

The impact of climate change on suspended sediment transport in the river Rhine

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Abstract

Erosion, transport and deposition of fine suspended sediments are both directly and indirectly influenced by climate conditions. In this study, the suspended sediment transport regime of the river Rhine under present and future climate conditions was assessed. The impact of climate change on the sediment transport regime was investigated using sediment rating curves in combination with flow duration curves, developed using the BaU-climate scenario, and three sediment production scenarios. The results indicate that a climate change under changed land use conditions will result in a 14% increase in total annual suspended sediment load. A larger part of the yearly sediment load will be transported at discharges over 4000 m³/s. This probably results in increased floodplain sedimentation rates.

1. INTRODUCTION

The increased emission of CO₂ and other greenhouse gases during the 20th century, is expected to enhance the greenhouse warming of the lower atmosphere. This may cause a world-wide climate change in the forthcoming decades, resulting in changes in temperature and precipitation. The climate induced changes in vegetation cover and water discharge in turn will affect erosion, transport and deposition of suspended sediments in the river Rhine.

Within the scope of the National Research Program (NRP 1) the impact of climate change on discharge, and the suspended sediment transport regime of the river Rhine was studied. The IPCC "Business as Usual" (BaU) scenario projected on the Rhine catchment, was used as climate change scenario (Kwadijk, 1993).

The aim of this study is to investigate the processes of sediment transport through the river Rhine under actual climate conditions, and to assess the effect of climate change on the suspended sediment transport regime, depending on changes in discharge and sediment supply to the rivers.

2. METHODS

Since wash load is a non capacity load, the amount of fine suspended sediment transported by the river Rhine depends on the availability of loose material and to a lesser extent on the capability of the river to transport this material. Therefore, sediment transport rates cannot be calculated using stream power related transport formulas. Instead, the so-called rating curve technique can be used. A sediment rating curve describes the average relation between discharge and suspended sediment concentration. The most commonly used relationship between discharge and suspended sediment concentration is a rating curve in the form of a power function (a.o. Walling, 1974). In this study a power function with additive constant term was used:

$$c = p + a * Q^b$$

where c is suspended sediment concentration (mg/l), Q is river discharge (m^3/s) and a , b and p are regression coefficients. Sediment rating curves were developed for five gauging stations along the river Rhine (figure 1), using daily discharge and suspended sediment concentration data, measured by the Bundesanstalt für Gewässerkunde (BfG), Germany.

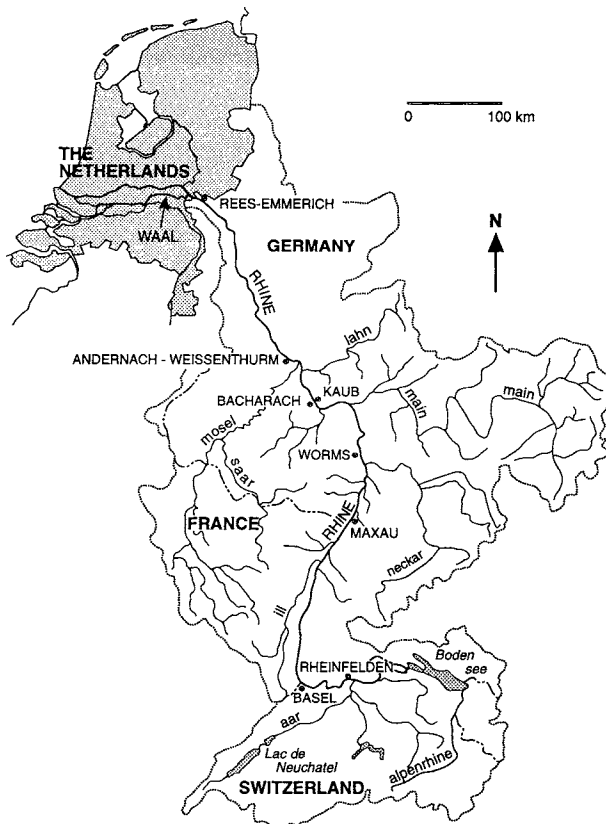


Figure 1. Location of the gauging stations.

