Integrated river management of a small Flemish river catchment

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Abstract In the framework of an integral water management policy, the sanitation of the water courses in the Flemish region is developed through small-scale projects to study the overall environment of local river catchments. Indeed, the complex processes need a multidisciplinary approach to guarantee successful implementation of water resources strategies. In the Zwalm catchment, a small river basin situated in the interfluve between the upper Scheldt and Dender rivers in the southwest of Flanders, this basic philosophy is explored in a pilot project. Local morphological circumstances require a study that focuses on the sediment transport and its management. A combination of sand/silt river beds, severe land erosion and discrete flood flows indicate the importance of sediment management in the clean-up programme. Sedimentation and transport of fine materials, as a favourite adhesive medium for pollutants, lead to general pollution of both water and river bed in the downstream reaches. Based on extensive field recordings on sediment transport in the river channels, total suspended load in the downstream water reach (15600 t year^{-1}) is revealed to be 100 times higher than the bed load in the corresponding Zwalm channel (140 t year^{-1}). Upstream steep areas (45 % of the catchment surface) deliver about 65 % of the total sediment load. It is clearly identified that, during very limited time periods, discrete flood events transport the main part of the total sediment volume.

INTRODUCTION

The general environmental policy in the Flemish region strives for an integrated water management system to tackle the sanitation of the water courses (Biswas, 1997). Small-scale projects, based on this integrated conduct strategy, have been developed to realize the overall improvement in water quality and river habitat of the Flemish river systems. Sand-silt river beds, severe runoff erosion and major flood flows mean that a sediment transport evaluation is essential. Indeed, mainly moveable, contaminated sediments lead to general pollution of water and river beds in the downstream reaches of the water system. Therefore, the initial principal targets of the water system study can be formulated as:

- sediment transport identification map of the catchment,
- spatial/temporal evolution of the sediment transport over the region,
- practical measures to control sediment mobility in the river branches, and
- formulation of general clean-up strategies.

THE ZWALM RIVER CATCHMENT

The River Zwalm is a small tributary of the River Scheldt, situated in the southwestern part of Flanders in the interfluve between the upper Scheldt and the Dender (Fig. 1). The Zwalm stream rises in the hilly country around the city of Ronse (about 146 m a.m.s.l.) and debouches into the River Scheldt about 20 km upstream of Gent (8 m a.m.s.l.). The longitudinal trajectory of the main stream of the catchment is about 22 km. The Zwalm catchment (area: 116 km^2) has been chosen for a pilot project because of the intensive measuring activities in this area over the last decades. Besides the extensive database on water quantity and quality, a detailed topographic and runoff characterization is recorded for the river basin. Due to the relatively steep slopes in the upper reaches of the catchment and the local river bed load (sand/silt/clay), the river environment is very sensitive to erosion and sediment transport (Shen & Julien, 1993).

This preliminary study also tackles aspects of land erosion, as an input factor for sediment transport in the river itself. A statistical analysis of the digital data on land use, surface characteristics, topography and river basin structure identifies the critical regions for land erosion in the catchment. The well-known empirical USLE-formula (Van Orshoven *et al.*, 1991) is used to estimate the potential wash-load in the river branches. *In situ* recordings are used to validate and calibrate the model. No further details on this runoff study are described as the focus of this paper is the transport of sediments in the river channels of the catchment and not the input of sediments. Practical management measures are suggested, particularly for these sensitive areas. Only an innovative and controlling government can apply these suggested control procedures to avoid land erosion, runoff, land slide, or river bed degradation.

