6 EUROPE'S FLOODS TODAY AND IN THE FUTURE

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6.1 Introduction

Extreme flood events can cause tremendous damage to economy and ecology and, in the worst case, bear enormous risks for life. At the same time, climate change scenarios generally imply an increase in rainfall variability and, on global average, an increase in total precipitation which could lead to even more frequent and severe floods. Modeling the impact of climate change on future river floods, flood frequencies or the risk of flooding thus draws increasing attention both from a scientific and political point of view.

Typically, hydrological assessments on floods and flood frequencies apply basin-specific, mesoscale approaches, and consequently focus on single basins or subbasins. But as climate change affects the whole globe, it is also necessary to carry out additional studies on a larger, continental or even global scale in order to provide a comprehensive picture of possible scenarios. In this chapter we therefore introduce a concept of how to analyze the possible impacts of climate change on future flood frequencies in Europe. Knowledge from natural and social sciences and engineering are combined in an integrated assessment by applying the global integrated water model WaterGAP.

The primary goal of this study is not to provide quantitative results in terms of absolute or single-event flood discharge values. Rather we aim to analyze the following question: *In which European river basins can we expect a significant increase of extreme floods due to climate change?* In order to answer this question, we develop a spatially consistent methodology to arrive at comparable results throughout the whole of Europe.

It should be noted, that in this paper a *flood* is defined strictly in terms of discharge. To what extent a given discharge value is related to a real *flooding*, in terms of bursting river banks and setting a considerable area under water, is a complex question. To answer it, additional information would be required, in particular a high-resolution elevation model. These data are currently not available on a continental scale. However, knowing the frequencies and volumes of extreme flows is a step towards assessing the risks of river floods.

6.2 Methodology

6.2.1 General overview of flood and flood frequency calculations

In rivers, floods are usually expressions of the temporal and spatial distribution of rainfall and snowmelt, i.e. their quantity, intensity, time, duration and frequency, interacting with river basin characteristics. The basin characteristics can be broadly divided into overall basin form, hillslope properties and channel network properties. Whether a flood actually occurs is mainly determined by (Jones, 1997):

a) The volume of direct or near-surface runoff. This volume is strongly related to the effective rainfall or snowmelt quantities as well as antecedent soil moisture conditions.

b) The uniformity of runoff times from different parts of the basin. The more uniform the response and travel times, the greater the likelihood of the river flow building up at a certain river confluence into a high peak flow. In basins that have such uniformity, this may create flood flows out of discharge volumes that in others would pass as a more subdued event. Uniform response is largely a product of a compact basin form and a compact, dendritic channel network, but it may also depend on the speed of drainage, mainly affected by hillslope properties or drainage densities.

Different approaches are suggested to assess the change in flood frequencies driven by climate change. One approach is to investigate the change in extreme precipitation events, e.g. the Probable Maximum Precipitation (PMP). This information is then analyzed in order to derive the induced change in discharge, i.e. the Maximum Probable Flood (MPF) (Jones, 1997). An alternative approach is adopted in this study, namely to apply a hydrological model as a tool for estimating current as well as future river flows. The obvious disadvantage of this approach is that by introducing a complex model for transforming rainfall into different runoff components on a physical basis, the inherent uncertainties will increase. The advantages, on the other hand, are that:

a) Precipitation is not the only "driving force" to flood formation. Additional parameters representing the physical basin characteristics like land use, hillslope or antecedent soil moisture conditions as well as external influences like water withdrawals or flood control can have significant effects. Taking these factors into account, the same change in precipitation in two different basins does not necessarily lead to the same change in flood frequency. In principle, a rainfall-runoff model reflects these needs, in particular when an adequate river routing scheme is included.

b) An integrated water model like WaterGAP can be applied to assess not only the impact of climate change on future floods but also some other effects of global change, like the impact of changes in land cover and water use.

The general objective of flood frequency analysis is to relate the magnitude of a flood to its frequency or probability of future occurrence. The analysis commonly starts by selecting either the highest discharge in each year (annual maximum series), or all discharges above a certain threshold (partial duration series). Methods that combine the two options (annual exceedence series) are rarely used, as they are more complex and in practice often show too little improvement to justify the efforts. To derive a basin’s flood frequency distribution, the selected discharge values are ranked and fitted to a model statistical distribution or probability density function (pdf) which allows for inter- and extrapolation of the frequency distribution. Several distribution functions have been developed to serve this purpose, but no single statistical distribution has been found that fits all data (Jones, 1997).

6.2.2 Data limitations

All approaches for assessing the impacts of climate or global change on flood frequencies are basically limited by the quality of their respective input data. The climate data requirements for large scale studies are addressed by General Circulation Models (GCMs) which provide meteorological data representing the climate change scenarios on a low spatial resolution. The accuracy of GCM results is difficult to judge (see Chapter 4). Tests with two different state-of-the-art GCMs (ECHAM4 and HadCM3, Chapter 4), for example, showed good correlation in precipitation values for some areas, but clear disagreements for others. Being the result of long time series calculations, the daily precipitation values of GCMs are largely influenced by the chosen initial and boundary conditions. As a consequence, changes in precipitation variability on a daily basis due to climate change are, at present, not considered to be quantitatively reliable. A better accuracy is assumed for long-term annual or monthly means. Within this study it is thus generally assumed that the temporal and spatial distribution of a GCM’s precipitation data on a day-to-day basis is less reliable, if not misleading, than aggregated mean values. We therefore refrain, even for the following flood calculations, from applying daily meteorological input data for the WaterGAP model runs but keep the model’s standard input of monthly means.

