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IMPACT OF CLIMATE CHANGE ON THE DISCHARGE OF THE RIVER RHINE

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Abstract

Climate change influences the water balance of drainage basins in several ways. In a project of the International Commission for the Hydrology of the Rhine basin the possible consequences for the discharge regime of the Rhine are investigated. In the first phase of this project detailed models have been developed and applied for selected sub-basins and a simple water balance model has been developed for the whole Rhine basin. Results are presented for climate scenarios assuming an increase in temperature of about 3°C and an increase in annual precipitation. The consequences of such a climate change are largest in the Alpine part of the Rhine basin, and are also considerable in other parts of the basin and for the basin as a whole. In general the Rhine changes towards a rain-fed river. The winter discharge increases, which can have consequences for safety, and summer discharge decreases with consequences for shipping, industry, agriculture and ecology.

1. Introduction

Climate change influences the components of the water balance of drainage basins in several ways. Precipitation patterns may change and because of a higher temperature also the timing and amount of snow fall and snow melt. Evapotranspiration is directly influenced by an increase in temperature. An increased CO_2-concentration affects plant physiology and may lead to changes in water use too. Furthermore climate change may induce changes in land use, which is an important factor in evapotranspiration and runoff processes. Changes in these water balance components will of course affect the discharge.

The River Rhine is economically the most important river of Western-Europe. Its drainage basin, see figure 1, stretches from the source in Switzerland to the mouth in the North sea, covering an area of 185.000 km^2 and is habitat to about 55 million people. The river is one of the most intensively navigated inland waterways in the world and is of major importance for the supply of water to large economically important areas. Changes in its discharge regime can have consequences for safety and for the water availability for shipping, industry, domestic use, agriculture, the natural environment and recreational purposes.

Against this background, the International Commission for the Hydrology of the Rhine basin (CHR) initiated a project to assess the consequences of climate and land use changes for the discharge regime of the River Rhine. Since a proper tool for this was lacking, the main purpose of the project was to develop a water management model for the whole Rhine basin. This model should be used to analyze the changes in average and extreme discharges and the effectiveness of mitigating measures. Several institutes from the Rhine riparian states cooperate in the project (Parmet, 1993). The Netherlands contribution to this project is incorporated in the Dutch National Research Program on Global Change (NRP).

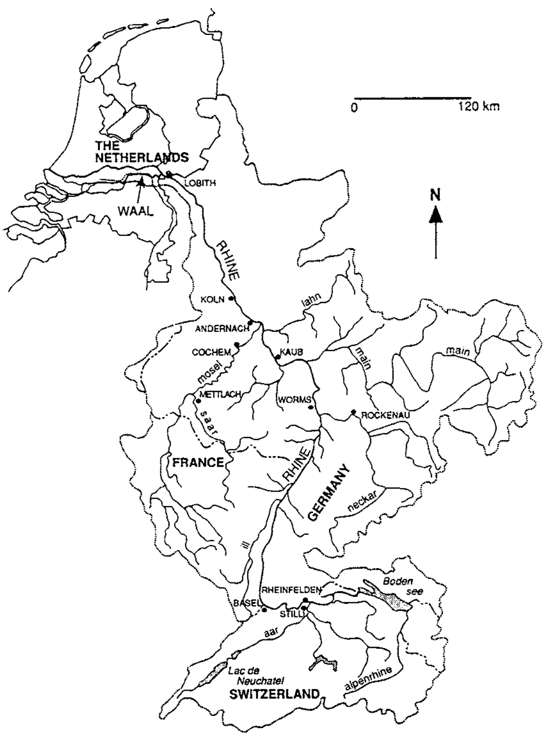

Figure 1. Drainage basin of the River Rhine

2. Method

The model will be developed in two phases. In the first phase model development takes place along a bottom-up and a top-down approach. In the second phase both approaches will be combined. Along the bottom-up approach hydrological models are developed for selected sub-basins. These models are detailed in time and space and can be used to simulate the effects of climate and land use changes on average and peak flows. Sub-basins were selected in three distinct areas; the Alpine area, the Middle Mountains and the Lowland area. Different model concepts are used because the relevant hydrological processes differ. Snow accumulation and melt, for example, is very important in the Alpine area and groundwater flow for the Lowland. Along the top-down approach a GIS-based water balance model is developed with a course resolution in time and space. This model can be used to study the sensitivity of the average discharge regime of the river Rhine and its main tributaries for climate change.