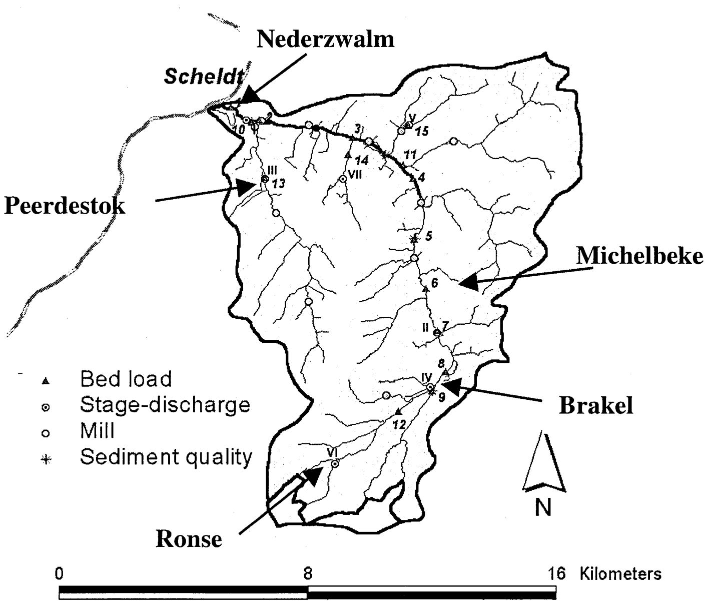

Fig. 1 Map of the Zwalm catchment.

A detailed inventory of the natural environment and its vulnerability is also used as a reference tool to develop engineering solutions (Kirby & White, 1994).

SEDIMENT TRANSPORT MEASUREMENT

Local conditions in the Zwalm catchment indicate the importance of a sediment management approach in integrated water resources engineering. All aspects (from supply by erosion over transport mechanisms to possible sedimentation) are covered in the monitoring and inventory programme. Since flow characteristics form the principal driving forces for transportation and sedimentation of materials in the main streams of the catchment, a detailed inventory and on-line registration of local water levels and associated discharges have been set up in several limnimetric gauging stations. As a result of statistical analysis of the available limnimetric data (over the period 1982–1997), the following flow parameters can be identified: $Q_{1\%} = 8.12\ \mathrm{m^3\ s^{-1}}$ and $Q_{50\%} = 0.74\ \mathrm{m^3\ s^{-1}}$, where $Q_{x\%}$ is the discrete discharge value associated with a water flow that is exceeded for $x\%$ of the time. An illustrative example of the on-line recording of a flood event on the downstream Zwalm reach shows the sharp and quick response to the rainfall of both water level and discharge (Fig. 2).

Besides these traditional hydrodynamic records, a specific measuring programme to record sediment transport phenomena over the catchment has been developed. A complete view on the sediment mobility and appearance is formed by discrete (in time) registrations in 20 discrete (in space) locations on representative river branches of the catchment, during a study period of about four years (1995–1999). Sediment erosion, mobility and deposition are studied within the river system, as well as the spatial dispersion of both physical and qualitative sediment material characteristics.

A specially designed bed load sampler BEDMAN (Fig. 3(a)) and turbidity sensors (Fig. 3(b)) are applied in a practical field configuration to record sediment transport volumes (Van Rijn, 1986).

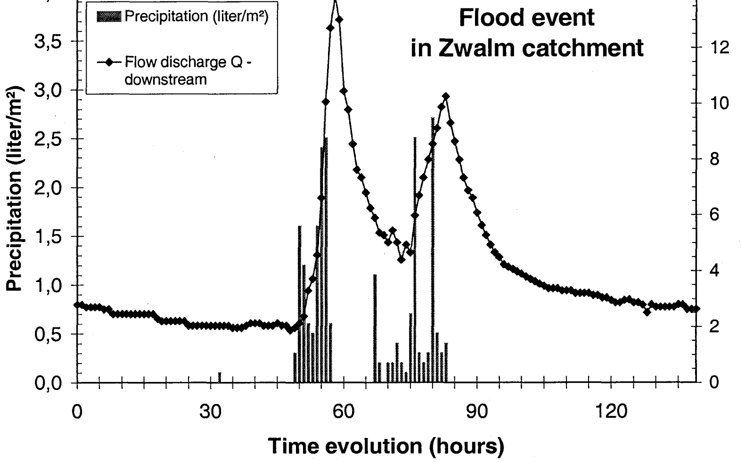

Fig. 2 Flood flow response to heavy precipitation event.

