Modelling Soil Erosion, Sediment Transport and Closely Related Hydrological Processes (Proceedings of a symposium held at Vienna, July 1998). IAHS Publ. no. 249, 1998.

Variations in sediment yield from an agricultural drainage basin in central Belgium

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Abstract At the outlet of a 250 ha agricultural drainage basin in the Belgian loess belt, discharge and suspended sediment samples were sampled to study variations in sediment yield. Sediment yield during the observation period of 14 months equalled 9.8 t ha^{-1} $year^{-1}$. In winter suspended sediment concentrations are relatively high because of the absence of significant vegetation cover on the fields. In summer, fields with high vegetation cover produce runoff but very little sediment. Furthermore, these fields trap sediment eroded further upslope, resulting in lower sediment concentrations for similar discharges. However, early spring events contribute the most to total sediment yield as they have very high discharges. Within most events a clockwise hysteresis was observed. Grain-size distribution of the suspended sediment is discharge-dependent: up to a discharge of 0.25 m^3 s^{-1} the sediments were enriched in fine particles.

INTRODUCTION

The sediment delivery from drainage basins is poorly understood. One reason for this is the lack of sufficient high-quality data on runoff and sediment dynamics as well as the fact that very often no linkage is made between the sediment production as recorded at the outlet and the runoff and sediment producing processes within the drainage basin (Walling, 1990).

Therefore, data on discharge and sediment concentration were collected at the outlet of an agricultural drainage basin of 250 ha in the Belgian Loessbelt south of Leuven, during one year (July 1996–August 1997). In total, 15 important runoff events were recorded during this period. These measurements were completed with surveys in the drainage basin providing data on land use, soil surface and location of ephemeral gullies and sedimentation areas in order to establish a relationship between conditions in the drainage basin and the sediment yield data at the outlet.

MATERIALS AND METHODS

This study was carried out in a small agricultural catchment in central Belgium, locally called Kinderveld. The catchment has a surface area of *c.* 250 ha and a rolling topography with slopes up to 20%. Soils in the catchment are mainly loess-derived luvisols, truncated by erosion processes and possibly by quarrying to various

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* Fund for Scientific Research, Flanders.

degrees. The topsoil typically contains 10% sand, 80% silt and 10% clay (dispersed). Locally, sandy outcrops do exist.

Most of the catchment consists of cultivated land, mainly used for winter wheat, sugar beet and maize, with smaller areas occupied by potatoes, chicory and endives (Fig. 1). Pastures and wooded areas are mainly located on the steeper parts.

At the start of the observation period (March 1996) a measurement station was installed in a small water course at the outlet of the drainage basin. The station consists of a discharge measurement structure (San Dimas flume) equipped with a flow meter and an automatic sampler to collect suspended sediment samples during high water levels, i.e. after a rainfall event. The rate of sampling depends on the stream discharge: for every 100 or 150 m^3 an 800 ml sample is taken. From these samples the suspended sediment concentration was determined as well as the grain-size distribution by using a laser diffractometer (Coulter LS-100). From the grain-size distributions obtained by diffractometry the equivalent pipette sand, silt and clay fractions can be calculated with good accuracy (Beuselinck *et al.*, 1998a). Rainfall was measured using a high-resolution (0.2 mm) tipping-bucket raingauge.

Most of the runoff events which occurred during the observation period were adequately sampled. However, for an important event on 20 May 1997, only data on water level variations and two manually taken samples for sediment concentration are available as the sediment sampling equipment failed due to the extreme storm

