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Separate in-situ entrapment of sand and silt in river systems

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ABSTRACT Problems of erosion and sediment transport in river basins are not necessarily caused by large-scale soil erosion. During the last 50 years, comprehensive land reallotment programmes have been executed in the sandy parts of the Netherlands, which were accompanied by significant improvements of the drainage conditions. This led to a further increase of the already naturally occurring deposition of sand and silt, where the rivers which drain these areas enter the flat alluvial plains. Because of pollution of the sediment by point sources and diffuse sources this results in riverbeds which are heavily polluted. The costs of removing the polluted riverbed material are very high.

The water authority "Hoogheemraadschap West-Brabant" is executing a study on possible actions to alleviate the above-mentioned problems. Those actions will comprise the construction of sand and silt traps, measures to reduce pollution from point sources and diffuse sources and dredging of polluted river bed material. The paper will focus on the objectives of this study, and on the required monitoring programme.

INTRODUCTION

The problem of polluted sediments in riverbeds becomes more and more manifest. By deliberately discharging all wastes into the water (or in the air) mankind has, for a while, been trying to avoid to pay the environmental bill for economic growth. Integrated water management, which as a policy is effected in the Netherlands since 1985, considers water as an ecosystem, thus including the embankment, the riverbed and connecting groundwater systems, and also including the fauna and the vegetation. Within the context of integrated water management the condition of the riverbed material is the biggest challenge the water authorities face. It is a challenge in terms of the necessity to stop the further degradation of the water systems and to arrive at gradual improvement, in terms of the cost of cleaning (which is about DFL.150.- for one cubic meter of polluted sediment) and in terms of the often uncomplete knowledge for solving the problem.

Because of the relatively flat topography of the Netherlands sediment transport in river basins is not caused by large-scale soil erosion, but by more gradually proceeding processes. During the last 50 years comprehensive land reallotment programmes have been executed in the Netherlands for the benefit of agriculture, especially in the relatively high sandy parts. These programmes were accompanied by significant improvement of the drainage conditions. Modern agriculture and intensified land use also resulted in more surface runoff and, consequently, more erosion. Higher flow velocities in the drainage system resulted in an increase of sedimentation where the rivers enter the alluvial plains.

Intensified use of land and the increase of the population resulted also in more dangerous pollutants, originating from both point and non-point (diffuse) sources, and in a greater diversity of pollutants. Due to an increasing number of treatment plants and to the contribution of modern agriculture to pollution the relative portion of diffuse sources to pollution increased. This makes sanitation of the remaining sources more difficult.

Results of the developments mentioned above are an increase in sedimentation in certain areas and a decrease in quality of the sediments. A poor quality of the sediment has negative consequences on the quality of the surface water and hinders the sound development of the (aquatic) ecosystem.
Another result is the growing cost of dredging of sediments, mainly caused by the extremely high costs of treatment of polluted sediments. Dredging is necessary to maintain a certain water depth for shipping and to ensure an adequate drainage. Dredging to improve locally the quality of the riverbed and the quality of downstream surface water also becomes more and more necessary.

In this paper we will first discuss Dutch quality standards for sediment, followed by a discussion of the study area (in the southern part of the Netherlands) and of possible solutions to riverbed pollution, paying particular attention to separate in-situ entrapment of sand and silt in river systems. Thereafter we will describe the sampling strategy for a study on the viability of this approach and on possible locations of these sand and silt traps. We conclude by giving some preliminary results of the study and some conclusions.

DUTCH QUALITY STANDARDS FOR RIVERBED SEDIMENT

The Dutch National Water Management Plan 1989-1994 presents a number of Environmental Water Quality Criteria for water, sediment and suspended solids (Ministry of Roads and Public Works, 1989). These criteria aim to protect the aquatic environment. They criteria are based on several considerations, such as bio-availability, toxicity and biomagnification. The bio-available fraction is estimated by the dissolved fraction. Through the use of equillibrium partitioning, criteria for sediment and suspended solids were derived from the dissolved concentration. The quality of the aquatic environment with respect to a given parameter is assessed in that part of the aquatic environment (water, sediment, suspended solids) with maximum impacts on the local ecosystem (van der Gaag et al., 1991).

The above-mentioned criteria can be seen as a national minimum objective that should be achieved by the year 2000. For sediments the quality standards are defining four quality classes. These classes are:

- Class 1: clean sediment;
- Class 2: slightly polluted sediment;
- Class 3: polluted sediment;
- Class 4: severely polluted sediment.