6.2.3 The WaterGAP 2.1 model

For the studies presented within this chapter, the global integrated water model WaterGAP is applied in its version 2.1. A detailed model description is provided in Chapter 2 of this report. Here, only the aspects most relevant for flood calculations are highlighted:

Water use. All calculations carried out within this flood study are performed applying the water use simulations of WaterGAP 2.1 as defined in Chapters 2 (today) and 4 (Baseline-A scenario). Actual river discharge is thus derived as natural discharge minus consumptive water use. Typically, floods are determined by extreme daily or even more short-term peak flows, and abstractions for households, industry or agriculture are not considered to have a major impact on these events (except for reservoir management, see below). Therefore, the actual river discharge is analyzed in this chapter, and no separation into individual effects of natural discharge (assumed dominant) and consumptive water use (assumed unimportant) is carried out or discussed further.

Land cover. Although in principle WaterGAP is able to take into account the impact of changing land cover on runoff generation via its direct or indirect effect on root depth, albedo, soil moisture and interception, all following flood discharge calculations are performed without a change in land cover or land use. This is mainly due to the absence of realistic, reliable macroscale land use change scenarios, which are expected to be available at a later stage. For the interpretation of the results, this simplification has to be considered.

Lakes, reservoirs wetlands and lateral transport. For flood formation, discharge retention through lakes, reservoirs and wetlands, as well as lateral transport along the river courses play a major role. In WaterGAP, these processes are addressed by *local* lake, reservoir and wetland storage within each cell, and by applying a global drainage direction map along which the discharge is routed downstream from cell to cell; on this passage the discharge can re-enter *global* lake, reservoir or wetland storage. Although WaterGAP 2.1 distinguishes between lakes, reservoirs and wetlands, at present a rather simple non-linear storage approach is applied to all freshwater storage as no further data on reservoir management or retention behavior is available. Also, there is no information on existing or planned canals for flow diversion implemented in the model. As a consequence, WaterGAP will locally underestimate the possible human influence of flood control.

Pseudo-daily precipitation values. WaterGAP accounts for the impact of climate change on runoff generation via the change of monthly temperature and precipitation within the vertical water balance. For flood formation, however, the daily precipitation pattern is expected to play a dominant role. In WaterGAP, pseudo-daily precipitation values are generated from monthly values by utilizing the given information on the number of rain days per month, such that there are days with and without precipitation. The monthly rainfall volume is then equally distributed over all wet days. In order to include information on rainfall persistency, the distribution of wet days within a month is modeled as a two-state, first-order Markov chain (see Chapter 2). This conceptual approach excludes the option of simulating single flood events, as there is no "real" daily precipitation input into the model. Nevertheless, when looking at long time series, the overall stochastic sequence of wet and dry spells as well as the main basin characteristics influencing runoff formation are reflected in the model. This backs the assumption that the statistical distribution of "relative" flood events might be preserved in the model although the single flood events do not occur at the correct times and in correct magnitudes (e.g. a "relative" flood that exceeds 3 times the mean annual peak discharge occurs once in 100 years both in reality and in the model, but not in the same year). To what extent WaterGAP is able to simulate statistical flood frequency distributions is investigated in Section 6.2.5.

6.2.4 Flood calculations with WaterGAP

In order to derive today’s and future flood discharges or flood frequency distributions, the following procedure is applied in the same manner to all cells of the WaterGAP grid, as well as, for evaluation purposes, to the data of selected gauging stations:

1. Daily discharge values (WaterGAP provides daily output) are applied. This temporal resolution is used as
    a) a longer time step is considered not appropriate for flood calculations,
    b) the day is the highest temporal resolution for which WaterGAP calculations are conceptually designed (e.g. pseudo-daily rainfall and temperature values are derived from given monthly averages), and
    c) no higher-resolution measurement data is available on a global scale for evaluation purposes.
2. For the flood and flood frequency calculations, the annual maximum discharge series is chosen. Thus, for every year only the highest discharge value is selected from the daily time series.
3. As flood calculations generally require long discharge series, the 30-year series 1961-90 is applied to calculate today’s floods (data before 1961 is considered increasingly uncertain). For the future scenarios, 30-year projections are applied (i.e. 2011-40 for the 2020s, 2061-91 for the 2070s; for more details on deriving the climate scenarios see Chapter 4).
4. In order to finally derive flood frequency probabilities, the commonly used Log-Pearson Type III distribution is fitted to the ranked annual maximum series. This leads to a statistical distribution function which can be inter- and extrapolated. Within this study, extrapolations are analyzed up to 200-year floods only as, when looking at the model and data uncertainties described above, any statements on more extreme events are not considered justified.

6.2.5 Evaluation of WaterGAP regarding flood assessments

For the evaluation of WaterGAP concerning its capability to assess floods, various comparisons of model simulations and discharge measurements are conducted. Most of the measurements (provided by the Global Runoff Data Center, GRDC, Koblenz, Germany), however, were also used for calibrating the model in the first place (as it was aimed to include all suitable GRDC stations for calibration). The evaluation is still an attempt to get an impression of the general reliability of flood calculations derived from a model that (i) uses monthly precipitation values and (ii) is calibrated to long-term average discharge only. As time series for the comparisons the 1961-90 “climate normal” period is chosen. The flood frequency distributions are extrapolated from these data.