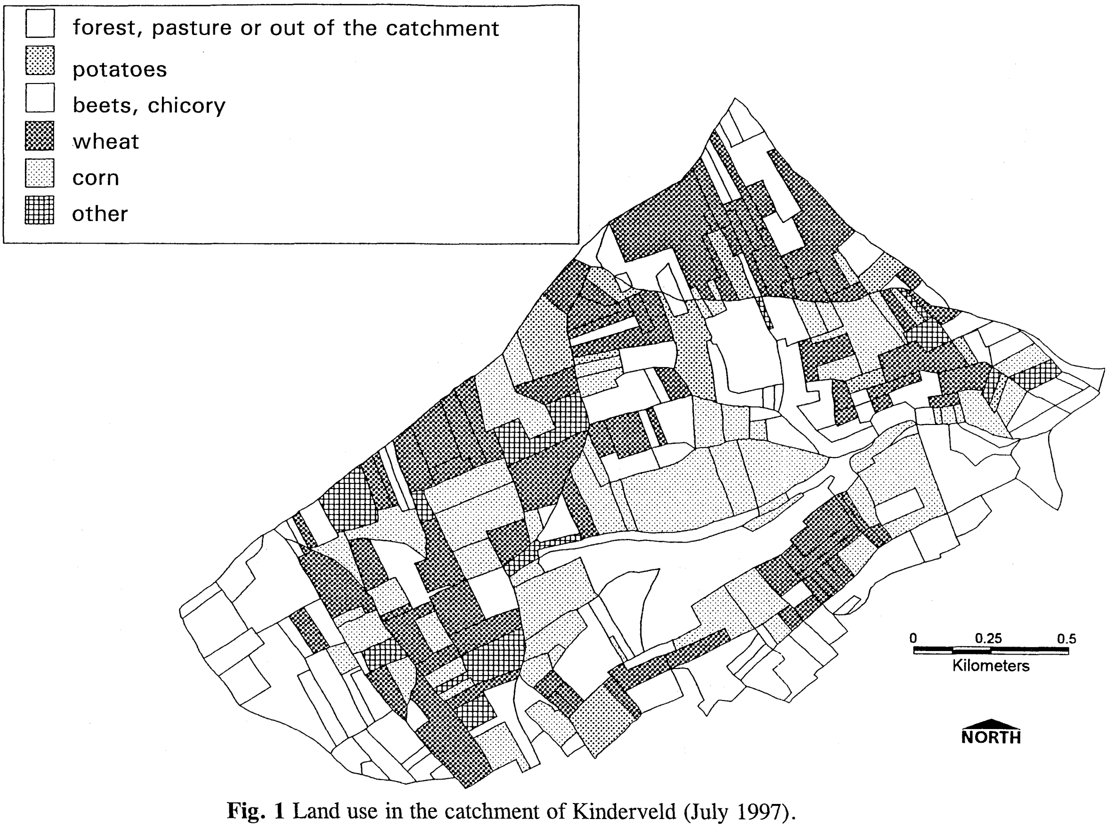

Fig. 1 Land use in the catchment of Kinderveld (July 1997).

conditions which also caused the measurement flume to overflow.

For the extreme event on 20 May 1997, it was possible to make two independent estimates of the maximum discharge by surveying in detail the channel section at the gauging station which had been wetted during the event as well as a section of a nearby sunken lane where the total discharge of the event had passed. Both estimates were very similar (Table 1). The data on flow depth were then used to estimate discharge variations using the relationship for the calibrated flume for flow depths lower than the flume top and a linear relationship between flow depth and discharge for flow depths exceeding the flume's capacity. From the latter sediment concentrations and sediment yield were calculated using discharge–sediment concentration relationships for the rising limb and the falling limb derived from measurements during other spring and summer rainfall events. Estimated sediment concentrations were limited to 160 kg m^{-3}, corresponding to the maximum measured value. The value so obtained for total sediment yield is believed to be realistic but conservative as the total volume of rills and ephemeral gullies measured in the catchment exceeds the sediment yield.

During the observation period, periodic surveys were made within the catchment. At these occasions crop type, cover percentage, surface roughness, degree of crusting and erosion features were recorded for each field.

Table 1 Comparison of maximum discharge as measured at the gauging station and in a sunken lane during the rain event of 20 May 1997.

	Gauging station	Sunken lane
Cross section (m^2)	4.75	3.45
Wetted perimeter (m)	9.53	5.59
Hydraulic radius (m)	0.499	0.617
Slope	0.0078	0.0101
Manning roughness coefficient (n)*	0.035	0.033
Velocity (m s^{-1})	1.59	2.21
Discharge (m^3 s^{-1})	7.54	7.61

* Manning roughness coefficient n for open channel surfaces (Chow *et al.*, 1988).

RESULTS AND DISCUSSION

Relation between discharge and sediment concentration

Total sediment yield from the drainage basin Over a period of 14 months (July 1996–August 1997), total sediment export from the drainage basin equalled *c.* 2870 t, corresponding to 9.8 t ha^{-1} $year^{-1}$ (pastures and forest included). This is a very high value: Baade (1996) measured an average sediment yield of 1.3 t ha^{-1} $year^{-1}$ for a small loess-covered catchment with similar topography in western Germany. The value we obtained is strongly affected by the extreme event of 20 May 1997. If this event is not taken into account, sediment yield drops to 3.8 t ha^{-1} $year^{-1}$, which is still relatively high. These values illustrate the relatively high soil losses by water erosion in central Belgium.