Because the bio-availability and binding forces in sediments are related to the amount of organic material and lutum the quality criteria depend on these two parameters. In order to classify a given sediment sample it is necessary to compare the amount of pollutants with the quality criteria for a "standard soil" (with 10 % organic matter and 25 % lutum). This results in quality standards that are more severe in coarse, sandy sediments. On the other hand, coarse sediments do not contain as much pollutants as fine, organic sediments.

STUDY AREA

This paper outlines the problem of separate entrapment of sand and silt for the Mark-Vliet river system which is located in the Dutch-Belgium border region (Fig 1). The upper reaches of the Mark-Vliet system drain a relatively high (10-30m above sealevel) region of pleistocene sands, while the lower reaches drain polder districts of holocene clay, more or less at sealevel. The Mark and Vliet drain into Lake Volkerak-Zoom (Fig. 1). Until 1987 this was part of the estuary of the rivers Meuse and Rhine. Due to the construction of dams it became a freshwater lake with a stable waterlevel. At present the lake is clear and eutrophic and has increasing limnologic values. In the nearby future the policy of the Dutch government is to have this lake allotted the status of wetland. To maintain the waterquality it is necessary to minimize the input of nutrients which for a substantial part originate from the Mark and Vliet (Table 1). Due to the eliminated tidal influence in the Lake Volkerak-Zoom sedimentation of polluted material has increased in the lower reaches of the Mark and Vliet. The polluted riverbed material may easily be transported to the Lake Volkerak-Zoom, leading to its further uploading.

TABLE 1 Phosphate sources (tons P/year) for the Lake Volkerak-Zoom.

Country	Upper reaches	Source	Quantity
Belgium	(Mark-Vliet system)	Agriculture	48
		Treatment plants	74
		Other sources	68
the Netherlands	(Mark-Vliet system)	agriculture	75
		Treatment plants	35
		Other sources	65
the Netherlands	(Hollands Diep)		80-130
the Netherlands	(polders directly draining into the Lake Volkerak-Zoom)		60

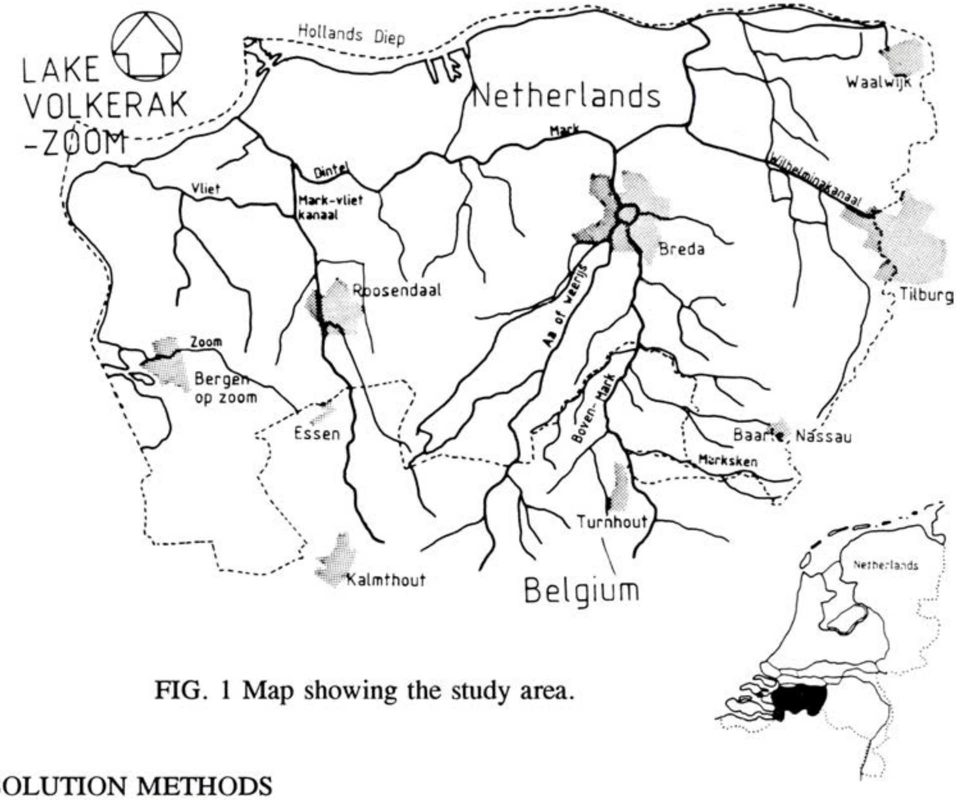

FIG. 1 Map showing the study area.

