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The impact of climate change on the sedimentation rates on the embanked floodplains in the Netherlands

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Abstract

Sedimentation on the embanked floodplains in the Netherlands was studied on different time scales. Many sections of the embanked floodplain along the river Waal were formed only during the past centuries. Spatial differences in floodplain sedimentation rates were investigated using heavy metals as a tracer. Average sedimentation rates during the past decennia range between 2 and >15 mm/yr, depending on the floodplain topography. Present sedimentation rates were measured using sediment traps. Sediment accumulation decreases exponentially with distance from the river channel; relatively large amounts of sediment are deposited in depressions. The effects of the IPCC BaU climate scenario on floodplain sedimentation were evaluated in detail for a small floodplain section, and for the entire Waal floodplain. The results indicate that a climate change alone will increase floodplain sedimentation by at least 50%; the yearly average sediment load transported over the entire Waal floodplain becomes more than three times as large as at present.

1. INTRODUCTION

The increased emission of CO_2 and other greenhouse gases into the lower atmosphere is expected to lead to a warming of the earth's surface. This greenhouse effect may cause a world-wide climate change in the forthcoming decades, resulting in a.o. changes in temperature, precipitation and evaporation. A climate change will affect the river Rhine discharge regime and the suspended sediment load transported into the Netherlands. As a result, the sedimentation rates on the embanked floodplains in the Netherlands may change.

For the assessment of the impact of climate change the IPCC scenario BaU-best (Kwadijk, 1993) is used. Kwadijk (1993) investigated the expected changes in the discharge of the river Rhine and its tributaries using the RHINEFLOW model. Asselman (1994) described the relation between discharge and suspended sediment load by a sediment rating curve. Changes in sediment production may change the present sediment rating curves. Asselman (1994) defined four sediment rating scenarios associated with different combinations of the BaU climate scenario and land use changes, resulting in different sediment rating curves for the Rhine at the Dutch-German border. In this project the sedimentation on the embanked floodplains is investigated. Past and present sedimentation rates are reconstructed using various methods, and the possible effects of climate change on future floodplain sedimentation are investigated (Middelkoop, 1994).

The objectives of this study were to assess:

- the sedimentation rate on the embanked floodplains in the Netherlands in relation to flooding-frequencies during the past decennia, and centuries,

- the spatial variability of floodplain sedimentation,
- quantitative relationships between sedimentation rates and (1) floodplain morphology and (2) the characteristics of flood periods, and
- possible effects of climate change on future floodplain sedimentation.

The sedimentation on the embanked floodplains was studied from different points of view and on various temporal and spatial scales. The investigated floodplain sections are shown in figure 1. The effects of the BaU climate scenario were investigated for a small floodplain section using the WAQUA-DELWAQ model, and for the entire Waal floodplain using the average sediment discharge as an estimator for potential sedimentation.

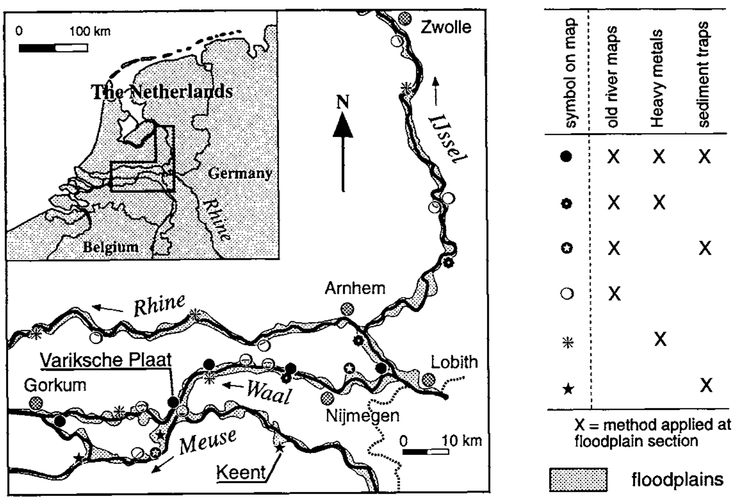


Figure 1. Study area and location of investigated floodplain sections.