First, in order to assess the general performance of WaterGAP concerning the simulation of high flow periods, its capability to model the seasonal discharge behavior is investigated. 30 GRDC stations are selected in equal distribution over Europe, of which 25 were also used for calibration (Figure 6.1). Based on monthly discharge values it is evaluated to what extent WaterGAP, in the long run, simulates the correct month with maximum discharge. For 22 stations WaterGAP showed correspondence within plus or minus one month to the GRDC stations, the maximum difference lying at four months (maximum possible difference: six months). WaterGAP is therefore believed to cover the overall regional trend, but fails at certain locations.

Second, in order to judge the capability to compute basin characteristic flood frequency distributions, the accuracy is evaluated to which WaterGAP calculations correspond to flood frequency distributions derived from discharge measurements. For this purpose, 21 European GRDC stations are selected which provide complete daily discharge measurement series for the years 1961-90 (this criterion, however, excluded Southern European GRDC stations, Figure 6.2). 19 out of the 21 stations were used for calibration.

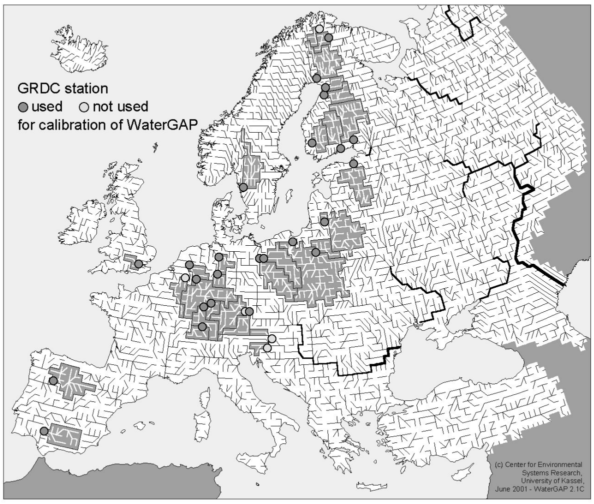

Figure 6.1: 30 GRDC stations selected for the evaluation of WaterGAP regarding seasonal high flow periods.

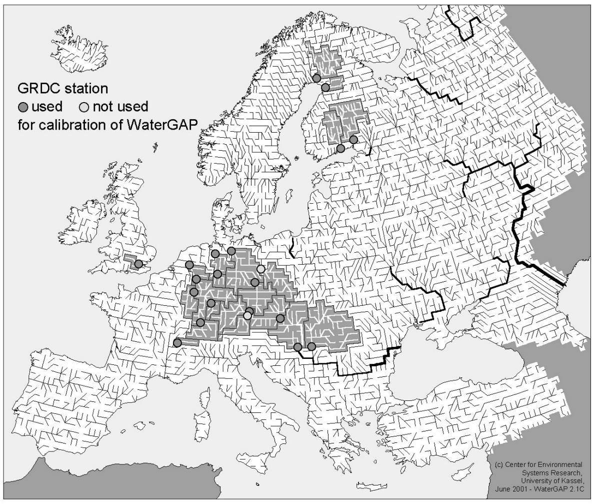

Figure 6.2: 21 GRDC stations selected for the evaluation of WaterGAP regarding flood frequencies.

Figure 6.3 presents the flood frequency distributions for the Czech part of the Elbe river basin at gauging station Decin (i) as derived from the GRDC daily discharge series, and (ii) as derived from WaterGAP 2.1 results. The GRDC curve shows generally lower values, with an absolute difference varying from approx. 500 m^3/s for the 2-year flood to 1400 m^3/s for the 200-year flood (to compare: the long-term average discharge is at approx. 300 m^3/s). The higher discharge values of WaterGAP in this basin are most likely due to an overestimation of flood inducing snowmelt events (compare Chapter 3). An overestimation of the basin area could be another explanation.

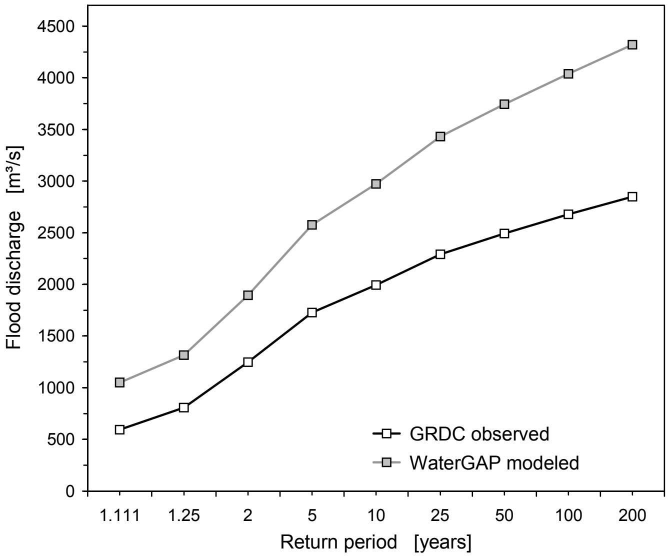

Figure 6.3: Flood frequency distributions for the Elbe river at station Decin (51 000 km^2), extrapolated from daily discharge values for period 1961-90, Log-Pearson Type III distribution.