SOLUTION METHODS

The water authority "Hoogheemraadschap West-Brabant" is executing a study on possible actions to remedy the problems caused by polluted sediments. Of course, the ultimate goal is to eliminate the pollution sources until an acceptable level in the quality of sediment and water is reached. However, it would be unwise to rely only on a source-oriented approach, especially as the three most important sources of pollution are difficult to manipulate. Improvement of the water that enters the region from Belgium is beyond direct control by Dutch water authorities. The same applies more or less to the quality of atmospheric deposition which is the dominant source of Polycylic Aromatic Hydrocarbonates. Also, a reduction of the output of nutrients by agriculture is difficult to achieve, as a substantial part of the soils is saturated with respect to phosphates and nitrates. Hence, a combination of effect-oriented as well as source-oriented actions is aimed at:

(a) Construction of sand and silt traps. This will result in a substantial reduction of the downstream sediment loads.

(b) Dredging of the polluted riverbed material. The construction of sand and silt traps will make possible a durable sanitation of the riverbed downstream of the traps by dredging the polluted sediments. Because of resuspension, the riverbed at present acts as a source for the Lake Volkerak-Zoom.

(c) Sanitation of pollution sources. By law as well because of international treaties, several targets exist with respect to future emission levels (Table 2). It should be realised, however, that these targets are formulated in terms of total emission for a given region. Thus, a water authority can set its own priorities with respect to the localities or sources. As the sand and silt traps will result in a partitioning of the river basin, the priorities should be geared to this. In particular, the objective should be to have as few as possible sources downstream of the silt traps and to have the sand which is trapped to be as clean as possible.

TABLE 2 Emission reduction goals (with respect to 1985) for industrial waste water.

Parameter	Emission reduction in 1995
BOD	10 mg/l (in year 2000)
Nutrients	50 % (N,P)
Heavy metals	≥ 70 % (Hg, Cd, Pb) ≥ 50 % (others)
Organic micro's	50-90 %

A key element clearly is the construction of sand and silt traps. Traditionally, this is not a popular measure among water authorities. First, the construction of sand and silt traps implies that more sediment is trapped within the river basin as a whole. Also, downstream of the traps enhanced erosion will occur and, normally, the material will be deposited in downstream parts of the river. Second, the sediment almost invariably is of poor quality, while the durable improvement of the quality of the riverbed remains questionable. In short, the construction of sand and silt traps will easily lead to a larger quantity of polluted sediment, while the enviromental benefits are questionable. We feel, however, that a combination of actions (properly designed and managed sand and silt traps, dredging, and sanitation of sources) will lead to cost-effective solutions, which are also profitable for the aquatic environment. We will first give one hypothetical example, and will thereafter turn our attention to the proper design and management of the sand and silt traps.

EXAMPLE

The following example shows that theoretically it is possible to separate a polluted sediment (class 3) into a clean fraction (class 2) and a polluted fraction (class 3). Due to the formulae used to calculate the concentrations in a "standard sediment", the separation of sediment into a clean part in sand traps and a polluted part in silt traps only leads to different quality classes if the amount of lutum of the material collected in the sand trap can be reduced below 3% and the amount of organic material can be reduced to below 2%. These are the lower limits used in the classification. The upper limit for organic material is 30 % (CUWVO, 1990).

TABLE 3 Hypothetical class 3 sediment, to be separated in a sand and a silt trap.

Parameter	Concentration in sediment	Concentration in "standard-sediment"	Class
% < 2 μm	4.0	25	
% organic material	3.0	10	
Cr mg/kg dw	11	19.0	1
Cu mg/kg dw	8	15.0	1
Zn mg/kg dw	80	168.4	1
fluoranthene mg/kg	0.2	0.7	2
benzo (k) fluoranthene mg/kg dw	0.25	0.8	3
benzo (b) fluoranthene mg/kg dw	0.35	1.2	3
benzo (a) pyreen mg/kg dw	0.04	0.1	2

Table 3 shows a hypothetical class 3 sediment. The sediment is qualified as class 3 due to its content of Polycyclic Aromatic Hydrocarbons (PAH).