Seasonal variations The winter period contributed only 8% to the total sediment export, i.e. 234 t from November 1996 till March 1997. Most sediment was produced by a series of short, intense thunderstorms in spring producing very high discharges and sediment concentrations. Other researchers already identified this period as a risk period for soil erosion because of the combination of high-intensity rainfalls with a relatively high percentage of bare soil surfaces (Vandaele & Poesen, 1995; Vandaele, 1997). However, our data contrasts with that of Baade (1996) who reported that over 80% of the total sediment export in his catchment occurred during the winter period.

The observation of relatively important sediment yields at the end of the summer is rather exceptional and resulted from a series of extreme rainfalls (64 mm in 2 days: 28–29 August 1996).

The smaller discharges during winter runoff events are the principal explanation for the low sediment yields in this period. When sediment concentrations (SC) are compared it can be seen that for the same discharge (Q) much higher sediment concentrations can be observed in winter (Fig. 2). In both cases, the relationship can be described using a log-log relationship:

winter: $\log SC = 1.45 \log Q + 2.74$ ($r^2 = 0.55$ and $n = 64$)

summer: $\log SC = 0.79 \log Q + 1.68$ ($r^2 = 0.54$ and $n = 120$)

This is opposite to the results of Gregory & Walling (1973). They explain the higher concentration in summer by assuming that the baseflow in summer is relatively lower and that the soil surface is drier. Also the higher rainfall intensities in summer are important, leading to an important flushing effect.

At present, the reason for the higher sediment concentrations in winter is not entirely clear, but possible explanations are related to the difference in the distribution of vegetation cover on arable land within the catchment. In the winter period, almost all arable land has a very low vegetation cover. Therefore, most of it will contribute to both runoff and sediment production. In early spring, 38% of the arable fields (mostly those used for wheat) have already a vegetation cover of more than 70%. This will have some important effects:

(a) fields with a high cover will generate relatively large amounts of runoff (due to

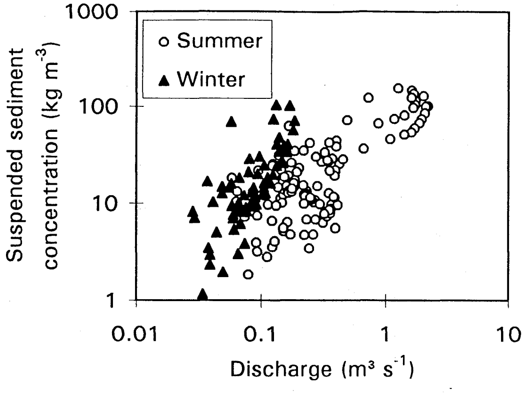

Fig. 2 Relation between discharge and sediment concentration for six events in winter and six in summer.

the high rainfall intensities and the presence of a surface crust);

(b) they will not contribute to sediment production due to the protection by vegetation;

(c) they will act as sediment traps for sediment produced upstream.

Overall, this will lead to a dilution of the sediment produced in a larger water volume and an increased loss of sediment between the source and the catchment outlet. Therefore, lower sediment concentrations for similar discharges will be obtained in summer.

In the winter period, there is a clear evolution of both water and sediment discharge over time. In early winter (November–December) both discharges and sediment concentrations are relatively low, while at the end of the winter period higher discharges and sediment loads are measured. This increased catchment response can be attributed to the evolution of the soil surface state of the fields. In early winter, most fields are freshly cultivated and have a high infiltration rate whereas many field surfaces are covered by a surface crust by the end of the winter (Fig. 3(a) and (b)), leading to increased runoff generation and erosion (Poesen & Govers, 1985).

Within-event variations During the summer as well as in winter a clockwise hysteresis was observed between the sediment concentration and the discharge during each runoff event (Fig. 4). The basic reason for this phenomenon is the fact that water from nearby runoff and sediment sources reaches the outlet first (di Cenzo & Luk, 1997). Water travelling a longer distance (with more possibilities to deposit part of the sediment load due to variations in vegetation and/or topography) will have a lower sediment load. Hysteresis is often also explained as the consequence of the removal of sediment produced in an interstorm period by the first flush of water (Gregory & Walling, 1973). This is not a major factor in our catchment: hysteresis was also observed when runoff events followed each other very rapidly. Furthermore, observations in the catchment clearly indicate that rills and ephemeral gullies are the major sediment source.

It is important to point out the very dynamic nature of both discharge and sediment load at the catchment outlet. Good data on both discharge and sediment can only be obtained when sampling is carried out with a very high resolution. An interval time of 15–30 min, as used in some other studies (e.g. Baade, 1996), may lead to erroneous results.

