Sediment and the Environment (Proceedings of the Baltimore Symposium, May 1989)
IAHS Publ. no. 184, 1989.

Soil erosion and floodplain soil pollution: Related problems in the geographical context of a river basin

H. Leenaers and C. J. Schouten
Department of Geography, State University of Utrecht
P. O. Box 80.115, 3508 TC Utrecht, The Netherlands

ABSTRACT In the Netherlands, like in other parts of western Europe, a slow process of land use changes began in the 1950s. Due to an increase of the urban area and sealed roads, as well as a scale-enlargement and modernization in agricultural practice, the infiltration capacity of the physical environment has decreased. In the hill country of the province of Limburg this process has contributed to an increase of surface runoff, causing severe problems of water damage in urban areas and soil erosion on agricultural cropland. The discharge of the River Geul, with a catchment area of 350 km², heavily depends on rainfall. The increasing amount of surface runoff is reflected in a flashier discharge regime, i. e. under similar rainfall conditions a higher peak discharge is produced in the present situation, as compared to the situation in the 1950s.

Because of mining activities in the past, the alluvial deposits in the Geul valley are severely polluted with heavy metals (lead, zinc and cadmium). During floods, the contaminated streambank deposits are eroded and therefore continue to act as a source of heavy metals. This process of sediment reworking has intensified since the 1950s, as can be derived from an increase of the rate of channel migration and the frequency and magnitute of floods. As a result, the area that is regularly flooded has grown and contaminated sediments are deposited in the floodplains at high rates.

INTRODUCTION

Schouten et. al (1985) reported on the increasing magnitude and frequency of soil erosion events and claims for water damage in the hill country of the Province of Limburg (The Netherlands) during the last decades. They argue that an increase of the urban area and the number of sealed roads, and a scale-enlargement and modernization in agricultural practice are the major causes of these changes. Such developments may have major effects on the functioning of the hydrological cycle during flood events (Hollis, 1975; Leopold, 1968). The net effects may be that a higher proportion of rainfall is translated into runoff, this runoff occurs more quickly, and floods are therefore higher and 'flashier' than was the case in the catchment before the land use changes (Hollis, 1975).

The river Geul is one of the main streams that drains the hill country of the Province of Limburg. In view of the fact that the alluvial deposits are polluted with heavy metals (Rang et al., 1986; Leenaers et al., 1988), a 'flashier' discharge regime may have serious environmental implications. During high flow stages the contaminated streambank deposits are reworked, causing high metal levels in suspended sediments which may be deposited in downstream floodplains during floods. An increase of the frequency and magnitude of floods may have a major influence on the rate of sedimentation and the quality of the deposited sediments.

THE CATCHMENT OF THE GEUL

Hydrological aspects

The Geul is a tributary of the River Meuse (see Fig. 1). From its source to its confluence with the Meuse the Geul is 56 km long, of which 20 km are in Belgium, and it drops 242 m. The catchment covers an area of 350 km^2. The Geul river discharge largely depends on amounts of rainfall. At the Dutch-Belgian border its average flow is 1 m^3/s, maximum discharge being in the order of 30 m^3/s. These values increase to respectively 3 and 60 m^3/s as the Geul flows towards its confluence with the Meuse. Relatively low flow peaks are produced within 24 hours after a period with moderate rainfall in the catchment. Prolonged rainfall may lead to overland flow because of the saturation or slurrying of the top soil. As a result, a pronounced high flow peak is rapidly produced; this may cause severe erosion of the streambanks and temporary inundation of the floodplains.

Land use changes, soil erosion and water damage

In the southern part of the Netherlands, the Geul valley incises a loess-covered plateau that consists of cretaceous limestone. Cultivation of the forested valley slopes began in Roman times. Ever since, soil erosion processes have supplied loess materials, that are rich in the silt and fine sand fractions. As a result, the alluvial deposits have a relatively coarse texture (i.e. 10-20 % clay) (Westeringh, Van de, 1980). In this period the first soil conservation measures were taken. Within the practice of small-scale agriculture only small areas laid fallow at a time and it was common practice to lay down the steepest slopes to grass. At the dividing lines between the parcels on the valley slopes 'graften' (linchets) developed and these were kept intact by the farmers.