The first phase of the CHR project is almost finalized. Along the bottom-up line, several detailed models are developed and also existing models are applied for representative sub-basins. For the Alpine area an existing hydrological model, the IRMB model, was applied for several small drainage basins (Bultot, 1992, Schädler 1992). In the Middle Mountains area, a model will be developed for the Saar basin, a sub-basin of the Mosel. Results are not yet available. The Lowland model is developed for the drainage basin of the Overijsselsche Vecht (Parmet and Mann, 1993, Parmet and Raak, in prep). This model consists of a hydrological component, that is used to compute the daily evapotranspiration and discharge for sub-basins, and a flow-routing component, that combines the sub-basins and routes their discharges towards the mouth of the Overijsselsche Vecht. For the Rhine basin as a whole the water balance model RHINEFLOW was developed (Kwadijk, 1993). It is a simple water balance model based on a Geographical Information System.

3. Results

3.1. Effects of climate change in representative basins in the Alpine area

With the IRMB model the effects of a climate change for several components of the water balance were simulated for three drainage basins, Murg, Ergolz and Broye. A climate scenario as defined by Bultot was applied (Bultot, 1988). The monthly temperature and precipitation changes are given in table 1. Changes in physiological behavior of plants were not taken into account. Simulations with changed climate were carried out for the period 1981 to 1988.

The simulations showed an increase of annual potential evapotranspiration of 10%. Actual evapotranspiration increased somewhat less because during the summer period there is a slight decrease in soil moisture. Discharge increased during the winter period with 10%. This is due to the fact that the amount of winter precipitation increases and less precipitation is stored as snow. Furthermore the accumulated snow melts faster. The duration of the snow cover decreases considerably, especially below an altitude of 1500 m. Discharge in summer decreased with about 15%. This follows from a reduced contribution of melt water, a larger evapotranspiration and a slight decrease in precipitation. The total annual discharge hardly changes. The daily maximum discharge increases and the daily minimum discharge decreases.

3.2 Effects of climate change in representative basins in the Lowland area

The climate scenario that was used for the Lowland area was based on a method developed in the framework of the NRP (Klein Tank and Buishand, 1995). The monthly changes in temperature and precipitation are given in table 1. Compared to the other scenarios used in this study, this scenario is rather wet. Computations were carried out for the basin of the Overijsselsche Vecht for the period 1965-1990. Changes in plant physiological characteristics were taken into account.

An increased CO_2-concentration influences plant physiology. For most plants the water use efficiency increases and the biomass production increases. An increase in temperature for the temperate zones generally leads to an increase in production too. Present knowledge indicates, for doubled CO_2-concentrations and an increase in temperature of about 1.5°C, a small decrease in evapotranspiration for most crops and forests (Roetter en van Diepen, 1994; Hendriks, 1994). Based on this knowledge, plant physiological parameters were provisionally adapted in the Lowland model (Parmet and Raak, in prep).

Table 1
Monthly temperature (T) and precipitation (P), used for representative Alpine basins and for the representative Lowland basin

Month	J	F	M	A	M	J	J	A	S	O	N	D
T_{alpine}, °C	3.1	3.4	3.4	3.1	2.8	2.7	2.5	2.3	2.3	2.7	2.8	3.2
P_{alpine}, % [1)]	10	14	11	10	-1	-2	-2	-2	0	6	10	10
$T_{lowland}$, °C	3.0	3.0	2.3	2.3	2.3	3.7	3.7	3.7	3.4	3.4	3.4	3.0
$P_{lowland}$, %	21	20	15	13	5	12	11	9	3	8	19	18

[1)] The percentual change is an average for the three basins Murg, Ergolz and Broye (Schädler, 1992)