The sediment in Table 3 is characteristic for the riverbed material in the upper reaches of the Mark-Vliet system. Now, what will happen if a sand trap is constructed? The normal effect of constructing a sand trap is to collect more material with a larger proportion of fines, that is, more polluted material. Of course, this is not what we are aiming at. The goal should be to collect more material with a lesser proportion of fines. This means that sedimentation of fines during low flow conditions should not take place, whereas during floods instead of erosion of coarse material, sedimentation should take place. Because of this, the sand trap should be relatively small, and low flows should be diverted by means of a diversion canal. We will return to this later.

TABLE 4 Material collected in the sand trap; hypothetical example.

Parameter	Concentration in sediment	Concentration in "standard sediment"	Class
% < 2 μm	1.0	25	
% organic material	0.8	10	
Cr mg/kg dw	3.8	1.96	1
Cu mg/kg dw	2.0	4.0	1
Zn mg/kg dw	20	45.2	1
fluoranthene mg/kg dw	0.05	0.3	1
benzo (k) fluoranthene mg/kg dw	0.06	0.3	2
benzo (b) fluoranthene mg/kg dw	0.09	0.5	2
benzo (a) pyreen mg/kg dw	0.01	0.1	1

Suppose we can get rid of half of the fine fraction and double the efficiency of entrapment of the coarse fraction. Then Table 4 shows the characteristics of the material entrapped in the sand trap. The sediment in the sand trap is qualified as class 2 due to PAH.

TABLE 5 Material collected in a silt trap; hypothetical example.

Parameter	Concentration in sediment	Concentration in "standard sediment"	Class
% < 2 μm	20	25	
% organic material	15	10	
Cr mg/kg dw	110	122.2	1
Cu mg/kg dw	80	80.0	2
Zn mg/kg dw	800	845.3	2
fluoranthene mg/kg dw	2	1.3	2
benzo (k) fluoranthene mg/kg dw	2.5	1.7	3
benzo (b) fluoranthene mg/kg dw	3.5	2.3	3
benzo (a) pyreen mg/kg dw	0.4	0.3	2

Table 5 gives the results for the material collected in a silt trap downstream of the sand trap. The concentration levels in Table 5 are typical for sedimentation areas in the downstream part of the Mark-Vliet system. They cannot be calculated in a straightforward manner from Tables 3 and 4, because of two additional effects. First, in the downstream parts the soil material changes from sand to clay. Second, where the rivers enter the alluvial plain, there is a concentration of cities and, hence, of industrial activities (Fig. 1). This results is an additional source of fines and pollution. The overall effect is a sediment which is qualified as class 3 (due to PAH).

DESIGN AND MANAGEMENT OF THE SAND TRAPS

The design of the silt trap is not much of a problem. They should be effective in the sense that, after an initial dredging of polluted riverbed sediment, a good quality of the sediment downstream of the silt trap can be maintained. They should be located just downstream of the transition of the sandy region to the alluvial plain. In selecting the location of the silt trap, attention should be given to the location of the most important pollution sources as well.

The design and management of the sand traps is a more difficult problem. They should be located in the sandy region, just upstream of the transition to the alluvial plain. Again, it will be necessary to pay attention to the location of important pollution sources in the final selection of the locations of the sand traps. Despite the wide variation in hydrological conditons the material collected in the sand traps should be coarse (and clean). This means that the sand traps should be relatively small and that during low flow conditions the flow should be diverted. Eventually it may be necessary to use the diversion canal also during extreme flows, in order to avoid erosion of the material already collected in the sand traps. Because of their small size, they will have to be emptied annually.

The design of the sand and silt traps and their effects on downstream riverbed quality will be assessed by model studies. These will be executed by Delft Hydraulics. The theory of sediment flow is rather well established (cf, van Rijn 1984a,b,c). A mathematical description of processes gouverning the quality of riverbed sediment is presented in Delft Hydraulics (1990). Because the latter processes are much more difficult to describe, an extensive monitoring programme is needed in order to calibrate and verify the models used.

SAMPLING STATEGY OF THE STUDY

To collect the required information a sampling programme was designed, covering sediment, suspended solids and water.

Sediment

Distributed throughout the Mark-Vliet watersystem 25 locations have been selected in order to investigate the quality of the top layer (upper 5 centimeters) of the sediment. Each location comprises a riversection of 1000-2000m. In every section one sediment sample has been assembled by mixing 10-20 subsamples. To investigate the particle size of the riverbed sediment the top layer has been sampled on 35 locations, by mixing at each location 20 subsamples. The locations reflect different flow conditions as well as influences from different pollution sources. Fig. 2 shows the location of the sampling sites. Also extensive soundings have been made. By comparing their results to earlier soundings, the sedimentation rate throughout the region has been established.