2. FLOODPLAIN GEOMORPHOLOGY AND GENESIS

The genesis and geomorphology of the embanked floodplains were investigated by geomorphologic mapping and corings, and by analysis of old river maps and historic records of water levels. Old river maps provide a rough indication of the beginning of sedimentation on the enclosed floodplains.

The present embanked floodplains along the rivers Rhine and Meuse consist of point bars of meandering rivers as well as lateral bars separated by side channels. Many lateral bars were formed only during the last two to three centuries. Lateral bars are mainly found along the river Waal. The development of lateral bars is related to land reclamation from the river bed. Using old maps, a succession scheme was developed showing the stages of development of lateral bars, side channels and vegetation (Middelkoop et al., 1992). Assuming that the yearly sedimentation rate is proportional to the product of inundation time and suspended sediment concentration it was found that at the beginning of the floodplain formation the sedimentation rates were 3 to 4 times as great as at present, and varied between 1 and 3 cm/year.

3. RECONSTRUCTION OF FLOODPLAIN SEDIMENTATION RATES USING HEAVY METALS AS A TRACER

The river Rhine sediments that are deposited on the embanked floodplains in the Netherlands are contaminated with pollutants, including heavy metals. The heavy metals in the floodplain soil profiles were used as a tracer to calculate floodplain sedimentation rates.

Sediment accumulated in dike-breach ponds was analysed to reconstruct changes in heavy metal pollution of the river Rhine sediment during the past 200 - 300 years. From historic dates, Pb-210 dates, palynological information and variations in sediment compaction, a time-depth control of the sediment fill of the dike-breach ponds was obtained. The reconstructed changes in the heavy metal pollution of the Rhine sediment are shown in figure 2. The heavy metal pollution increased during the first half of this century; maximum pollution occurred around 1960; since 1970 the heavy metal pollution has strongly decreased.

From various sections of the embanked floodplains, samples from vertical soil profiles were collected and their heavy metal content was measured. The samples were taken from sites with different inundation frequencies, local elevations, and distances to the main channel. The heavy metal content of floodplain soils was related to these factors. Average sedimentation rates during the past decades were reconstructed by comparing the heavy metal profiles in the floodplain soils with the pollution history of the Rhine.

The heavy metal profiles obtained from the floodplain soils generally have the same shape as the pollution curve reconstructed from the dike-breach pond sediment. Depending on the sedimentation rate, the vertical profile is more or less stretched, and the total heavy metal content varies (figure 3). The total soil pollution can be very different from the pollution in the upper 10 cm. The sedimentation rates for the past decennia that were estimated from the heavy metal profiles range between 2 and >15 mm/yr.

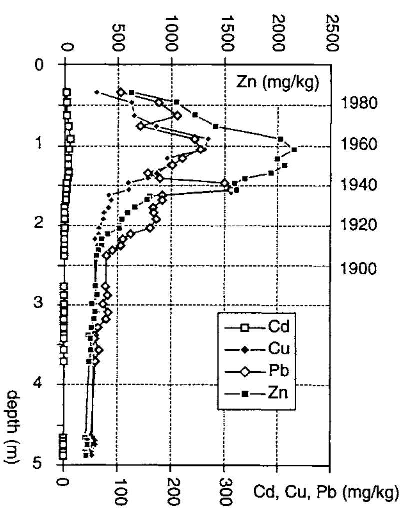


Figure 2. Heavy metal pollution history of the river Rhine reconstructed from a dike-breach pond along the river Waal.

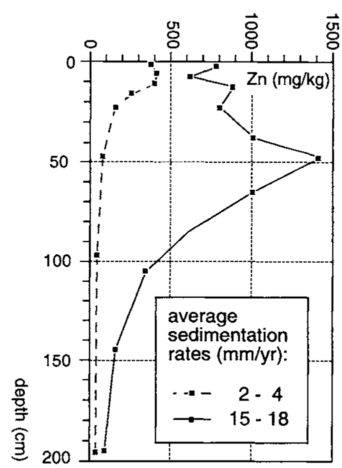


Figure 3. Zinc profiles of floodplain soils as a result of different sedimentation rates.

