Assessment of sediment-fixed nutrient export from small drainage basins in central Belgium using retention ponds

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Abstract Sediments deposited in eight small retention ponds in central Belgium were sampled and analysed for P, K, Mg, Na and Ca-content to study the spatial variation in sediment-fixed nutrient export. For drainage basins ranging from 7 to 1400 ha, total P export varied from 0.53 to 4.82 kg ha^{-1} $year^{-1}$. These high values of nutrient losses are primarily attributed to high sediment yield values and, to a lesser degree, to the moderately high nutrient content of the sediments. The total P content varied from 0.51 to 1.09 mg P per g sediment. Nutrients are predominantly fixed on the very fine sediment fraction. If a retention pond is not capable of trapping the fine sediments, more nutrients will be delivered downstream.

INTRODUCTION

Nutrients applied in agriculture are often fixed to soil particles (e.g. Clark *et al.*, 1985; Sibbesen, 1995). Soil erosion and delivery processes are therefore responsible not only for high sediment loads in rivers, but also for high concentrations of nutrients found in rivers and river-bed sediments. This can lead to severe eutrophication, certainly in the case of phosphates, with major impacts on the aquatic ecosystem (Clark *et al.*, 1985). To tackle this problem, control measures should be taken. However, before appropriate measures can be taken, it is necessary to define those areas which significantly contribute nutrients to the drainage system. This can be done by analysing the nutrient content of suspended sediment taken at regular time intervals at gauging stations (e.g. Steegen *et al.*, 1998). Such techniques can provide information on the temporal dynamics of sediment and sediment-fixed nutrient export. However, this requires not only the use and maintenance of expensive monitoring equipment, but also a lot of time for collecting and analysing the suspended sediment samples. Therefore, these methods are most often limited to selected study areas. An alternative, but much less expensive, technique for revealing the spatial variation of sediment-fixed nutrient export is the study of sediments deposited in small retention ponds. Many small ponds in central Belgium are currently being studied for estimating sediment yield values (Verstraeten & Poesen, 1999). In this study, sediments sampled in eight retention ponds in central Belgium were analysed for their nutrient content, with particular attention to total phosphorus.

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RESEARCH SITES AND METHODOLOGY

In central Belgium, more than 100 retention ponds have been built for preventing small-scale flooding of housing and roads over the past few decades (Verstraeten & Poesen, 1999). Their size ranges from 50 m^3 to more than 5 million m^3 corresponding with drainage basins ranging from 7 to 50 000 ha. Central Belgium is characterized by silt loam and sandy silt loam soils and a rolling topography. Arable land occupies approximately 45% of the area. Soil erosion and sediment delivery are quite substantial and cause rapid siltation of the many retention ponds.

Eight representative retention ponds were selected for studying the sediment-fixed nutrient export (Fig. 1). Volumetric sediment accumulation was measured yearly with an automatic theodolite. Submerged samples, or samples of highly saturated sediments, were taken with a piston corer which has a clear perspex tube (internal diameter = 57 mm) with an inflatable valve at the bottom, to prevent sediment losses when lifting the corer to the surface. Aerated sediments were sampled by using a thin-walled metal corer (internal diameter = 37.8 mm). Dry bulk densities of the sediments were measured by weighing the oven-dried (24 h at 105°C) sediments and dividing the dry weight by the volume the sediment sample occupied in the corer. Sediment texture was obtained by laser diffractometry using a Coulter LS-100 and converted to sieve-pipette values by using the equations of Beuselinck *et al.* (1998). The nutrient content (total P, Mg, Na, Ca and K) of the sediments was determined by multi-acid digestion (HNO_3/HCl) of the sediment samples according to DIN 38414/S7 followed by ICP spectrometry.

The sediment-fixed nutrient export value for each basin draining to a retention pond was calculated by:

$$NE = \frac{SV \sum_{i=1}^{n} dBD_i \, NC_i}{n \, A \, TE_n} \qquad (1)$$

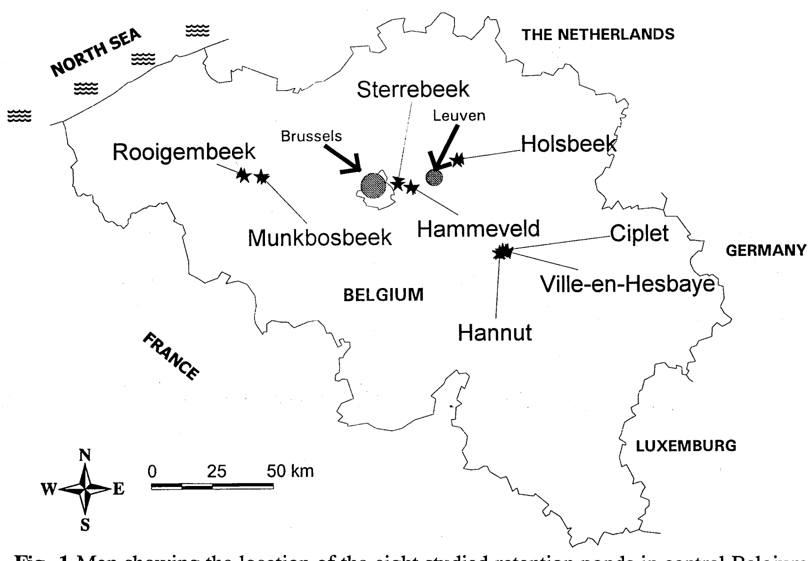

Fig. 1 Map showing the location of the eight studied retention ponds in central Belgium.

where *NE* represents the sediment-fixed nutrient export (kg ha^{-1} $year^{-1}$), *SV* the measured volumetric sediment accumulation rate (m^3 $year^{-1}$), dBD_i the dry bulk density of sediment sample *i* (t m^{-3}), NC_i the sediment-fixed nutrient content of sample *i* (mg g^{-1}), *n* the number of samples, *A* the drainage area (ha) and TE_n the nutrient trap efficiency of the pond (%). The nutrient trap efficiencies of the ponds were not determined and the sediment trap efficiency (*TE*) was used in the application of equation (1).

Within the retention pond at Ciplet (Fig. 1), multiple cores were taken to identify sedimentary events. Both sediment texture and nutrient content was determined in more detail for these sediment profiles.

RESULTS AND DISCUSSION

Nutrient content of sediment samples

The nutrient content of the sediment samples shows large variations between the selected retention ponds (Table 1). Even within a single pond, a high variability could be observed (Table 1). Total P content of a single sediment sample, for instance, varied from 0.26 mg g^{-1} as the lowest measured value in the Hammeveld pond, to 2.06 mg g^{-1} as the highest measured value in the Holsbeek pond. Mean total P content for each retention pond varied from 0.51 to 1.09 mg g^{-1}. Similar observations could be made for Na, K, Mg and Ca. Additionally, there does not seem to be a good correlation between the nutrients in each pond. Sediments in the Holsbeek retention pond, for instance, have very high values of total P, K and Na compared to other ponds, but rather low values for Ca. This suggests that differences in the presence of sediment-fixed nutrients and their delivery exist between the selected drainage basins.

The measured values are comparable to those found in other studies. De Boer (1994), for instance, measured the nutrient content of lake sediments from agricultural basins in the Canadian prairies for which the P content ranged from 0.25 to 1.75 mg g^{-1} and that of Mg from 2.5 to 10 mg g^{-1}. The total P content of the sediment flowing into a small agricultural retention reservoir in Missouri was 0.45 mg g^{-1} (Schreiber & Rausch, 1979).

Table 1 Nutrient content of sediments in eight retention ponds in central Belgium.

Retention pond	*n*	Total P (mg g^{-1}):			Ca (mg g^{-1}):			Mg (mg g^{-1}):			K (mg g^{-1}):			Na (mg g^{-1}):		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Ciplet	8	0.64	0.87	0.74	2.43	3.20	2.82	0.07	0.08	0.07	2.80	2.87	2.83	2.60	3.24	2.92
Hannut	4	0.49	0.54	0.51	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Hammeveld	10	0.28	0.83	0.53	1.51	3.71	2.32	0.04	0.09	0.06	1.74	3.21	2.40	1.73	3.54	2.47
Holsbeek	6	0.32	2.06	1.09	6.42	18.02	12.97	0.07	0.23	0.14	1.04	3.43	1.99	2.51	4.62	3.78
Munkbosbeek	4	0.30	1.20	0.68	1.19	3.00	2.02	0.05	0.10	0.07	3.46	9.64	4.95	1.17	3.05	2.19
Rooigembeek	5	0.26	1.98	0.91	0.81	4.78	2.14	0.06	0.23	0.10	2.38	18.05	6.23	1.34	5.26	2.51
Sterrebeek	4	0.51	1.29	0.77	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ville-en-Hesbaye	5	0.67	1.25	0.91	2.52	4.61	3.62	0.06	0.10	0.08	2.82	7.12	4.51	2.63	4.46	3.50

n = number of sediment samples.
n.a. = not available.