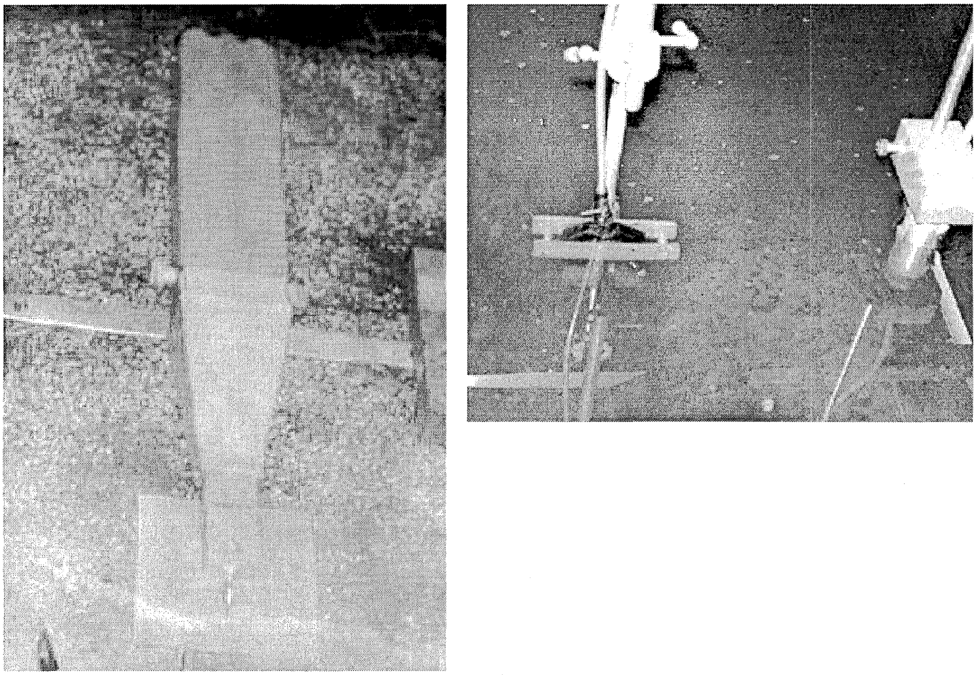

Fig. 3(a) Bed load sampler, BEDMAN and (b) turbidity sensors.

Sediment and river bed quality is identified by both a chemical and ecotoxicological analysis of the collected samples (ASTM, 1993). Chemical analysis shows the actual state of contamination while the ecotoxicological study of the sediments reveals the bioavailable contaminant loads to quantify toxic risk potentials for the river environment. Following a biological evaluation, both analysis results are

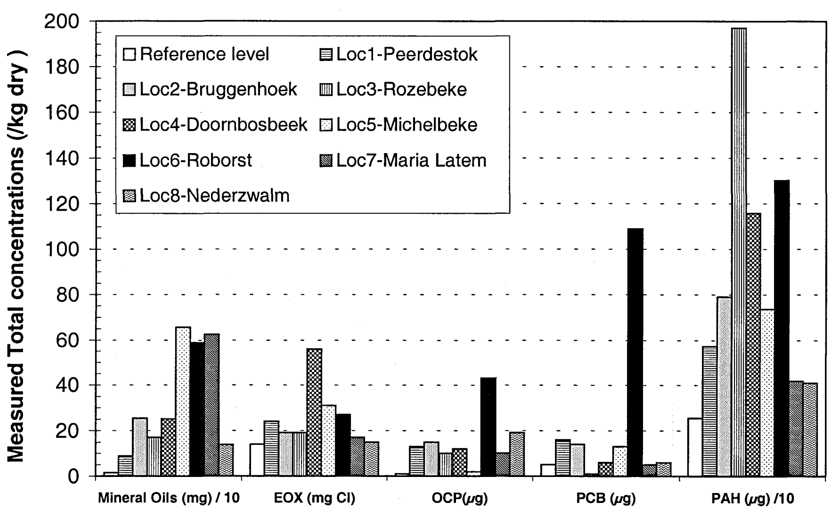

Fig. 4 Sediment quality recordings for river bed samples.