The 20 other European GRDC stations were investigated in the same manner. In Figure 6.4 only the flood discharges with a return period of 100 years are extracted and analyzed. WaterGAP equally over- and underestimates the 100-year flood discharges. The underestimation can be explained as a consequence of applying pseudo-daily precipitation values, as the magnitude of extreme rainfall events is likely to be subdued by this method (extreme rainfall events reflect situations where nearly all monthly precipitation falls in one event rather than equally distributed over all pseudo-rainfall-days within the month). With a modeling efficiency of 0.78 the correspondence of the 100-year flood discharges derived from observed data and from model results is acceptable, especially when considering all limitations and restrictions discussed above.

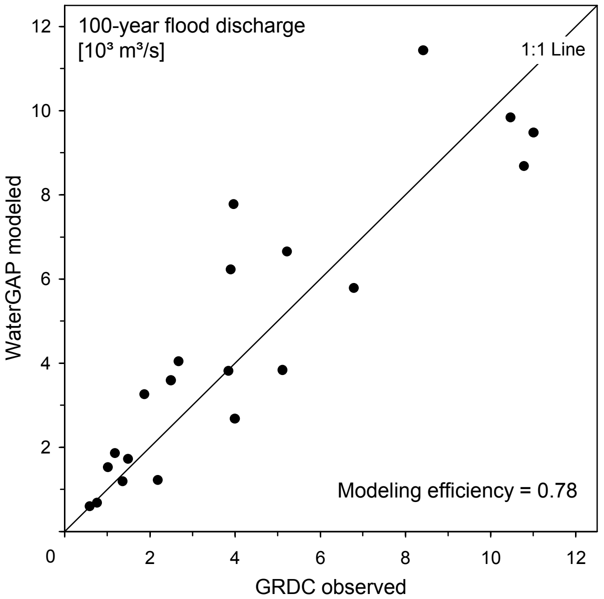

Figure 6.4: Comparison of GRDC observed and WaterGAP modeled 100-year discharge values for 21 selected European stations, period 1961-90.

A second look at Figure 6.3 indicates that the overall shape of WaterGAP's flood distribution function is comparable to the GRDC distribution function, differing only by a more or less constant factor. For a better interpretation of this behavior the *index-flood* method is applied. The index-flood procedure was originally introduced as a simple regionalization technique and has a long history in hydrology and flood frequency analysis. The concept underlying the index-flood method is that the distribution of floods at different but comparable sites in one region is the same except for a scaling or "index-flood" factor which reflects the size, rainfall and runoff characteristics of each watershed (Maidment, 1993). This means that the shape of the dimensionless flood frequency distribution, normalized to an index-flood value, is characteristic for a particular site. Generally, for normalization the mean discharge, or a flood flow of lower return period, e.g. 2 or 2.33 years, is employed as the index-flood value (Dyck and Peschke, 1995; Maidment, 1993; WMO, 1994).

Figure 6.5 includes again the example of the Elbe basin at station Decin. The frequency curves have been normalized by dividing every discharge value by an index-flood value, here chosen as the respective 2-year flood. The index-flood curves based on GRDC data and on WaterGAP results show very good agreement. Additionally, the index-flood curves of three other basins are presented in Figure 6.5. The distinctive shapes of the GRDC curves reflect the different flood behavior of the four basins due to their physical characteristics as well as their typical rainfall or snowmelt patterns. The WaterGAP curves are in good to very good agreement with the GRDC results.