Table 1a: Landuse (% area) in an area covering 11 municipalities in the Dutch part of the catchment of the Geul (50 % of the total catchment area)

	cultivated area	forest	roads & railways	urban area
1955	78	10	4	7
1985	71	11	5	12

Table 1b: Agricultural landuse (% area) in South Limburg (van der Helm et al., 1987)

	grass	cereals	potatoes	sugar beets	maïze	other
1960	51.0	32.6	4.0	8.0	-	4.4
1976	47.2	19.6	3.8	15.4	6.0	8.1
1986	43.1	17.2	4.5	16.1	13.4	5.7

During the last decades the urban area and the number of infrastructural works have increased in this part of the Netherlands (see Table 1a). In addition, a number of changes in agricultural practice (see Table 1b) have had a major impact on the functioning of the hydrological cycle. Crops like maïze and sugar beets are now grown instead of cereals, so that large areas lay fallow during about 6 months per year. The application of large amounts of fertilizers and insecticites probably has a negative impact on the soil stability (Van Eijsden & Imeson, 1985), which is also affected by the use of heavy farm machinery. Other changes are the rationalisation measures that are taken: the enlargement of parcels, the increase of the cultivated area, ploughing in a direction perpendicular to the contour lines, the removal of linchets and the breaking up of pasture on the valley slopes (Schouten et al, 1985). As a result, the infiltration capacity of the soil and the area in which rainfall can infiltrate into the soil are reduced, and overland flow can take place readily on the relatively smooth impermeable surfaces. These changes have led to increasing runoff, increasing soil loss and a considerable reduction of the crop yields. Bouten et al. (1985) estimate the average soil loss in South Limburg at 15 ton/ha/yr. At these locations, the loss of yield due to erosion may be in the order of 5-10 % of the total yield (Schouten et. al, 1985). However, in financial terms the water damage caused by flood events in urban areas probably is the largest burden for the communities in the study area. The estimated annual expense on maintenance and repair of infrastructural works varies from 5 to 40 % of the local budget for maintenance of roads (Schouten et. al., 1985).

Mining activities

Important occurrences of metal ore are found near Plombières and Kelmis, both situated in the Belgian part of the Geul basin. Exploitation of the zinc and lead ores probably began in the 13th century. The heyday of minig was 1820-1880, the last mine closed in 1938. The seperation techniques were inefficient and resulted in high concentrations of ore particles and metal-rich spoil in the effluent, which was discharged directly into the river. The reject material and tailings were dumped in large heaps along the riverbanks. Some of these heaps still exist.

EXPERIMENTAL PROCEDURES

Two series of continuous discharge recordings, covering the periods 1955-1958 and 1972-1986, were available. The more recent series is based on records from a gauging station of the Provicial Water Authorities of Limburg near the village of Meerssen; the other series is based on records from a gauging station near Valkenburg (Zeeuw, De, 1966) (see Figure 1). It has been noted that, because of the lack of major tributaries between the two gauging stations, the discharge hardly increases along this section (Heidemij, 1973). However, in order to obtain comparable discharge figures it was decided to correct for the size of the upstream catchment area: the records from Valkenburg were multiplied by a factor 1.1. Since the frequency of rainstorms may have a major impact on the results of a flood frequency analysis, it is necessary to compare periods that have similar rainfall characteristics. Therefore, daily rainfall figures from a gauging station in Valkenburg, covering the period 1955-'86, were used to compute for a number of periods the recurrence intervals of selected amounts of daily precipitation (based on exceedance frequencies). The results are listed in Table 2.