For suspended sediments, it was concluded from previous studies (e.g. Steegen *et al.*, 1998; Sibbesen, 1995) that nutrients, and in particular phosphorus, are primarily fixed to clay-sized particles. However, when the total nutrient content for each sediment sample was considered, no relationship with sediment texture was found in this study. This was not surprising because the sediment samples were a mixture of many sedimentation events with different magnitudes. However, for the cores taken in the Ciplet retention pond (and analysed in more detail), the correlation between nutrient content and sediment texture was clear (Fig. 2). In these cores, four sedimentary events could be identified. At the bottom of each event layer, light coloured sediments were found which primarily consist of coarse silt and fine sands, while at the top of each event layer, very fine silt and clay is deposited as a dark

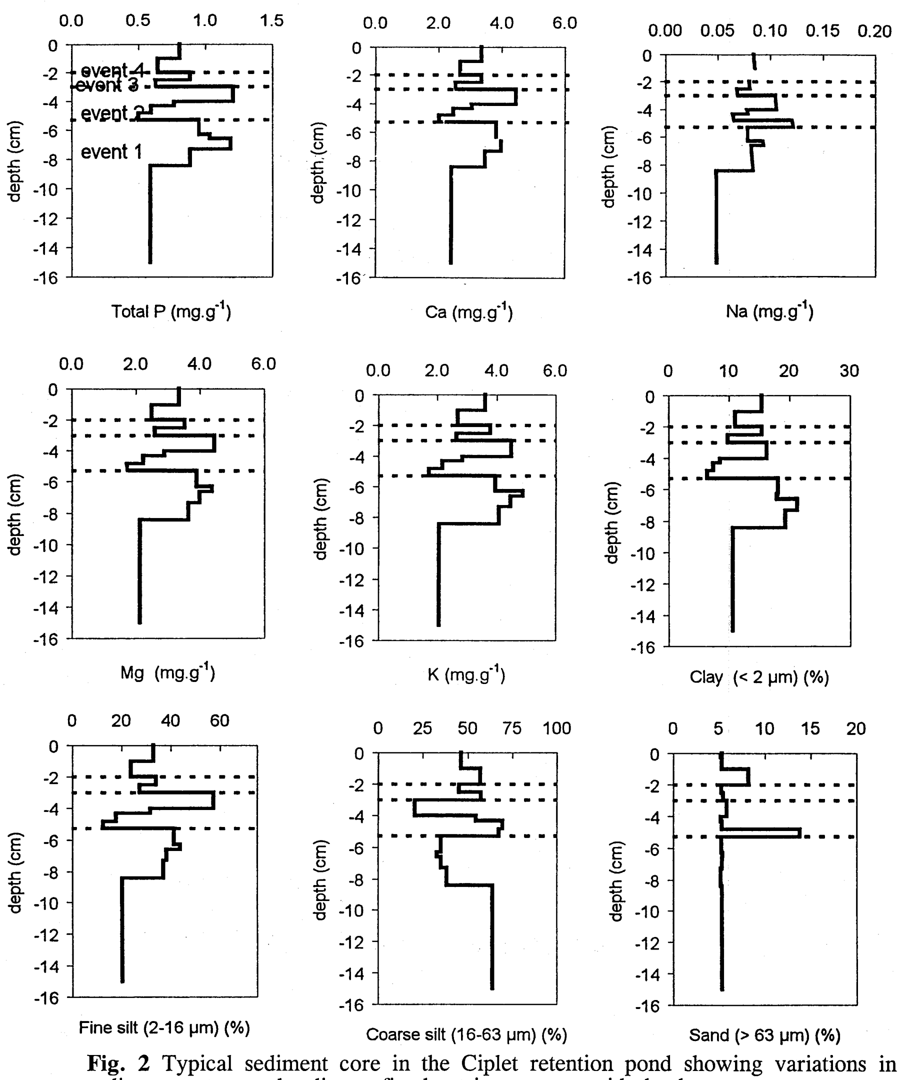

Fig. 2 Typical sediment core in the Ciplet retention pond showing variations in sediment texture and sediment-fixed nutrient content with depth.

coloured sediment. A distinctive difference in nutrient content can be observed: the bottom of each sediment layer is very poor in nutrients compared to the top sediments. It can also be observed that, for individual events within one pond, there is a good correlation between all nutrients. The relationship between nutrient content and sediment texture for the profiles sampled in more detail is therefore very good compared to such a relationship using bulk samples covering the total sediment depth (Fig. 3). The rather low variation in nutrient content with sediment texture for the bulk samples is due to the mixing of layers with high and low nutrient content, obscuring the correlation.