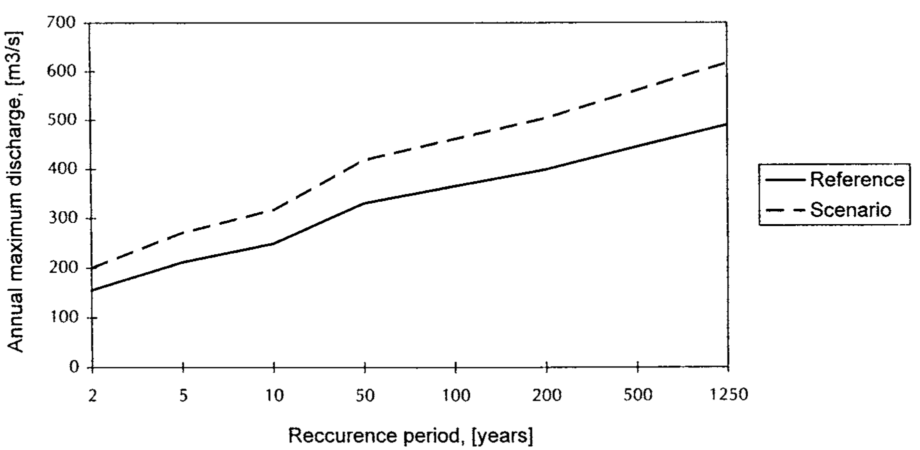

Figure 2. Discharges for different recurrence periods for reference and scenario conditions, as computed with the lowland model for the drainage basin of the Overijsselsche Vecht.

Simulations for the lowland showed an increase in actual evapotranspiration of about 7%. The CO_2 effect on water use does not compensate for the increase in temperature of 3 °C. The annual discharge increased with 22%. Winter discharge increased with 25%. The increase in evapotranspiration in summer does not exceed the increase in precipitation. Discharge in summer increased with 19%. The maximum discharge increased considerably. The distribution of annual maxima can be described using a Gumbel distribution (Mendel, 1993). According to fitted Gumbel functions for the reference (r^2 = 0.98) and scenario (r^2 = 0.97) simulations, peak flows with different recurrence periods change as indicated in figure 2. River dikes in the Netherlands are designed for a discharge with a recurrence period of 1250 years. The figure shows an strong increase of 26% in this design discharge for the river Vecht.

3.3 Effects of climate change, Rhine basin

Consequences for the whole Rhine basin have been computed with the RHINEFLOW model. The sensitivity of the discharge regime was examined with a wide range of climate scenarios for the period 1956 to 1980 (Kwadijk, 1993). Here the results of computations with one scenario, the so-called BAU-best scenario, are presented. The scenario is based on the IPCC Business as Usual scenario (IPCC, 1991). It is given in table 2. Changes in land use and physiological characteristics of plants were not taken into account.

Table 2
BAU-BEST scenario for temperature (T) and precipitation (P), for different parts of the Rhine basin (Kwadijk, 1993)

	Year		Summer		Winter	
Part of Rhine basin	T, °C	P, %	T, °C	P, %	T, °C	P, %
North	3.5	11	2.9	4	4.3	19
Middle	3.5	8	2.9	-1	4.2	19
South	3.5	7	2.9	-4	4.1	19

For the Alpine part of the Rhine basin, the changes as computed with RHINFLOW have the same direction as the results for the representative Alpine basins. As can be seen from figure 3, winter discharge increases. This is caused by increased precipitation and snow melt. During summer the discharge decreases due to a smaller contribution of melt water, increased evapotranspration and a slight decrease in precipitation. The increase in winter discharge is much larger than for the representative basins, upto 100% with an average of 60%. This can be explained partly from the used scenarios. Both the increase in temperature and in precipitation is smaller for the Bultot scenario compared with the BAU-best scenario. Furthermore it can be explained by differences in model components, especially the snow component, and off course the considered area is not the same. The changes during summer are comparable, both for the alpine area as a whole and for the representative basins in the alpine area, a decrease of about 15% was computed.

The changes for the area downstream, the Middle and Lowland part, are much less pronounced. The discharge increases during winter and spring and decreases during summer and autumn, as can be derived from figure 3. The increase in evapotranspiration causes the soil water deficit to increase. As a result, summer discharge decreases, but because part of the winter surplus is stored as groundwater, not untill July. The water surplus during autumn is partly used to replenish soil water, which explains the decrease of discharge during autumn. Because the scenario used for the representative basin for the lowland is wetter, especially for the summer period, than the BAU-best scenario, the changes in discharge are not directly comparable.