Table 2: Recurrence intervals (days) of daily precipitation (mm).

precipitation (mm)	1955-'58 (906 mm/yr)	1972-'79 (756 mm/yr)	1980-'86 (943 mm/yr)
5	6	7	6
10	15	19	14
15	36	50	29
20	69	182	65
25	97	294	98
30	122	370	182

It is clear that both in terms of total amounts of annual rainfall and in terms of the frequency of larger storms, the periods 1955-'58 and 1980-'86 have comparable characteristics. Both periods differ considerably from the period 1972-'79, which was relatively dry. On the basis of these results it was decided to restrict the flood frequency analysis to the former two periods.

The frequency of flood events was estimated using a Monthly Exceedance Series and the number of peaks considered was set equal to the number of record months from which the peaks were abstracted. The use of monthly data rather than the more frequently used annual series (Gregory & Madew, 1982) was chosen since our main interest is directed towards floods with short recurrence intervals. For both series it was checked that all peaks considered are independend. If the maximum discharges of N months of record are ranked from highest (rank, m=1) to lowest (m=N), the resulting series forms N+1 rank classes. The probability of a random event of magnitude x being equal to or greater than an event ranked m is $P(x) = m/(N+1)$, and the mean recurrence interval (in months) of this event is $1/P(x) = (N+1)/m$. Discharges of specified recurrence interval are estimated by fitting an appropriate theoretical probability distribution, which normally must model the positive skew common in extreme event distributions. A Log-Pearson Type III distribution (Richards, 1982; Morel-Seytoux, 1979; Bobée, 1975) appeared to provide a good fit to the series and floods with a recurrence interval of 6, 12, 18 and 24 months were determined for the periods 1955-'58 and 1980-'86.

Data on metal concentrations of floodplain soils, streambank deposits and recent flood deposits were derived from published and ongoing research of the author (e.g. Leenaers et al., 1988). The analyses of the extracts were done by flame absorption spectrometry after treatment of the samples with 8 ml 25 % HNO_3 at 100 ^{o}C for 2 hours.

DISCHARGE REGIME CHANGES

In a review of the effect of urbanization on the flood characteristics of a river, Hollis (1975), employing data from more than 15 investigations, concludes that small floods may be increased ten times by urbanization but that the effects decline in relative terms as flood recurrence intervals increase. In this case study both the effects of urbanization and of the changes in agricultural practice are of interest and only floods of short recurrence intervals are studied.

Figure 2 shows flood frequency curves of the periods 1955-'58 and 1980-'86. At very small recurrence intervals, i.e. in the order of a few months, the two curves coincide. Floods with larger recurrence intervals appear to be considerably higher in the 1980s than in the 1950s. Table 3 lists the discharges at a number of selected recurrence intervals that were derived from the fitted Log-Pearson type III frequency distributions. From these figures it follows that in the range of recurrence intervals of 0.5-2 years the flood size has increased 40-50 % during the last 30 years. Because of the limited size of our data set, conclusions about floods with recurrence intervals of more than 2 years will remain tentative. Nevertheless, considering the shape of both curves, it seems reasonable to assume that in that range too notable changes have occurred.

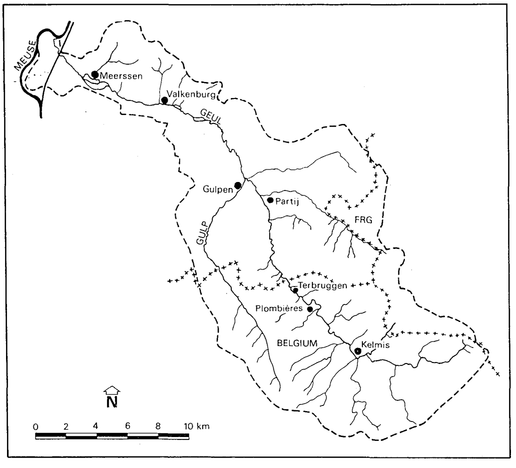

Fig. 1 The catchment of the Geul.