The amount of sediment transported at a certain discharge is given by the sediment rating curve. The frequency of occurrence of a certain discharge is given by the discharge frequency distribution. Both curves were combined to obtain the sediment discharge curve. This curve shows at which discharges most suspended sediment transport takes place.

Changes in the sediment discharge regime were studied using the flow duration curve and sediment rating curves, developed in accordance with the BaU climate scenario. Monthly scenario discharges were calculated by Kwadijk (1993). The monthly average discharge values were converted into daily discharges using statistical methods based on the method described by Kwadijk and Middelkoop (1994).

Changes in suspended sediment production by soil erosion in the Rhine basin under BaU climate and land use conditions were assessed using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). Three sediment production scenarios were used, each resulting in a different sediment rating curve. These sediment rating curves were combined with the BaU flow duration curve to obtain sediment discharge curves. The sediment discharge curves show the changes that are expected to occur in the sediment transport regime of the Rhine, when climate changes in accordance with the BaU scenario.

For Rees, near the Dutch-German border (figure 1), the following sediment transport scenarios were used:

- 1) Sediment loads are determined by hydraulic properties of the river, as shown by the sediment rating curve developed for present climate conditions. This rating curve remains valid under changed climate conditions. Changes in sediment production in upstream areas have no direct effect on the sediment load near Rees.
- 2) Sediment loads are determined by the erosion rates in upstream parts of the river basin under BaU climate, and present land use conditions.
- 3) Sediment loads are determined by erosion rates in upstream parts of the river basin, as expected for the BaU climate and land use scenario.
- 4) Sediment loads are determined by changes in sediment production due to autonomous changes in land use, no climate change is taken into account. This scenario is used as a reference scenario to evaluate the effect of climate change under changed land use conditions.

3. RESULTS

The sediment rating curves developed for the selected gauging stations are shown in figure 2. The sediment rating curves can be used to obtain information on the availability of sediment in a certain area in combination with the erosive power of the river itself.

Steep rating curves, as observed near Rheinfelden, are characteristic for river sections with little sediment transport taking place at low discharge. An increase in discharge results in a large increment of suspended sediment concentrations, indicating that the power of the river to erode material during high discharge periods is great, or that important sediment sources become available when the water level rises.

Flat rating curves, as found near Rees, are characteristic for river sections with intensively weathered materials or loose sedimentary deposits, which can be transported at all discharges. The constant p-coefficient can be seen as a background concentration, a minimum concentration of suspended sediment occurring at very low discharges. Since the

steepness of the rating curve decreases in a downstream direction, it can be concluded that (1) the importance of high discharge events in transporting suspended sediment decreases in a downstream direction, and that (2) near the Dutch-German border large quantities of fine material are available for transport at all discharges.

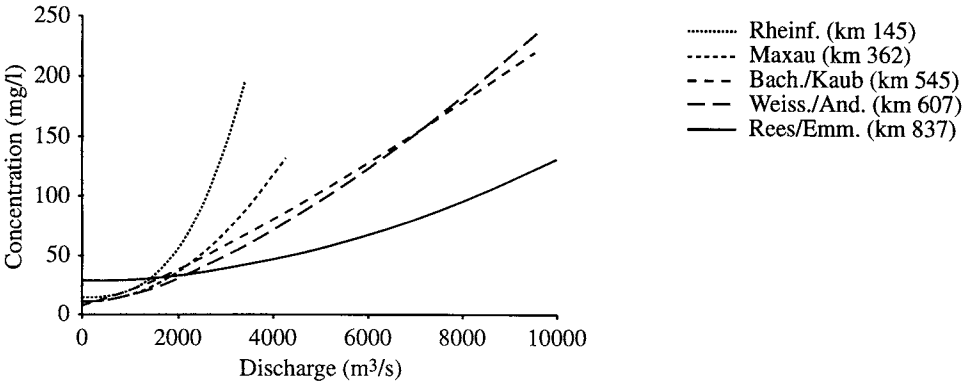


Figure 2. Sediment rating curves developed for several gauging stations along the river Rhine, under actual climate conditions.

