

9.1 Introduction

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, has recently been a source of concern (Schouten et. al., 1985). Increase in 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 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. Because the alluvial deposits are polluted with heavy metals (Rang et al., 1986), 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 (see Chapter 7). An increase of the frequency and magnitude of floods may cause an acceleration of sedimentation and an increase of the area that is regularly flooded and polluted.

9.2 Experimental procedures

Land use data of South Limburg were collected during a large scale investigation of areas that are susceptible to soil erosion and areas that suffer from water damage (Schouten et al., 1985; Van der Helm et al., 1987). Additional data on the landuse in the catchment of the Geul were derived from historical records.

Two series of continuous discharge recordings, covering the periods 1955-1958 and 1972-1986, were available for flood frequency analysis. The more recent series is based on records from a gauging station of the Provincial Water Authorities of Limburg near the village of Meerssen; the other series is based on records from a gauging station near Schin op Geul (Zeeuw, De, 1966). 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 Schin op Geul were multiplied by a factor 1.1. The frequencies of flood events were 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 was directed towards floods with short recurrence intervals. For both series it was checked that all peaks considered were independent. 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.

Since the frequency of rainstorms may have an 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).

During a sampling campaign in 1986 and 1987 742 samples of topsoil were collected in the Geul floodplains. The locations were chosen with the aid of a geomorphological map (Van de Westeringh, 1980), and in such a manner that all individual map units are represented in the dataset. The samples were taken at a depth of 0-10 cm and contain a volume of ca. 100 g each. The extraction and analysis of heavy metals in these samples was done as described in Section 3.3.1.

A series of aerial photographs (from 1949, 1973, 1976, 1983 and 1986) of a sequence of meander bends of the Geul was studied in order to estimate rates of channel migration. Data on metal concentrations in streambanks that exhibit marks of recent erosion were available from previous studies (see Chapter 7).

9.3 Land use changes

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 (see Section 2.3). 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 'grafter' (linchets) developed and these were kept intact by the farmers.

During the last decades the urban area and the number of infrastructural works have increased in this part of the Netherlands (see Table 9.1a). In addition, a number of changes in agricultural practice (see Table 9.1b) have had a major impact on the functioning of the hydrological cycle. Crops like maize 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 insecticides

Table 9.1a Landuse (% area) in an area covering 11 municipalities in the Dutch part of the catchment of the Geul (i.e. 50 % of the total catchment area)

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

Table 9.1b Agricultural landuse (% area) in South Limburg (van der Helm et al., 1987)

| year | grass | cereals | potatoes | sugar beets | maize | 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 |

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 have been taken: the enlargement of parcels, the increase of the cultivated area, ploughing in a direction perpendicular to the contour lines, the removal of lynchets (old cultivation terraces) 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 on cultivated slopes 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 infra-structural works varies from 5 to 40% of the budget for maintenance of roads of the local authorities (Schouten et. al., 1985).

9.4 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. Figure 9.1a provides flood frequency curves of a theoretical 1 mi² catchment in various states of urbanization, derived from the results of a large number of studies (Leopold, 1968).

The results of the storm frequency analysis are listed in Table 9.2. 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. So it may be concluded that climatic change is not a long-term problem, except the period 1976-'79 was dry and therefore benign. On the basis of these results it was decided to restrict the flood frequency analysis to the former two periods.

Table 9.2 Recurrence intervals (days) of daily precipitation (mm)

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

* mean annual precipitation

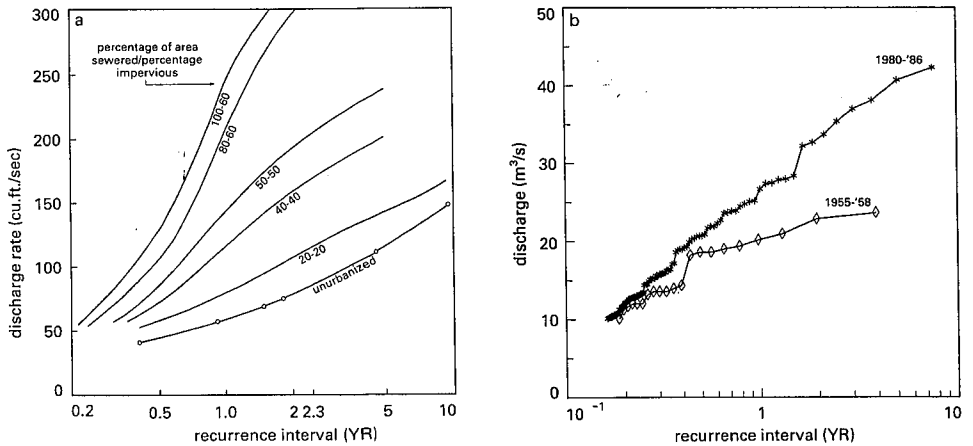


Figure 9.1 Discharge frequency curves of a) a 1 mi² catchment (1 mi²=2.59 km²) under various states of urbanization (source: Leopold, 1968; redrawn) and b) the Geul at Meerssen in the periods 1955-'58 and 1980-'86.

Figure 9.1b 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. Figures 9.1a and 9.1b exhibit similar curve shapes and both demonstrate the tendency of the curves to diverge at large recurrence intervals. This suggests that the land use changes in this study have a similar impact on flood frequency as does urbanization. Table 9.3 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 25-40% 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 for those larger floods too notable changes have occurred.

