-1.5 metres thick). A weir of several metres high can create siltation of the river bed on several kilometres due to the gentle slope of the River Wensum 1.1 m km-1 (see Demars and Harper 2002b). Finally the silt has a high content of TP: 2.3(more or less 0.7) mg g-1 (Demars and Harper 2002a). In conclusion, huge stores of TP exist upstream from the weir. During high flows a relatively small proportion of this pool of TP is washed down the system. This has probably explain the tight relationship between discharge Q and flow, and allowed us to simplify dramatically our approach.

Fornightly or monthly data collected by governmental agencies generally do not allow to study successions of single events to test for the 'first flush' event. Here since TP loads were found to be tighly linked to river discharge Q, there is no reason to suspect that this 'first flush' event was important to take into account in this type of river system impacted by point sources and weirs. This would not be the case for catchment not polluted by point sources (see section 2.2 above)

Different river systems behave differently as highlighted in our introductory section (p.40, 6-14) and as shown by the massive TP retention of the River Wensum.

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2.5 Calibration and standard errors.

Previous lack of data led us to be rather pragmatic. However with the Spixworth Beck data (see section 1.3 above), we can easily assess the standard error of the parameters a, b0, b1. The relative uncertainty of the background load B will even be considerably reduced. The goodness of fit of equation (1) above is r2=0.39.

The goodness of fit of equation (2) above is r2=0.73 and r2=0.85 for the before and after P removal periods respectively. The standard error of c and d can now be obtained as suggested by R1.

2.6 Parameterisation before and after P control

The retention coefficient will change with change in point source loads. If the point source loads decrease, then one would expect less net retention under low flows and less net remobilisation (after a possible delay) under high flows. Therefore it is necessary to calculate the parameters c and d before and after phosphorus stripping. It would be interesting to see how sensitive r is to change in point source TP loads.

2.7 Background loads

Referee 1 raised a fair point. We did not provide an independent tests for equation (3) and (4). Corrections will be made as suggested by R1 (see section 1.3 and 2.5 above)

2.8 Additional figures.

Figures requested by R1 will be provided with associated uncertainties.

2.9 Flow duration curve.

R1 correctly spotted a mistake: the TP mass balance was plotted against the percentage of time flow exceeded, not the flow duration curve as stated p.53 l. 4. R1 should note that we clearly and correctly defined the flow duration curve p.46, l. 12-15; and that Fig. 5, p.70 is not a cumulative distribution. Fig. 3, p.66 for example is a cumulative distribution.

2.10 typographic mistake

In line 16 of page 40, one should effectively read downstream.

3 Reply to professor Alberto Montanari

3.1 Novelty of the approach.

I have already dealt with this in section 1.4. To my knowledge (see the list of references in Demars et al. 2005) our approach is novel and demonstrate unambiguously the huge sediment retention in a lowland river impacted by both point source pollution and past engineering works. It does demonstrate that all rivers do not behave in the same way (see also Evans and Johnes 2004). The revised version of the manuscript will make this clearer. Further comments and references will be introduced in section 3 as suggested. Our regression approach is just an extrapolation technique, rather than 'modelling', and for modellers our approach could be taken as a null model (in similar types of rivers).

3.2. Performance and capability.

The goodness of fit equation (3) and (4) has now been presented above (section 2.5). The goodness of fit of a revised version of equation (5) in Demars et al. (2005) is r2=0.79 and r2=0.89 for before and after P removal periods respectively.

I agree fully that the regression coefficient provided above referred only to the calibration step. As it stands, the abstract of the paper could be misleading in that respect. We have used a long term data set, but there are not many high flow events. It looked reasonable however to split the data of the 1990-1999 period (before P removal) in two periods to conduct the test as suggested: 1990-1995 (six years) and 1996-1999 (four years). The first period of record (1990-95) was used to parameterize equation (2) above. The second period (1996-99) was used to calculate the predicted TP loads. Finally the predicted TP loads were regressed against the observed TP loads of the second period. The goodness of fit and the values of the parameters were similar for

equation (2) above: r2=0.74. The goodness of fit of a modified version of equation (5) in Demars et al (2005) was slightly higher, with r2=0.85 (compare to r2=0.79). However the expected 1:1 slope relationship between observed and tested TP loads dropped. Figures will be provided to illustrate this. The first period (1990-95) seemed to have more odd data points under low flow conditions which may be due to phosphorus analytical errors (P concentrations tended to be extremely high, several mg L-1; see also p. 44, l-2-5). This would explain the increase in goodness of fit between the two periods.

Our approach should perform well as long as mean daily discharge Q is a good predictor of TP loads.

3.3 Minor comments

The confidence bands provided were relative uncertainties (standard deviation divided by the value, noted delta x/x). This can be made clearer in section 4.2 of the paper.

The long term data set used to calculate the flow duration curve were based on the period 1990-2001.

We effectively calculated the monthly errors by summing up the daily errors. This solution does not overestimate the total monthly errors because the added errors are not independent and therefore do not cancel out each other.

From Fig 5a p.70, it seems that the critical discharges are the same and this is what I would expect if TP was mostly carried downstream by a physical process. This physical process will not be altered by P removal. My hypothesis is that the removal of the weir would have a more dramatic effect on the whole TP dynamics!

I would not draw strong conclusions about the change in critical discharge in the second industrial scenario because of the wide uncertainties.

New data (section 1.3) have allowed to reduce uncertainties in background load B. Further contacts with a poultry processing industry (accounting for 56% of industrial TP loads) revealed that the effluent of the plant do run at the consented maximum

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daily flow during the week, but not at the week-end. In the revised version of the manuscript we will therefore only be running one scenario with industrial phosphorus load calculations based on 80% consented maximum daily flow. Uncertainties will therefore be more reasonable throughout the manuscript.

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