These results suggest that the use of retention pond sediments provides good data only for the study of bulk nutrient content, not for detailed analysis of relationships between sediments and nutrients, unless sedimentary units can be distinguished in core profiles.

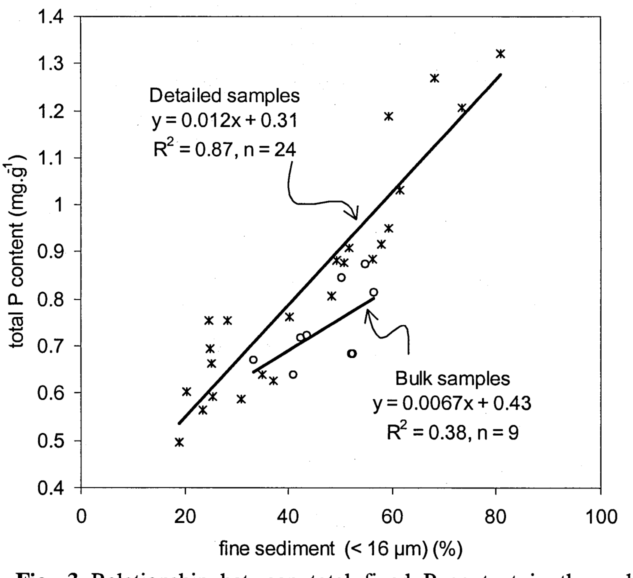

Fig. 3 Relationship between total fixed P content in the sediment and sediment texture both for detailed samples taken in the Ciplet retention pond and for bulk samples covering the total sediment depth.

Sediment-fixed nutrient export

Table 2 presents the sediment-fixed nutrient export values for each drainage basin as calculated by equation (1). Total sediment-fixed P export ranged from 0.53 to 4.82 kg ha^{-1} $year^{-1}$. This range is much larger than the range in mean nutrient content of the sediment samples taken in each retention pond, which is attributed to a larger range in sediment yield values. Although the mean nutrient contents for the sediments in the Hannut and Hammeveld retention ponds are similar, the large difference in sediment yield values results in a large difference in nutrient losses for these drainage basins. Nutrient losses, and in particular phosphorus losses, from agricultural drainage basins are quite high. The measured nutrient export values are similar to those

Table 2 Sediment yield and sediment-fixed nutrient export for selected drainage basins in central Belgium.

Retention pond	Drainage area (ha)	Sediment yield (t ha^{-1} $year^{-1}$)	Sediment-fixed nutrient export (kg ha^{-1} $year^{-1}$): Total P	Ca	Mg	K	Na
Ciplet	151	1.32	0.84	3.32	3.39	3.29	0.09
Hammeveld	29	9.23	4.82	22.10	22.80	21.40	0.55
Hannut	73	1.98	0.53	n.a.	n.a.	n.a.	n.a.
Holsbeek	260	4.31	4.41	7.95	16.47	7.10	0.43
Munkbosbeek	1104	0.90	0.59	4.25	1.89	1.81	0.07
Rooigembeek	1407	4.69	3.57	24.42	10.33	8.57	0.40
Sterrebeek	7	6.51	2.95	n.a.	n.a.	n.a.	n.a.
Ville-en-Hesbaye	103	1.83	1.46	7.28	4.97	5.75	0.13

n.a. = not available.

measured from continuous suspended sediment monitoring programmes in central Belgium, from which Steegen *et al.* (1998) reported total phosphorus losses of 0.6 and 8 kg ha^{-1} $year^{-1}$ for drainage basins of 150 and 250 ha, respectively.

The calculated nutrient losses should be considered as minimum values. In applying equation (1), an estimation of the sediment trap efficiency was made. However, since most nutrients are fixed to the finer particles and the efficiency of a pond for trapping these finer particles is normally lower than that of the bulk sediment, it is expected that the trap efficiency of sediment-fixed nutrients is lower than for sediment. This was observed for a reservoir receiving inflow from a farmed basin in Missouri (Rausch & Schreiber, 1981). Here, it was found that the sediment trap efficiency over a three-year period equalled 85% whilst the total P trap efficiency for this period was 77%. For a selected runoff event, the sediment trap efficiency of a retention pond in Ohio was 88.6%, whereas the total P trap efficiency was only 56.1% (Bhaduri *et al.*, 1995). The difference between sediment and nutrient trap efficiency will depend on the ability of the pond to trap the fine particles and on the relative presence of these fine particles in runoff.

The results suggest that a substantial reduction in delivery of nutrients to a river system can be done best by: (a) controlling soil erosion and sediment delivery, and (b) constructing retention ponds having a high trap efficiency for the fine sediment fraction.

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