Table 9.3 Discharges Q_{RI} (m³/s) in Meerssen with different recurrence intervals RI (years)

| period | Q 0.5 | Q 1.0 | Q 1.5 | Q 2.0 |
|-----------|-------|-------|-------|-------|
| 1955-1958 | 16.4 | 19.7 | 21.7 | 23.0 |
| 1980-1986 | 20.3 | 26.5 | 30.1 | 32.7 |

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 locally at relatively low flow stages, i.e. at a discharge of 20-25 m³/s (in Meerssen). Large scale inundations occur when the discharge exceeds 40 m³/s. From the above table it becomes clear that small scale inundations occur more frequently. In the present situation local flooding can be observed at least twice a year in contrast to once every one or two years in the 1950s.

9.5 River channel migrations

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). Floods with a recurrence interval of 1.5 years (i.e., $Q_{1.5}$) 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).

It has been noted that during the last two decades there is a rapid increase in the local erosion of the streambanks of the Geul. In the urban areas, the channel migrations cause serious damage to sheet-pilings and buildings on the river banks. Photos 9.1 and 9.2 show the effects of a major flood in February 1987 in the village of Valkenburg: the water level reached as high as the small bridge and the river banks collapsed a few hours before the flood peak (Photo 9.1),



Photo 9.1 Collapsing river banks during a flood in the village of Valkenburg.



Photo 9.2 A few hours after the flood peak at the same location as on Photo 9.1: the electricity station and the sheet-pilings are devastated.

which had a devastating effect on the sheet-pilings and the electricity station (Figure 9.2). Inspection of a sequence of aerial photographs of a small section of the river channel located in the rural area near Partij (see Figure 2.1), revealed that the local rate of channel migration may be as high as 5 meters/year (see Figure 9.2). Moreover, in a number of recent 3-4 year periods (1973-'76, 1979-'83 and 1983-'85) the channel displacement is of the same order of magnitude as in the 24 year period 1949-'73. No major storms occurred in the period 1973-'76 and no channel displacements could be seen on the photographs.

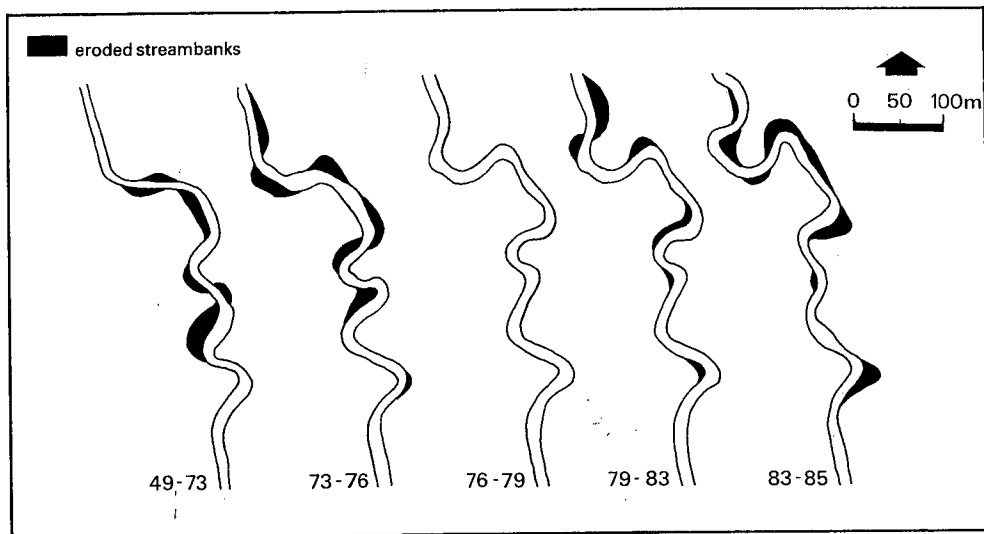


Figure 9.2 River channel changes of the Geul near Partij.

In Chapter 7 it showed that the streambanks of the Geul that exhibit marks of recent erosion may contain high concentrations of heavy metals. The C-value for Pb, Zn and Cd is exceeded in streambanks upstream of Mechelen, which contain on average 5 times as many heavy metals as those downstream of Mechelen. Through the process of streambank erosion large amounts of these historical sediments are supplied to the river channel, and these may be deposited on downstream floodplains.

9.6 The deposition of contaminated sediment during floods

Several 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; Section 5.4). Table 9.4 compares the quality of recent flood deposits with 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 backswamp areas (see also Section 10.5).

Table 9.4 Mean metal concentrations (mg/kg) of topsoils (0-10 cm) in geomorphological units and of recent flood deposits (n: number of samples).

| soil/sediment type | n | Pb | Zn | Cd | Cu |
|--------------------|-----|-----|------|-----|----|
| natural levee | 345 | 373 | 1177 | 3.8 | 17 |
| backswamp | 118 | 156 | 509 | 2.8 | 21 |
| colluvium | 12 | 41 | 147 | 1.1 | 11 |
| flood deposits | 122 | 477 | 2308 | 4.5 | 16 |

However, Pb, Zn and Cd concentrations in natural levee soils are still lower than those in recent flood deposits (see Table 9.4), so that the quality of these levee 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 may also have led to a simultaneous growth of the area where contaminated sediments are frequently deposited. Field observations at a number of floodplain locations suggested that during a single flood 20-50 cm of sediment may be deposited locally. It is concluded that in this polluted fluvial system changes of the discharge regime have a direct impact on the quality of floodplain soils.

9.7 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 25-40% 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, have a major impact on the rate at which heavy metals are dispersed and on the present and future quality of floodplain soils.

9.8 Summary

In the Netherlands, as 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 the number of 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, depends heavily 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. 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 magnitude of floods. As a result, the area that is regularly flooded has grown and contaminated sediments are deposited in the floodplains at higher rates.