Variation in grain-size distribution

A visual inspection of the grain-size distribution of the transported sediments reveals important variations in grain-size distributions (Fig. 5). Although a wide range of grain sizes is transported at all flow discharges, the transported material is dominantly finer than 21 μm when the discharge is low. The fraction >21 μm clearly increases with increasing discharge up to a discharge of *c.* 0.25 $m^3 s^{-1}$ (Fig. 6). The sediment appears to be slightly coarser in winter than in summer for the same discharge which may again be attributed to the enhanced trapping efficiency for coarser sediment during the summer season.

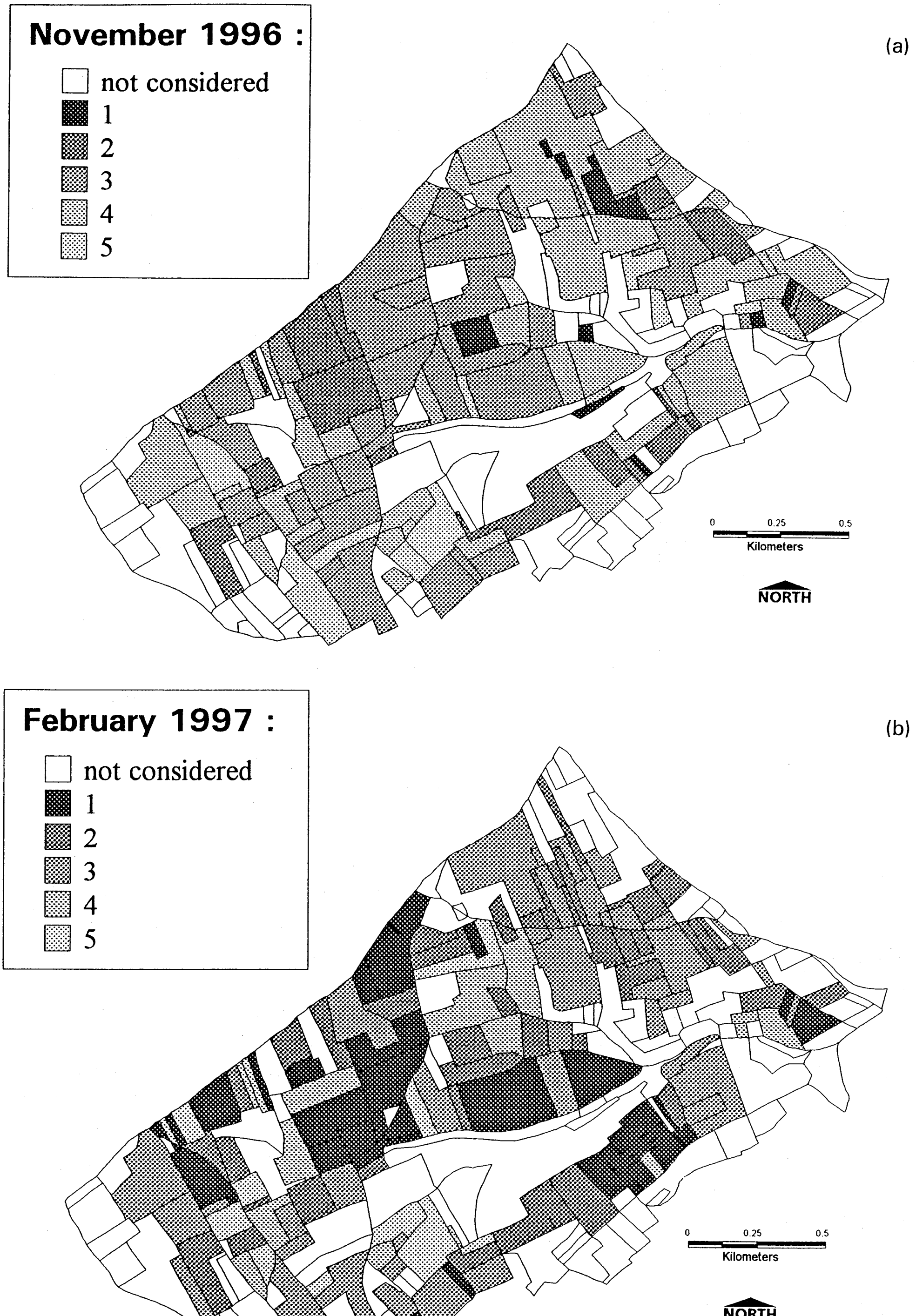

Fig. 3 Surface crusting at the beginning of the winter (a) (November 1996) and at the end of winter (b) (February 1997) (1 = completely sealed; 5 = no surface crusting).