integrated in a so-called TRIADE judgement system, where biological, ecotoxicological and chemical parameters are combined to evaluate the overall quality of the sediment sample. The main pollution in the river bed samples is due to the high levels of organochloride pesticides (OCP) and apolar hydrocarbons (PAH) (Fig. 4). The ammonium contamination (probably due to intensive manuring) seems to be the greatest threat for the aquatic biota. Local sewer overflows disturb the natural development by their abrupt and discrete pollution injection into the system. As a result, the high level of pollution of the transported sediments in the Zwalm River systems compromises the engineering plans to create (natural) flood plains along the downstream river branches. Therefore, one should try to trap the sediments in the upper reaches in order to avoid excessive pollution build-up as they move downstream, and uncontrolled sedimentation downstream. Settlement fields in the upstream part of the catchment both collect transported sediments in a spatially controlled environment and provide an important flood retention facility (Anderson *et al.*, 1996).

QUANTITATIVE EVALUATION OF SEDIMENT TRANSPORT

Detailed sieve analysis of respective sediment samples of both the suspended fraction and the bed material reveals a mainly sand-silt character (Fig. 5). River bed material over the catchment ranges from fine sand (D_{50} = 300 μm) to silt/mud material (D_{50} = 40 μm), while the mean grain size of the suspended material is given as D_{50} = 25 μm with an average organic content of about 4% (measured by calcination at 525°C and filtration). Due to the wide variation in sediment characteristics, appropriate calibration and reference tests under laboratory conditions are necessary to support reliable field recordings of sediment transport (Van Rijn, 1993).

Bed load transport is recorded with BEDMAN in discrete channels and along the main stream of the catchment. Extensive laboratory calibration tests lead to the establishment of a proper efficiency factor of the sampler (about 30%). The samples,

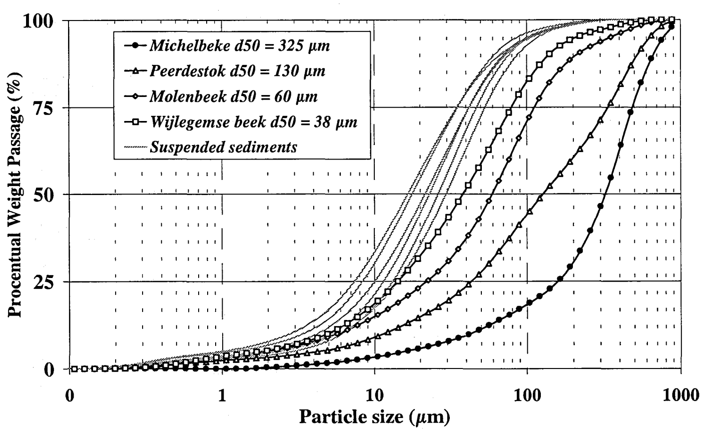

Fig. 5 Grain-size characteristics of suspended sediments and local river bed material.

collected along the main river channels during discrete (in time and place) measuring campaigns, are used to calculate an effective bed load transport volume over the recorded cross-section.

Suspended sediment concentrations are measured by a calibrated turbidity sensor at several recording points over the cross-section to evaluate the concentration distribution. Together with this on-line turbidity registration, traditional auto-pump sampling devices are operated. Thus, an interactive control of the two measuring systems is operated in the field. In combination with a fundamental laboratory study on the reliability and practical use of both measuring principles, an overall evaluation of the quality of the field records on suspended sediment concentrations is obtained. Given an accurate calibration with field sediments, turbidity sensors record the suspended sediment concentration with an overall accuracy of less than 10% of the measured value (De Sutter *et al.*, in press). Due to the fine material, a quite uniform dispersion over the complete cross section is found for all locations in the catchment. Therefore, one single measurement (in the middle of the cross-section, at 40% of the total water depth h above the river bed) as the mean value for the associated cross-section quantifies the total suspended load. A typical evolution of the suspended sediment concentrations with the water flow conditions (flood) for one single event is shown in Fig. 6.