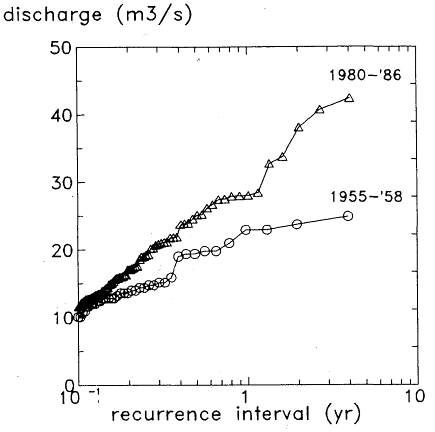

Fig 2 Discharge frequency curves.

The occurrence of inundation events depends on the hydrological characteristics of the individual flood as well as the prevailing surface form of the floodplain. Flooding in the Geul valley may begin

Table 3: Discharges Q_{RI} (m/s3) with different recurrence intervals RI (years)

	Q 0.5	Q 1.0	Q 1.5	Q 2.0
1955-1958	17.9	20.0	21.2	22.0
1980-1986	25.1	29.0	31.2	32.8

locally at relatively low flow stages, i.e. a discharge of 20-25 m^3/s (in Meerssen). Large scale inundations occur when the discharge exceeds 40 m^3/s. From the above table it becomes clear that the recurrence interval of small scale inundations has decreased notably. In the present situation, at least twice a year local flooding can be observed in contrast to once every one or two years in the 1950s.

RIVER CHANNEL CHANGES AND THE QUALITY OF STREAMBANK DEPOSITS

A number of studies have reported changes in water and sediment yield consequent upon land use change (e.g. Cooke & Doornkamp, 1978; FAO, 1965; Glymph & Holtan, 1969; Hudson, 1979). $Q_{1.5}$ can easily be increased 2.5 times downstream of urban areas (Gregory & Madew, 1982). The increase of peak discharges downstream of urban areas can give rise to enlarged channels (Knight, 1979). A substantial range of land use effects are included in recent reviews (Gregory, 1977; Gregory, 1979; Schumm, 1977).

During the last two decades it has been noted that locally the streambanks of the Geul are eroded rapidly. Inspection of a sequence of aerial photographs of a small section of the river channel revealed that the rate of channel migration may be as high as 5 meters/year (see Figure 3). Moreover, in a number of recent 3-4 yr periods (1973-'76, 1979-'83 and 1983-'85) the channel displacement is in the same order of magnitude as in the 24 yr period 1949-'73. The period 1973-'76 lacked the occurrence of major storms and no channel displacements could be derived from the photographs.

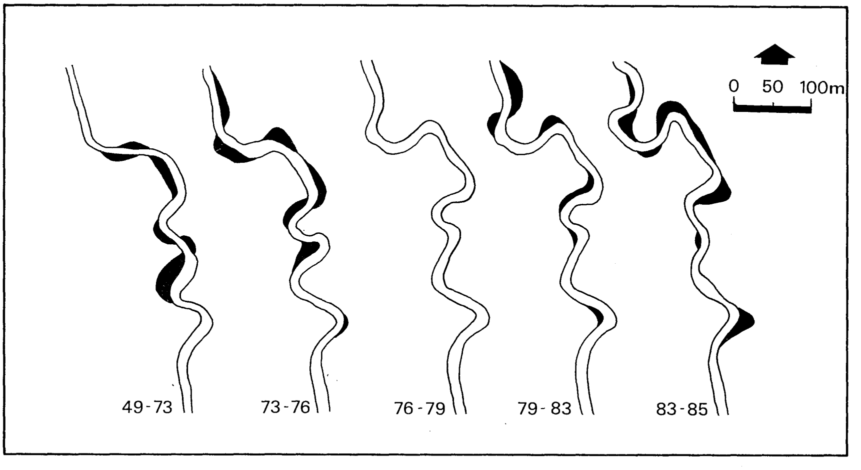

Fig. 3 River channel changes of the Geul.