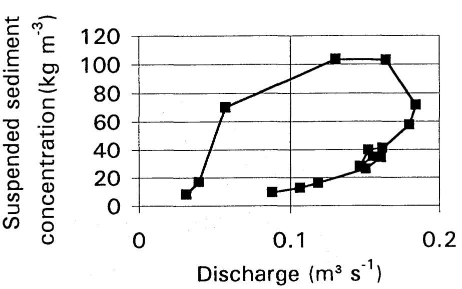

Fig. 4 Positive hysteresis observed during the event of 5 February 1997.

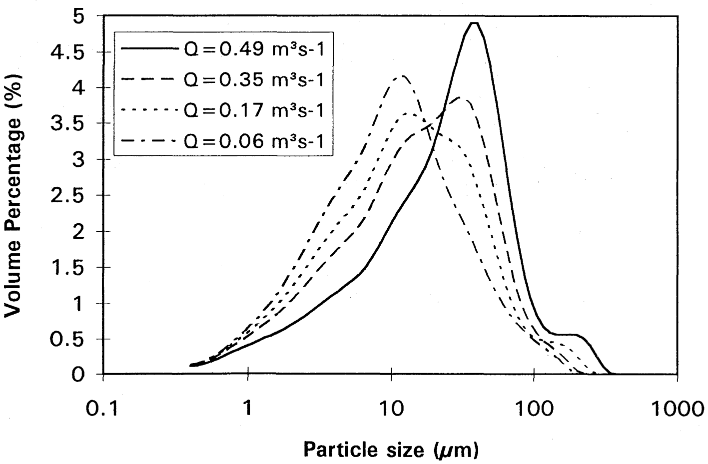

Fig. 5 Grain-size distribution of sediment sampled at different discharges during the event of 11 June 1997 (*Q* = discharge).

Our data contrast with those of Slattery & Burt (1997) who found that the sediment transported in the stream at the outlet of a 620 ha catchment in the Cotswold Hills (UK) became progressively finer with increasing discharges. They attributed this to the increasing contribution of the slopes to the stream sediment budget with increasing discharge. In our study, nearly all sediment is coming from the (cultivated) slopes. The increase in grain size with discharge found in this study, reflects the increase in flow competence with increasing discharge leading to less deposition and non-selective erosion (Govers, 1985; Beuselinck *et al.*, 1998b).

The variation of grain sizes with discharge may have implications for the transport of sediment-associated nutrients and pollutants out of the catchment. The contribution of minor events, characterized by low discharges, may be much more important with respect to the export of nutrients and pollutants compared to total sediment yield.

CONCLUSIONS

Sediment yield measured at the outlet of the studied catchment confirms that soil erosion by water is an important problem in the Loam Belt of central Belgium.

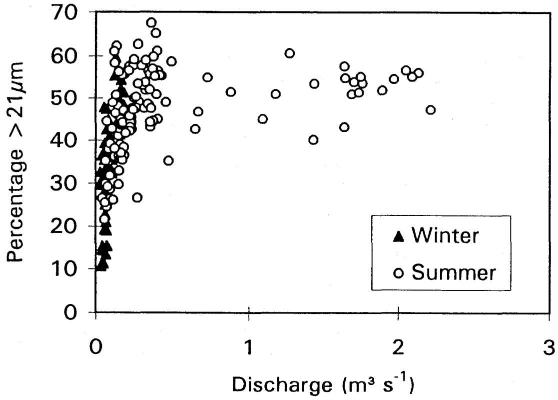

Fig. 6 Relation between discharge and percentage of the grains greater than 21 μm of the suspended sediment. A distinction is made between summer and winter (total: 12 events).

Sediment export shows important temporal variations, both on a seasonal and on an event scale. While total sediment export during summer events can be much higher than during the winter season, sediment concentrations for a similar discharge are lower in summer, which may be attributed to the effects of a higher vegetation cover in summer. Both the runoff coefficient and the maximum sediment concentration appear to increase over the winter period, due to the evolution of the soil surface over the winter period. The positive hysteresis which was observed during almost all events may be attributed to increasing deposition with increasing distance between the sediment source and the outlet. Sediment production and storage during inter-storm periods is not relevant.

Grain-size variations with discharge are surprisingly important and the mechanisms explaining them are at present not fully understood. Considering the potential implications for nutrient and pollutant export, further research on this topic appears to be necessary.

Acknowledgements This research is part of a project funded by the Fund for Scientific Research Flanders (G0215-96) and by the Catholic University of Leuven (OT 95/15). We are also grateful to Eng. J. Meersmans for his support during the construction of the flume and to G. Degraer for analysing the events of August 1996.

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