Comparing water flow and associated suspended load for several discrete events, an ambiguous relationship is revealed (Steegen *et al.*, 1998). Depending on e.g. flow history and development, seasonal vegetation variation, groundwater characteristics, local land use or runoff, a certain (identical) river flow may cause a six to eight times higher suspended sediment concentration during comparable flood events (Fig. 7). Comparing the absolute transport volumes, it is clear that the suspended fraction is much more important than the bed load under flood conditions. At flood conditions, the transport of sediment in suspension is about five to 10 times higher than the bed load transport. To gain a total sediment balance for the catchment, a mean relationship between water flow Q and suspended sediment concentration C (based on the field records) is used together with the yearly statistical flow distribution for

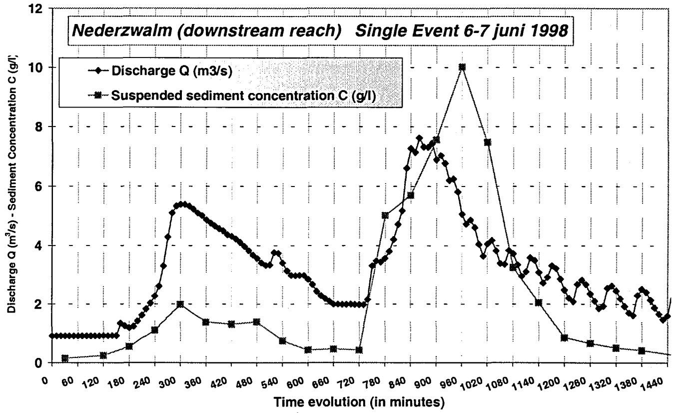

Fig. 6 On-line registration of water flow Q ($m^3\ s^{-1}$) and suspended sediment concentration C ($g\ l^{-1}$) for one single flood event at the downstream reach of the Zwalm.

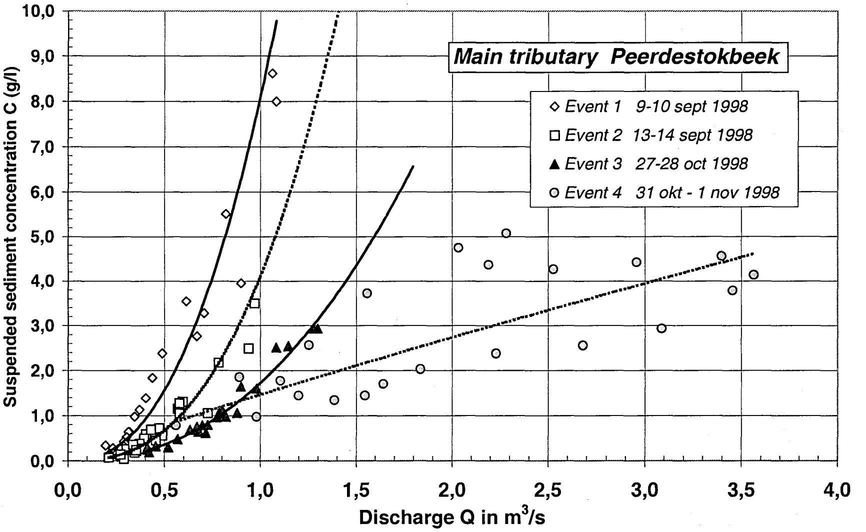

Fig. 7 Suspended sediment transport registrations during discrete flood events.