Through the process of streambank erosion large amounts of historical sediments are supplied to the river channel, and these may be deposited on downstream floodplains. Table 4 shows the vertical distribution of metal concentrations in an infilled channel loop that is cut off by the Geul. It is clear that the levels of Pb, Zn and Cd are unacceptably high and that these deposits may be considered a major source of metals to downstream floodplains. Rang et al. (1986) showed that the peak metal concentrations can be related to the heyday of ore mining some 100 years ago.

Table 4: Vertical distribution of heavy metals (mg/kg) in an infilled channel loop that is cut off by the Geul

depth (cm)	Pb	Zn	Cd	Cu
5	1466	5968	15.5	27
25	2059	6248	19.3	38
45	6119	10109	34.0	79
65	8141	11301	25.4	86
85	9189	8240	10.7	105
105	5797	9673	9.8	45
125	6163	14429	26.8	61

THE DEPOSITION OF CONTAMINATED SEDIMENT DURING FLOODS

A number of authors have reported on the relation between floodplain soil pollution and floodplain characteristics such as inundation frequency, soil type and sedimentary environment (Wolfenden & Lewin, 1977; Rang et al., 1987). In Table 5 the quality of recent flood deposits is compared to the quality of topsoils in the three major geomorphologic units that can be distinguished in the Geul valley. Remarkably, the natural levee soils are characterized by higher metal concentrations than those in the washback areas. However, Pb, Zn and Cd concentrations in natural levee soils are still lower than those in recent flood deposits (see Table 5), so that the quality of these soils is decreasing under influence of recent sedimentation. Moreover, the increased frequency of inundation events since the 1950s has not only reactivated the supply of contaminants by streambank erosion but has also probably led to a simultaneous growth of the area where contaminated sediments are frequently deposited. Field observations at a number of floodplain locations made clear that during a single flood 20-50 cm of sediment may be deposited. It is concluded that in this polluted fluvial system changes of the discharge regime have a direct impact on the future quality of floodplain soils.

Table 5: Mean metal concentrations (mg/kg) of topsoils (0-10 cm) in geomorphologic units and of recent flood deposits (n: number of samples)

	n	Pb	Zn	Cd	Cu
natural levee	345	373	1177	3.8	17
washback	118	156	509	2.8	21
colluvium	12	41	147	1.1	11
flood deposits	122	477	2308	4.5	16

CONCLUSIONS

Because of land use changes and changes of agricultural practice in the catchment of the Geul, the size of floods with short recurrence intervals (<= 2 yr) has increased by 40-50 % during the last 30 years. As a result, small scale inundations occur more frequently. In addition, the metal-contaminated streambank sediments are eroded at higher rates, causing high metal levels in suspended sediments which are deposited on downstream floodplains. The metal concentrations of recent flood deposits are higher than those in the (already) contaminated floodplain soils.

It is clear that the changes of the discharge regime of the Geul, induced by land use changes during the last three decades, has a major impact on the rate at which heavy metals are dispersed and on the future quality of floodplain soils.

REFERENCES

Bobeé, B. (1975) The Log Pearson type III distribution and its application in hydrology. Wat. Resour. Res., 11, 5, 681-689.

Bouten, W., Eijsden, G. Van, Imeson, A.C., Kwaad, F.J.P.M., Mücher, H.J. & Tiktak, A. (1985) Ontstaan en erosie van de lössleemgronden in Zuid Limburg (The origin and the erosion of löss soils in South Limburg). KNAG Geografisch Tijdschrift XIX, 3, 192-207.

Cooke, R.U. & Doornkamp, J.C. (1978) Geomorphology in Environmental Management. Clarendon Press, Oxford.

Eijsden, G. Van & A.C. Imeson, A.C. (1985) De relatie tussen erosie en enkele landbouwgewassen in het Ransdalerveld, Zuid-Limburg (The relation between erosion and crop type in the Ransdalerveld, South Limburg). Landschap, 2, 133-142.