4. PRESENT FLOODPLAIN SEDIMENTATION RATES

Present floodplain sedimentation rates and their spatial variability were measured after the two floods of 1993 and one flood in 1994 using a total of about 800 sediment traps of artificial grass. Measurements from the individual traps were interpolated using block-kriging to create raster maps of sediment accumulation (figure 4). The patterns shown on the maps were correlated with floodplain morphology and sedimentation mechanisms (Asselman & Middelkoop, in press.).

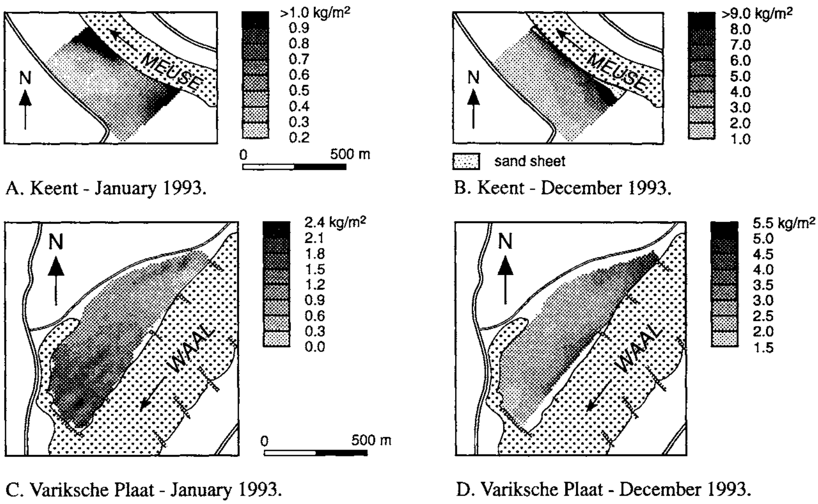


Figure 4. Sediment accumulation after a single flood, measured by sediment traps. January 1993: minor flood; December 1993: extreme flood.

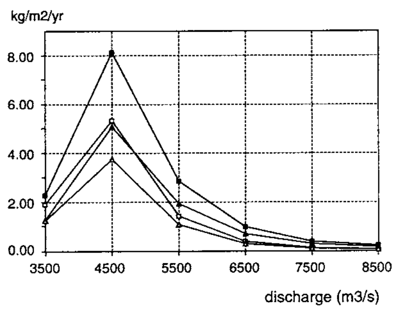
During the flood, sand is locally deposited directly behind a levee. The amount of deposited (fine) sand decreases exponentially with distance from the levee. This pattern agrees well with existing diffusion models. At distances larger than 50 to 100 m from the river channel the accumulated sediment consists mainly of material < 53μ. Here, differences in sediment accumulation are determined by the local topography, which causes differences in inundation times and ponding (figure 4c). The total amounts of suspended sediment < 53μ deposited in the investigated floodplain sections during the high flood of December 1993 ranged between 1.20 and 3.98 kg/m^2 along the river Waal, and between 1.0 and 2.0 kg/m^2 in the study areas along the river Meuse. Equivalent thicknesses of sediment accumulation during the flood ranged between 0.8 mm and 3.2 mm in the central parts of the floodplain sections. The estimated total amount of suspended sediment deposited during the flood on the entire river Waal floodplain was 0.24 Mton. This is about 19% of the total suspended sediment load transported through the river Waal in the same period. It is 7.7% of the average yearly load of suspended sediment transported by the river Rhine into the Netherlands. Comparison of sediment accumulation of different floods shows that the amount of sediment deposited on a floodplain increases less than proportionally with the flood magnitude.