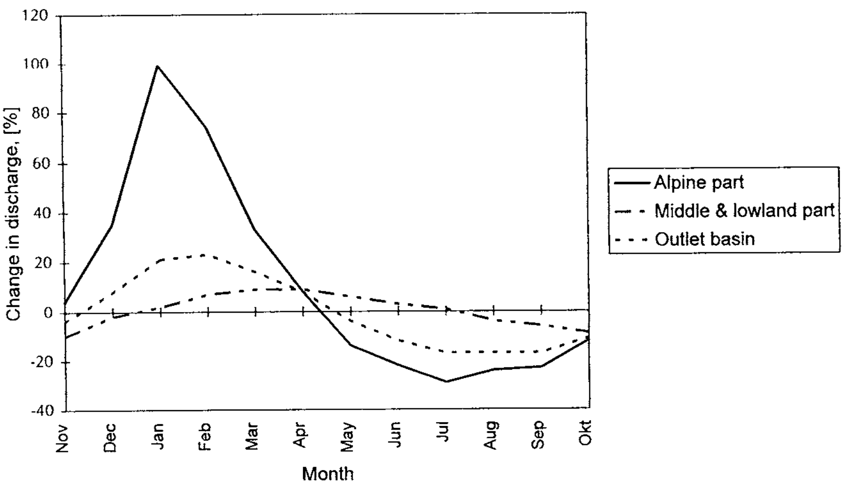

Figure 3. Changes in monthly discharge for different parts of the Rhine basin and near the basin outlet, for simulations with the BAU-BEST climate scenario, for the period 1965-1980.

Where the River Rhine enters the Netherlands, near the basin outlet, the changes in the Alpine, Middle and Lowland part are combined. The annual changes are small, the discharge increases with 2%. However, winter and spring discharge increase with about 15%, and summer and autumn discharge decrease with about 10%, see figure 3. Due to the changes in the alpine area the regime of the River Rhine changes from a combined rain-fed/snow-fed into a rain-fed river. The discharge pattern will become less smooth and the difference between maximum and minimum flows will increase. The number of months with low flows will increase. For example, the results indicate that the number of months with an average discharge below 1000 m^3/s increases for the period 1956 to 1980 with 13, which is about 60%. To make an assessment about peak flows with the monthly discharges computed by RHINEFLOW, a relation between average monthly flows and peak flows was derived. Using this relation it was shown that the probability of discharge peaks upto 7000

m^3/s increases significantly. This is important in respect to sedimentation on floodplains, because these are inundated for such discharges. The relation does not give well-founded results for the design discharge, and hence about consequences for safety.

4. Implications

Interim results of the CHR project show that climate change can have considerable effects for the discharge regime of the Rhine. With the assumed scenario for the Rhine basin, the winter discharge increases considerably. This could have consequences for safety, but the models are not yet suitable to assess consequences for design discharges. The contribution of melt water originating from the Alps during the summer period decreases, which is an important reason for a decrease in summer discharge. Furthermore evapotranspiration is expected to increase, which contributes also to a decrease in summer discharge. Consequently the frequency of periods with low flows increases. For water management in the Netherlands an increased frequency of low flows implies increasing costs for shipping. Ships can be loaded less and have to wait longer for sluices and bridges. Costs of electricity production will increase too. To avoid environmental problems with the temperature of cooling water, other more expensive, production units have to be brought into operation. Other industries that use water for cooling purposes may have to limit production or built cooling towers. Lower water levels will also have undesirable effects on ecological development in floodplains, dessication problems are expected to increase. Furtermore the increased frequency in low flows wil result in a more frequent intrusion of salt water. This can cause problems for intake of water of certain polders and may cause damage to agriculture. In general the changed discharge regime will also influence river morphology.

For the Rhine basin land use scenarios have been developed in the framework of the CHR project (Roetter, 1994; Roetter and v. Diepen, 1994; Hendriks, 1994; Veeneklaas et al, 1994). The effects of land use changes have not yet been studied in detail. From first computations it can be concluded that for Lowland areas the total discharge rather than peak discharges will be affected. For the Alpine and Middle Mountains area it is expected that also the peak flows are influenced. First estimates show that land use changes are very important for the production of suspended sediment, sediment transport and sedimentation processes (Asselman, 1994; Middelkoop, 1994). Further study is required.

The model RHINEFLOW in its present form is a usefull tool for sensitivity analysis. However, the simple process descriptions and the poor quality of the underlying database, limit its applicability. On the other hand the detailed models are only available for a relatively small part of the Rhine basin. To extend these models for the whole basin is a time consuming task. Therefore a promissing direction is to couple the rough and the detailed models, for example with transfer functions. RHINEFLOW has to be refined in time and space for this. Furthermore the detailed models have to be applied also in other characteristic areas, to cover the variability within the Rhine basin in a better way. It is recommended to investigate the possible effects of climate change also for other important river systems, like the Meuse. A similar approach as in the CHR project can be applied.

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