FAO (1965) Soil erosion by water - some measures for its control on cultivated lands, Agricultural Development Paper, 81.

Glymph, L.M. & Holtan, H.N. (1969) Land treatment in agricultural watershed hydrology research, in: Effects of Watershed Changes on Streamflow (ed. by Moore, W.L. & Morgan, C.W.), 44-68. Texas U.P., Austin.

Gregory, K.J. (ed.) (1977) River Channel Changes, John Wiley, Chicester.

Gregory, K.J. (1979) River channels. In: Man and Environmental Processes (ed. by Gregory, K.J. & Walling, D.E.), 123-143. Butterworths, London.

Gregory, K.J. & Madew, J.R. (1982) Land use change, flood frequency and channel adjustments. In: Gravel-bed Rivers (ed. by Hey, R.D., J.C. Bathurst and C.R. Thorne), 757-781. Wiley & Sons Ltd.

Helm, P.P.M. van der, De Roo, A.P.J. & Schouten, C.J. (1987) Bodemerosie en wateroverlast (Soil erosion and water damage). Publ. of Inst. of Geogr. Res., State Univ. Utrecht.

Heidemij (1973) Afvoerstudie Geul (Discharge study of the Geul). Rep. of the Provencial Wat. Auth. of Limburg (The Netherlands).

Hollis, G.E. (1975) The effect of urbanization on floods of different recurrence interval. Wat. Resour. Res., 11, 3, 431-435.

Hudson, N. (1979) Soil Conservation. Batsford Ltd, London.

Leenaers, H., Rang, M.C. & Schouten, C.J. (1988) Variability of the metal content of flood deposits. Env. Geol. and Wat. Sc., 11, 1, 95-106.

Leopold, L. B. (1968) Hydrology for urban land planning - a guidebook on the hydrological effects of urban land use. Circular United States Geological Survey 554.

Lewin, J., Macklin, M. G. (1987) Metal mining and floodplain sedimentation in Britain. In: International Geomorphology, Part I (ed. by V. Gardiner), 1009-1027. John Wiley & Sons Ltd.

Knight, C. (1979) Urbanization and natural stream channel morphology: the case of two English new towns. In: Man's Impact on the Hydrological Cycle in the United Kingdom (ed. by G. E. Hollis), 181-198. Geo-Books, Norwich, UK.

Morel-Seytoux, H. J. (1979) Forecasting of flows-Flood frequency analysis, chapter 3 in: Modeling of Rivers (ed. by Shen, W. H.), Wiley & Sons, New York.

Rang, M. C., Kleijn, C. E. & Schouten, C. J. (1986) Historical changes in the enrichment of fluvial deposits with heavy metals. IAHS Publication, 157, 47-59.

Rang, M. C., Kleijn, C. E. & Schouten, C. J. (1987) Mapping of soil pollution by application of classical geomorphological and pedological field techniques. In: International Geomorphology, part I (ed. by Gardiner), 1029-1044. Wiley & Sons, New York.

Richards, K. (1982) Rivers: Form and Process in Alluvial Channels. Methuen, London.

Schouten, C. J., Rang, M. C. & Huigen, P. M. J. (1985) Erosie en wateroverlast in Zuid-Limburg (Soil erosion and water damage in South Limburg), Landschap, 2, 118-132.

Schumm, S. A. (1977) The Fluvial System, John Wiley, New York.

Westeringh, W. van de (1980) Soils and their geology in the Geul valley. Mededelingen Landbouwhogeschool 80 (8), 1-26.

Wolfenden, P. J. & Lewin, J. (1977) Distributions of metal pollutants in floodplain sediments. Catena, 4, 309-317.

Zeeuw, J. W. De (1966) Hydrograph Analysis of areas with prevailing Groundwater Discharge, PhD thesis, Agricultural University of Wageningen. Veenman & Zonen N. V., Wageningen.