5. IMPACT OF CLIMATE CHANGE ON FLOODPLAIN SEDIMENTATION RATES

5.1 Local sedimentation rates

Sedimentation on a small floodplain section was simulated using the 2-dimensional WAQUA-DEWAQ model (Ubels, 1986). For a series of stationary discharge stages, the average yearly sediment accumulation was calculated by multiplying the sedimentation rates by the associated frequency of occurrence and suspended sediment concentration. The total yearly sedimentation is the summed total of the products. Sedimentation rates under changed climate conditions were calculated by using the BaU flow duration curve (Kwadijk & Middelkoop, 1994) and using the sediment rating curves provided by Asselman (1994).

The WAQUA-DELWAQ model demonstrates that sedimentation becomes very ineffective at high discharges (figure 5). Preliminary results indicate that under the BaU climate scenario the sedimentation rate in the test area increases by only 3% if both climate and land use change. A climate change alone, however, increases the sedimentation rates by about 50%. Sedimentation rates will increase much more on floodplain sections behind a minor dike and where sedimentation only occurs during relatively high discharges.



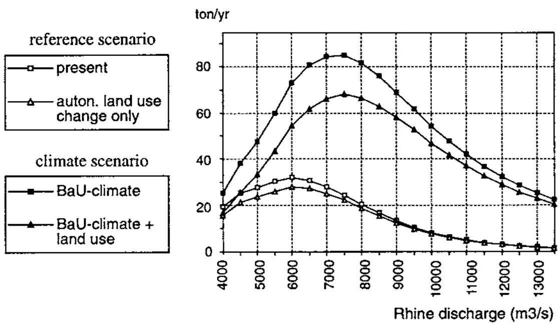


Figure 5. Effective sedimentation on a low floodplain section for different discharges.

Figure 6. Sediment load transported over the embanked floodplains for different scenarios.

5.2 Sensitivity of large scale potential sedimentation rates

The potential sensitivity of the sedimentation rate on the entire embanked Waal floodplain for a climate change was investigated from changes in the annual amount of river sediment load that is transported over the embanked floodplain. The 1-dimensional SOBEK model (Huyskens & Barneveld, 1994) was used to calculate for a series of discharge stages the percentage of the river discharge transported over the embanked Waal floodplain. At each stage, the sediment load transported over the floodplain was calculated from the product of (1) the discharge, (2) the suspended sediment concentration and (3) the relative frequency of occurrence. The summed totals of the product for all discharges gives the average yearly load, expressed in Mton/yr. This is the amount of sediment is potentially available for deposition. The effect of the BaU discharge scenario and four sediment rating scenarios on this sediment load was calculated to investigate the possible impact on floodplain sedimentation.

The BaU climate scenario will increase the average sediment load transported across the floodplains by a factor 3.5 compared to the present situation and by a factor 3.2 compared to the situation with autonomous land use changes (figure 6). The changes in effective sediment deposition will be smaller than the changes in the sediment load.

6. CONCLUSIONS

The present floodplain geomorphology comprises both pointbars of meandering rivers and lateral bars that have been formed during the past centuries. Floodplain sedimentation depends on floodplain characteristics, discharge frequency distributions and sediment concentrations, and therefore shows a high variability in time and space. Present floodplain sedimentation rates range between 0.5 and 15 mm per year.

The effect of the BaU climate change on floodplain sedimentation are considerable. High discharges will occur more frequently and sediment concentrations are expected to increase as a result of climate change. Under the BaU climate scenario, the yearly amount of sediment transported over the embanked Waal floodplain is more than three times as large as under present climate conditions. The increase of the effective sedimentation rates will be smaller, depending on the type of floodplain section. Sedimentation rates are expected to increase at least by about 50% on floodplain sections directly bordering the main channel and without a summer dike. The sedimentation rate on floodplains that are situated behind a summer dike is expected to increase more than 50%. If also the effect of changes in land use are taking into account, changes for low lying floodplains are insignificant. Nevertheless, the average sediment load transported over the entire floodplain increases still by a factor 2.8.

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