Suspended solids

On three locations within the watersystem solids are sampled two-monthly by means of a mobile centrifuge and analysed with respect to polychlorinated biphenyls and organochlorine compounds. On 16 locations throughout the watersystem two-monthly water samples are taken in which suspended solids are analysed with respect to metals and PAH. Particle sizes of the suspended solids are investigated by means of laser diffraction. By means of in-situ video photography of fall velocities and field pipette withdrawal tube measurements the fall velocities of the material to be collected in the sand traps will be established. This will also answer the question as to whether the material is really sand or conglomerates. The latter may be polluted. Clearly, these results will be essential in the final judgement of the viability of separate in-situ entrapment of sand and silt.

Water

On the above-mentioned 16 locations throughout the Mark-Vliet watersystem monthly water samples are taken at several depths and analysed with respect to nutrients, metals and organic compounds. These locations are also shown in Fig. 2.

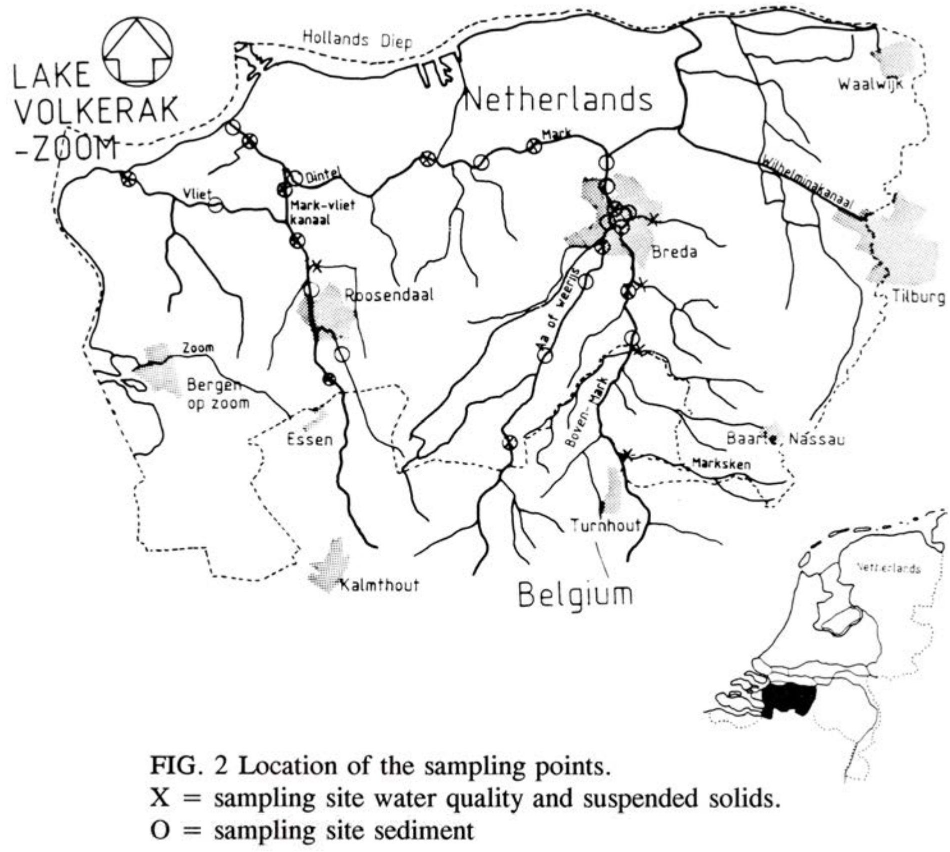

FIG. 2 Location of the sampling points.
X = sampling site water quality and suspended solids.
O = sampling site sediment

PRELIMINARY RESULTS AND DISCUSSION

Preliminary results indicate that the riverbed sediment in the upper reaches of the Mark-Vliet watersystem is locally polluted (class 3). This means that the design and management of the sand traps will be very critical.

The approach of separate in-situ entrapment of sand and silt can only be successfull if it is combined by sanitation of pollution sources. If the approach works, it will offer only a partial solution to the problem. That is, it will result in a reduction of the quantity of polluted sediments, and make possible the sanitation of the riverbed sediment downstream of the silt traps. What remains to be tackled is the way to dispose of the material which is collected in the silt traps: dredging, cleaning and its storage.

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