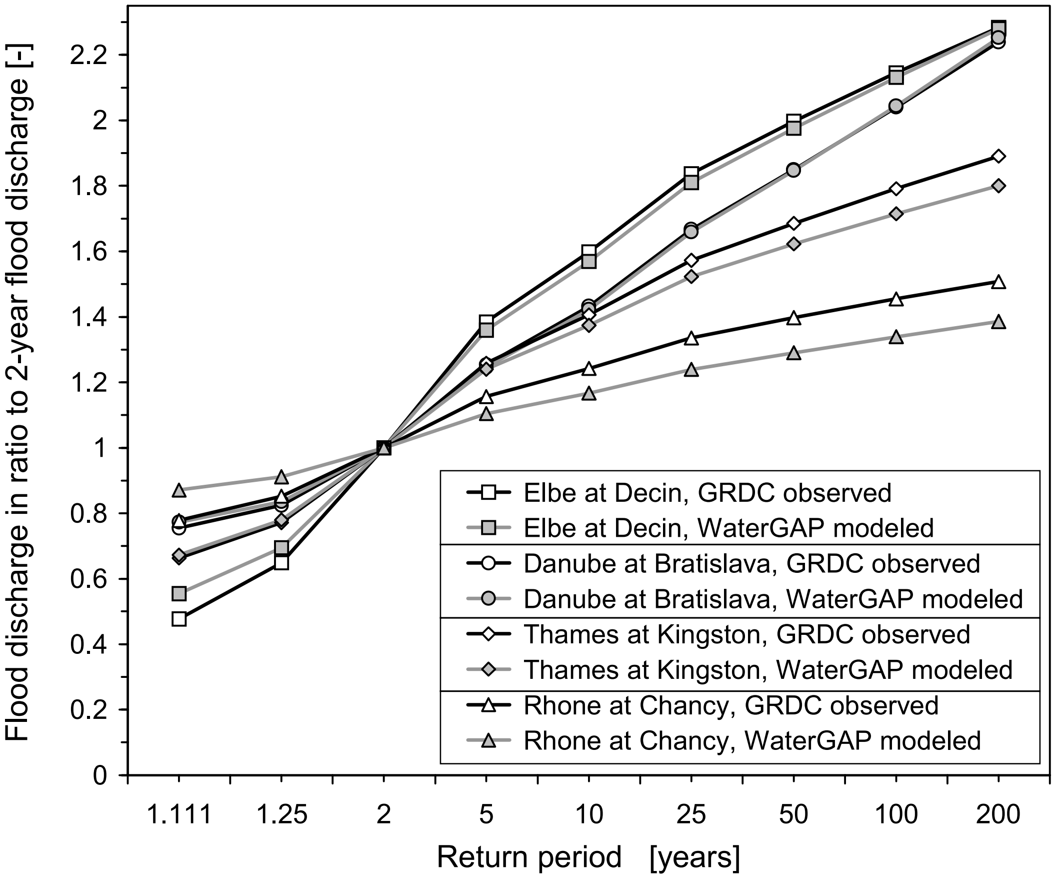

Figure 6.5: Observed and modeled index-flood curves for different basins: Elbe river at station Decin (51 000 km^2), Danube at Bratislava (132 000 km^2), Thames at Kingston (10 000 km^2), and Rhone at Chancy (10 000 km^2), period 1961-90, Log-Pearson III distribution.

The evaluation results presented in Figure 6.5 should not be mistaken for proof of the accuracy of WaterGAP. So far, 21 basins have been tested in a qualitative way: eleven (including the four stations of Figure 6.5) showed very good to good, six acceptable and four unsatisfactory (difference in discharge ratio about 1 unit for 200-year flood) correlation of the index-flood curves. More studies have to be carried out using a wide spectrum of test basins before the accuracy of WaterGAP concerning index-flood distributions can be judged finally. Nevertheless, the example suggests that WaterGAP is able to provide at least an acceptable estimation of *relative* flood frequency distributions for large scale watersheds.

Summarizing all presented evaluation results, WaterGAP seems to be capable of estimating the relative, basin-specific distributions of flood frequencies, but shows less accuracy when it comes to the absolute values. With respect to estimating the impact of climate change on floods this suggests that assessing the change of relative flood events or return periods (e.g. a 100-year flood "will occur every 50 years" or "will double its magnitude", without knowing the exact discharge level of today) is more reliable than giving absolute numbers (e.g. a 100-year flood "will increase by 1000 m^3/s"). Therefore, only relative changes in flood frequencies, both in terms of discharge and return periods, are investigated further in this study, but no absolute discharges are considered.

6.3 Results

All following results are visualized at the cell level of WaterGAP's calculation grid at 0.5° resolution. This, however, should not create the impression that every single cell result is meaningful by itself. But the more uniform and the larger a regional pattern occurs, the higher we assume its significance to be. We refrain from calculating basin or country averages here as the nature of flood frequences does not suggest spatial compensation as an appropriate assumption.

Before actually looking at flood frequency distributions, a first example of the overall complexity of changing flood characteristics due to climate or global change is presented in Figure 6.6. The influence of climate on floods is not only induced via changes in the spatial distribution of precipitation amounts, but also via temporal changes in the precipitation pattern, or, where snowmelt plays a role, via spatial and temporal changes in temperature. The change of the inner-annual discharge regimes should reflect some aspects of this complex situation, and in particular the month with the highest average runoff is likely to represent the main flood risk period within a year. Following these arguments, monthly averages of discharge were calculated with WaterGAP for today's climate (1961-90) and for the 2070s (using the results of the HadCM3 GCM; for a more detailed description of the GCM application see Chapter 4). For each raster cell of Europe the month with the highest average discharge is visualized in Figure 6.6.