the associated measuring point. Table 1 shows some calculated results for a normal year (year with average rainfall), leading to an overall mean suspended load of 1.5 t year^{-1} ha^{-1} for the whole Zwalm catchment. It is interesting to note that about 65% of the total suspended load appears in the upstream steep areas of the catchment over a limited area (45% of the catchment area). Further spatial distribution from upstream to downstream can not be identified: all sediment samples show similar randomly distributed grain characteristics, although a clear gradation in sediment quality from upstream to downstream is noticed. Perhaps the most important feature is the very concentrated appearance of the sediment transport during limited flood events. As illustrated in Fig. 8, the suspended load associated with the respective $Q_{1\%}$ and $Q_{2\%}$ discharge values already covers about 63% of the total yearly volume of transported sediments, while 88% of the total sediment volume is transported by discharges bigger than the $Q_{10\%}$ value. Instant response of runoff, straight to the river, in the sensitive upstream areas explains this highly concentrated event occurrence. Severe floods are clearly identified as the main driving force for the morphological development of the river bed and the critical delivery of sediments to the downstream River Scheldt (Misganaw, 1996).

Table 1 Sediment balance of Zwalm catchment.

Catchment	Catchment area (km^2)	Percentage area	Suspended load (t year^{-1})	Percentage suspended load	Bed load (t year^{-1})
Brakel	16	13.9	2 741	17.5	-
Michelbeke	31	26.9	5 302	34.0	-
Peerdestok	21	18.1	4 769	30.6	32
Nederzwalm	115	100	15 605	100	142

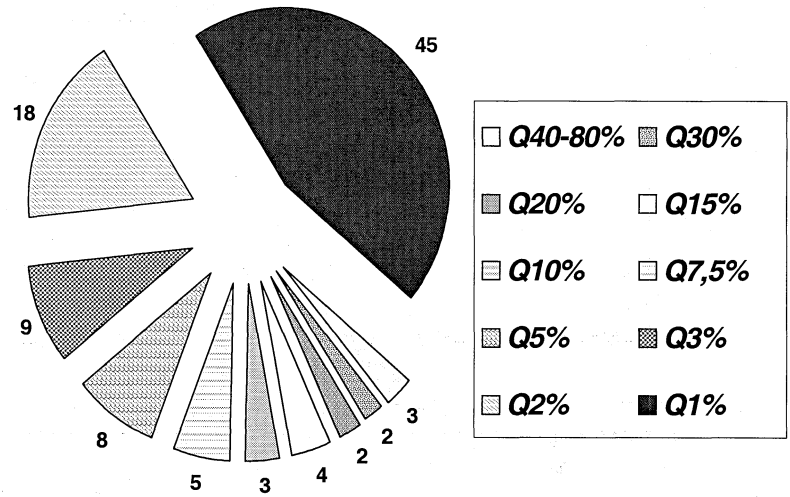

Fig. 8 Percentage contribution of suspended sediment transport volume in relation to the yearly flow regime distribution (discrete percentage discharges $Q_{\%}$).

SEDIMENT MANAGEMENT PROPOSAL

A management strategy can already be formulated for the Zwalm catchment based on the collected data and preliminary analysis. The relative importance of the absolute volume of suspended load during flood conditions, together with the very low sand fraction, forces any engineering solution to focus on the fine fraction in the water column (Raudkivi, 1990). It is clearly indicated that mainly flood flows will move the sediment volume over the river catchment during very limited time intervals. Indeed, the biggest part of the sediment transport occurs during a small, concentrated flood period. The high contamination level of this mud/silt material in the downstream part of the catchment limits the potential deposition areas for the sediments. An effective entrapment of the polluted silt/mud fraction as close as possible to its origin should be developed to clean the river environment. Appropriate locations in the upstream part of the catchment for these sedimentation fields are proposed by combining environmental demands, engineering knowledge and natural characteristics of the catchment. The input of fine sediments to the river by local land erosion in the upstream (rather steep) reaches should be avoided. Practical guidelines to prevent runoff or land erosion are conducted by local authorities. A specific sediment-oriented management specifically towards the polluted mud fraction, in combination with a strictly applied source-oriented sanitation plan and a well-considered land-use policy will ensure a general quality improvement of the Zwalm River environment.

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