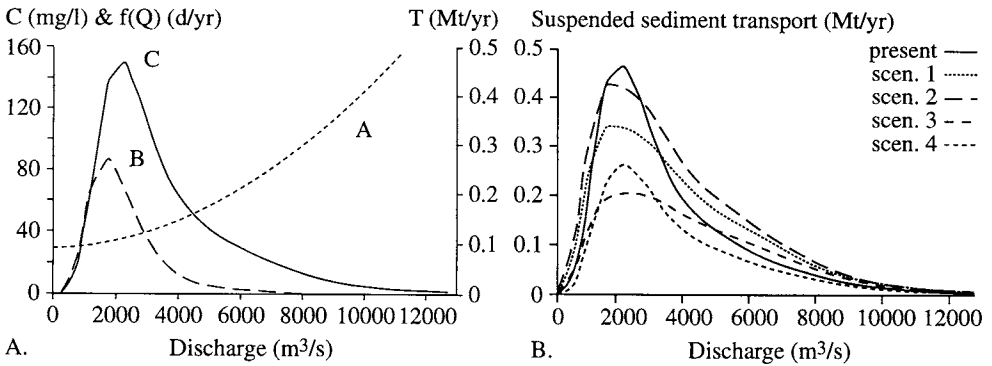


Figure 3. Sediment discharge curves developed for Rees under present and BaU climate conditions.

a) present climate conditions (A: suspended sediment concentrations (mg/l); B: frequency of occurrence of daily discharges (d/yr); C: suspended sediment transport (Mt/yr)). b) according to several sediment transport scenarios.

Figure 3a shows the sediment rating curve (A), the discharge frequency distribution (B), and the sediment discharge curve (C), developed for Rees under present climate conditions. The sediment discharge curve shows that under present climate conditions, most suspended sediment is transported at moderate discharges, with a high frequency of occurrence.

The sediment discharge curves developed for the different sediment transport scenarios are shown in figure 3b. The results are summarized in table 1. According to all scenarios, the importance of high discharge events in transporting suspended sediment will increase. This is mainly related to the expected changes in the discharge frequency distribution. The total annual sediment loads are different for each scenario.

The impact of climate change on sediment transport rates under future land use conditions can best be assessed by comparing scenarios 3 and 4. This comparison shows that a climate change as assumed in the BaU climate scenario, will result in a 14% increase in the total annual suspended sediment load near Rees. The suspended sediment load transported at discharges over 4000 m³/s, when several floodplains along the Dutch part of the river Rhine are inundated, will increase by about 47% from 0.66 to 0.97 Mt/yr.

Table 1
Sediment transport rates using four sediment transport scenarios

Scenario	p	Total load		Q > 4000		Q > 6000	
		%	Mt/yr	%	Mt/yr	%	Mt/yr
present	29	100	3.04	28	0.85	12	0.36
1a	29	106	3.21	38	1.22	17	0.55
1b	27	100	3.04	38	1.16	18	0.55
2	38	125	3.81	36	1.37	16	0.61
3	15	72	2.20	44	0.97	21	0.46
4	14	64	1.93	34	0.66	16	0.31

p = background concentration (mg/l)

total load = annual suspended sediment load in % of present transport and Mt/yr

Q > 4000 = percentage of average annual sediment load transported at Q > 4000 m³/s

Q > 6000 = percentage of average annual sediment load transported at Q > 6000 m³/s

Steepness of the rating curve is kept constant with a = 1.96*10⁻⁶ and b = 1.93

4. CONCLUSIONS

When climate changes in accordance with the BaU scenario, the annual suspended sediment load near Rees is expected to decrease by about 28% compared to the present load. However, the impact of climate change on the suspended sediment loads is best assessed by comparison of scenarios 3 and 4. This comparison shows that a climate change in addition to autonomous changes in land use will result in a 14% higher annual suspended sediment load near Rees.

According to all sediment transport scenarios a larger part of the yearly suspended sediment load will be transported at discharges over 4000 m³/s, when inundation of low lying floodplains occurs. Under present climate conditions about 28% of the yearly sediment load is transported at discharges over 4000 m³/s, this will be over 40% when land use and climate change in accordance with the BaU scenario.

5. REFERENCES

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