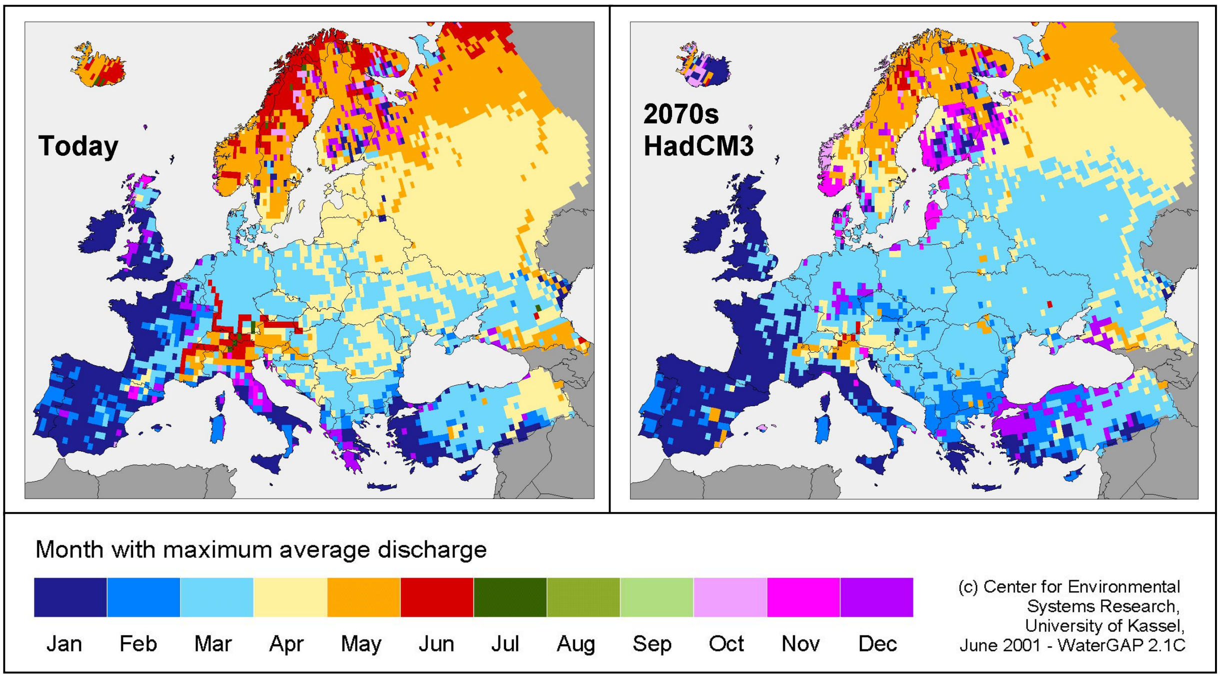

Figure 6.6: Month with maximum average discharge. Comparison of results calculated with WaterGAP 2.1 for today's climate (1961-90) and for the 2070s (HadCM3 climate model).

Figure 6.6 shows that for most of Europe the maximum monthly discharges occur from January to June, roughly arranged as zones in this order from the South-West to the North-East. This reflects, besides the general climatic pattern with winter rains in the maritime areas (Iberian Peninsula, Western France, Great Britain, Mediterranean countries), the rising influence of snowmelt in the continental and northern areas with snow accumulation in winter and melting periods from March until June (the latter being rather late, most probably due to problems in WaterGAP's snow module, compare Chapter 3). In the 2070s, the maximum average discharge occurs about one month earlier than today in Northern and parts of Central Europe. This can be explained by a general rise in temperature in the HadCM3 climate model for these areas, which induces an earlier snowmelt. The results are largely consistent with findings by Stanners and Bourdeau (1995) for today and Arnell (1999) for the 2050s.

In both maps of Figure 6.6 the Alps stand out, with later maximum discharge months than their surrounding. Within the mountainous area the annual flow regimes are snow-dominated and the rivers originating here carry this indicator for some distance (the clearly distinguishable red cell-lines represent the affected river courses in WaterGAP's routing scheme). Due to the increase in temperatures until the 2070s, the highest monthly discharge occurs significantly earlier than today in the case of the rivers Rhone, Rhine, Danube, and Po.

Finally, for all European cells flood frequency distributions were derived applying WaterGAP results for today and for future scenarios. An example is presented in Figure 6.7. The discharge amounts of the cells' individual 100-year floods were derived for present climate (1961-90) and the for the 2070s (HadCM3 climate model), and the relative change is visualized.

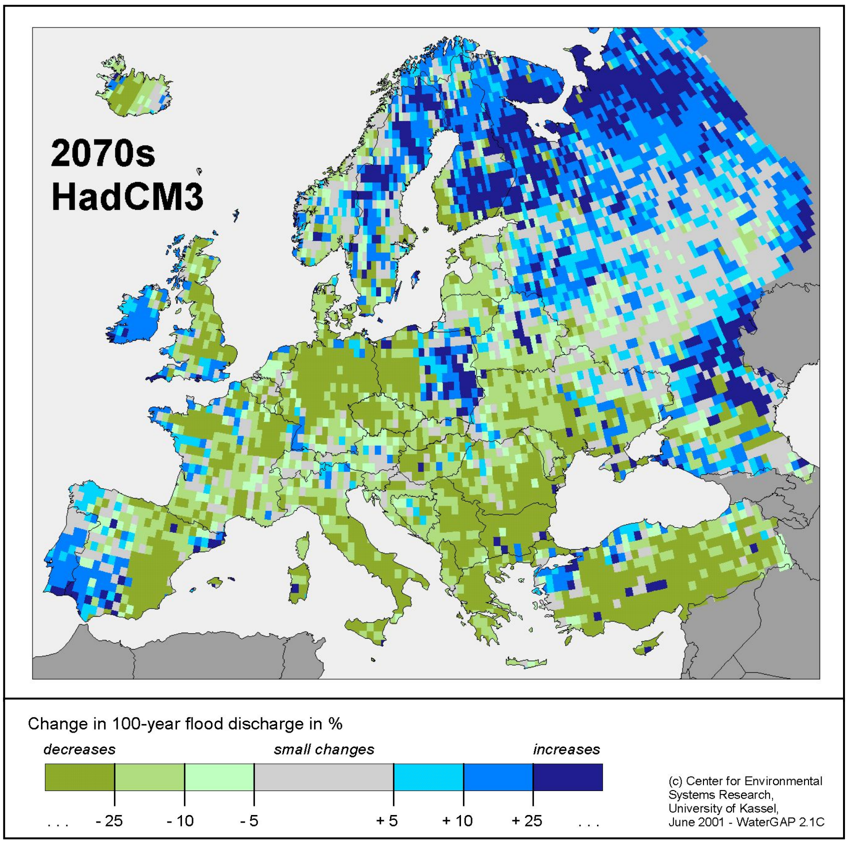

Figure 6.7: Change in magnitude of 100-year floods. Comparison of results calculated with WaterGAP 2.1 for today's climate (1961-90) and for the 2070s (HadCM3 climate model).

Figure 6.7 shows increases in the 100-year flood discharges for large areas in Northern and Eastern Europe (Sweden, Finland, Russia) with maximum rises of more than 25%. These results are generally in accordance with the areas identified in the ACACIA study as having significant increases in average annual river discharge (Parry, 2000). Besides the general increase in the precipitation amounts, the change in temperature is assumed to have a significant impact via its effect on the snowmelt pattern. Smaller areas affected by a clear rise of the 100-year flood discharge are the Wisla basin in Eastern Poland, the Irish Island and parts of Portugal and Spain. The latter is rather remarkable as the HadCM3 GCM predicts a decrease in the average precipitation amounts for this region in the 2070s (compare Figure 4.1, Chapter 4). The increase in the 100-year flood discharges must therefore be explained by an inner-annual change in the flow regime towards both more extreme high and, as a consequence, low flow months. On the other hand, it must be stressed at this point, that especially in the semiarid areas the calculation of flood frequency distributions is very critical, as there is a high probability that very few but extreme flood events determine the statistics and make the extrapolation of return periods very susceptible to errors. Amongst the Alpine rivers it is primarily the Rhine river which shows a significant increase in flood discharge for its upper and middle course. Large parts of Central and Southern Europe show a decrease in the 100-year flood risk, induced most probably by either a decrease in precipitation or a more equally balanced inner-annual flow regime in the future scenario.

A rise in the amount of a 100-year flood discharge can be interpreted equivalently as a higher frequency of recurrence of the flood discharge that marks today's 100-year flood

(Figure 6.8). As the latter is the more commonly used approach, it is adopted in Figure 6.9, where an overview is presented of the results applying two different GCMs at two different time slices (for a more detailed description of the GCM applications see Chapter 4).

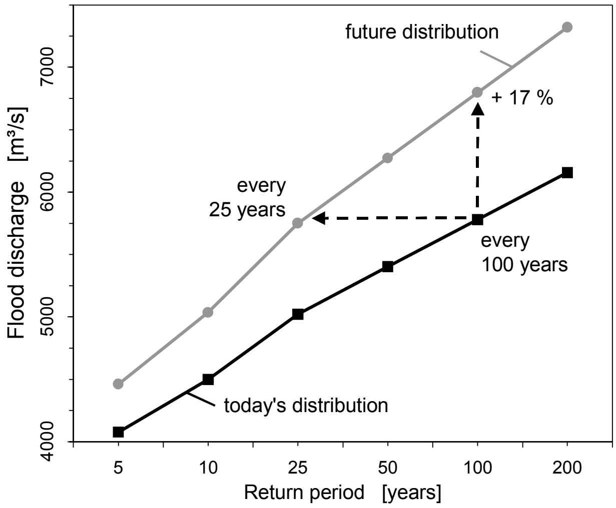

Figure 6.8: Characteristic values to describe a change in flood frequency distributions.

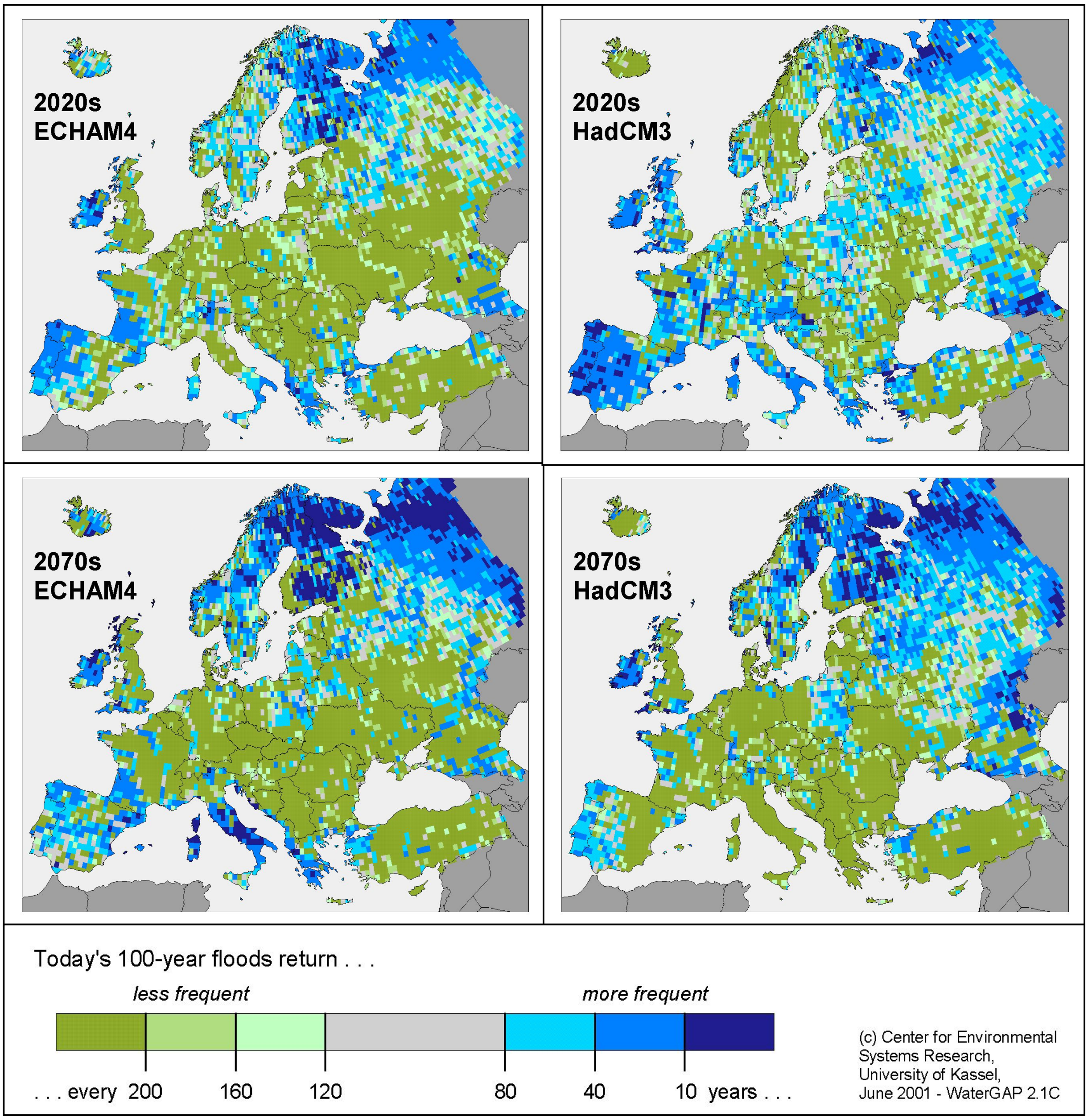

Figure 6.9: Change in occurrence of 100-year floods. Comparisons of results calculated with WaterGAP 2.1 for today's climate (1961-90) and for the 2020s and 2070s (ECHAM4 and HadCM3 climate models).

Due to the applied classification in Figure 6.9, the 2070s HadCM3 results show increasing (or decreasing, respectively) flood frequencies for basically the same regions as discussed in Figure 6.7. This implies that an increase of the 100-year flood discharge by about 10% can roughly be interpreted as a change in return period from 100 years to about 40 years, and so on for the other classes. As an exception the Wisla basin shows an increase of up to 25% and above in flood discharge, leading to a change in return period from 100 years to about 40 years only. This indicates a rather steep flood frequency distribution for this river basin.

Both climate models agree in their estimates of more pronounced changes for the 2070s, where a 100-year flood of today’s magnitude would return more frequently than every 10 years in parts of Finland and Russia. The predictions with HadCM3 are contradictory in several regions for the 2020s and 2070s (e.g. Eastern Spain, Alps, Greece), whereas the results with ECHAM4 seem to be more monotonic in time (with only few exceptions like Central Italy). Some smaller regions, like Italy, Greece and North-Eastern Spain develop oppositely according to which of the two GCMs is applied. Only a few areas like parts of Germany, the Balkan region, Ukraine and Turkey show a consistent decrease in flood frequencies throughout both GCMs and both time slices. Still, for the 2070s Eastern Great Britain, Central and South-Eastern Europe generally tend towards an improvement of the flood risk situation.

6.4 Conclusions

This chapter looked into a concept of how to analyze the impacts of climate change on future river floods and flood frequencies on a European scale. As an attempt to evaluate the applied global integrated water model WaterGAP with respect to flood assessments, the model’s flood flow calculations were first analyzed in order to determine to what extent they correspond to flood frequencies derived from measured discharge. This led to three main results:

1. Due to applying pseudo-daily rainfall values derived from monthly averages, WaterGAP is, at present, not qualified for explicit, single-event flood discharge calculations.
2. When looking at statistical flood characteristics (e.g. a 100-year flood), the quantitative accuracy of WaterGAP concerning absolute flood discharge values is limited. For 21 selected European stations WaterGAP both over- and underestimated the peak discharges of extreme flood events compared to GRDC observed data. Nevertheless, the overall correlation to the observed data is within acceptable bounds.
3. The application of the index-flood method showed for 17 out of the 21 test basins very good to acceptable agreement between normalized flood frequency distributions derived from WaterGAP results and GRDC observations.

In other words, WaterGAP seems to be capable of estimating the relative, basin-specific distributions of flood frequencies, but shows less accuracy when it comes to the absolute values. With respect to estimating the impact of climate change on floods this suggests that assessing the change of relative flood events or return periods (e.g. a 100-year flood "will occur every 50 years" or "will double its magnitude", without knowing the exact discharge level of today) is more reliable than giving absolute numbers (e.g. a 100-year flood "will increase by 1000 m^3/s").

As main findings of applying two different climate scenarios (results of ECHAM4 and HadCM3 GCMs as described in Chapter 4) for future flood frequency calculations within WaterGAP, the following statements can be distilled for the 2070s:

The climate change scenarios generally imply a change in flood frequencies for almost all regions of Europe. Central and Southern Europe show a decreasing trend in future flood frequencies. The region most prone to a rise in river flood frequencies is North-Eastern Europe, i.e. Sweden, Finland and Russia, with increases of 100-year flood discharges of over 25% (today's 100-year floods would return every 10 years). Also some smaller regions like the Wisla basin in Poland, the Irish Island or Portugal show indications for a rise in flood risk. For some regions like Italy or Greece, the two climate scenarios lead to contradictory results, allowing for no conclusions but rather reflecting the uncertainties of the model calculations.

In order to judge the presented findings, one should not forget the limits of flood risk assessment on a global scale. The calculations are inherently uncertain as the involved processes are complex and difficult to predict. "The fluvial system contains many complex interactions and while climate may be the 'driving force' there is a considerable 'cultural blur' in the history of European and many other rivers ... , which can make it difficult to distinguish between changes in flood frequency that are climatically induced and those that are due to human activity. Often the changes are a mixture of the two" (Jones, 1997).

6.5 References

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