7 EUROPE'S DROUGHTS TODAY AND IN THE FUTURE

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7.1 Introduction

As compared to floods, droughts are often perceived by society to play a less dominant role when thinking of natural hazards. This may be caused by the circumstance that, unlike the effects of a flood which can be immediately seen and felt, droughts build up rather slowly, creeping and steadily growing. Whatever the reason, this perception has led to a relative disregard for droughts, despite the fact that they regularly cause serious damage to economy, society and the environment both in the affected areas and further afield. According to data compiled by the National Drought Mitigation Center (2001), the average annual economic costs and losses through droughts in the United States (US$ 6-8 billion) are more than double the average annual costs for floods (US$ 2.4 billion). In the early 1990s Europe experienced severe droughts resulting in significant economic and environmental costs. The damage in Spain (1992-95), where the drought affected about 500 000 hectares of irrigated land alone in the Guadalquivir river basin, was estimated at several billion Euro (Garrido and Gómez-Ramos, 2000).

Droughts were long considered a hazard affecting mainly developing countries, but public awareness has increased in the past years in the industrial countries especially with respect to the climate change issue predicting more extreme hydrological conditions (Demuth and Stahl, 2001). Since the demand for European water resources has increased in the past decades, future conflicts between human requirements (commercial, social and political) and ecological needs are likely to increase, too. These conflicts are most critical and intensive during severe and extensive droughts.

Various studies conclude that in the last decades the drought situation in many European regions got more severe, due to an increase in frequency, duration or intensity of low flows (Demuth and Stahl, 2001; DVWK, 1998; Arnell, 1994). A further increase driven by global and climate change impacts is expected, in particular for Southern European areas (IPCC, 2001; Watson et al., 1997).

Drought is a phenomenon that is not constrained by international boundaries and can therefore grow to afflict many countries simultaneously. As low flows and droughts commonly cover large areas and extend for long time periods, it has been suggested that these events should be studied within a regional context (Demuth and Stahl, 2001; Tallaksen, 2000). In this chapter we therefore introduce a comprehensive concept of how to analyze the possible impacts of climate and global change on future low flow and drought frequencies on a European scale. 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 drought calculations. Rather we aim to analyze the following question: *In which European river basins can we expect a significant increase of drought events or severity due to global change (including climate change)?* In order to answer this question, we develop a spatially consistent methodology to arrive at comparable results throughout the whole of Europe.

7.2 Methodology

7.2.1 General overview of low flow and drought calculations

There is no universally accepted definition of drought (Tate and Gustard, 2000). Still, for any drought study a consistent definition is important. The following categories of droughts are frequently used (Tate and Gustard, 2000):

- Climatological drought (deficit in precipitation)
- Agro-meteorological drought (deficit in soil water)
- River flow drought (deficit in river discharge)
- Groundwater drought (deficit in groundwater storage)
- Operational drought (conflict of water shortage and water management demands)

Within this study the concept of river flow drought (or hydrological drought) is adopted, because

a) discharge as an integrative parameter reflects both climatological anomalies as well as additional influences (plant transpiration, soil, water abstractions) and
b) for any type of drought a concurrent reduction in river flows is very likely.

In order to identify drought events within a given streamflow hydrograph, various methods have been developed. The one applied in this study is the threshold level method: the drought events are selected by considering flow situations where the discharge is below a certain threshold level. As shown in Figure 7.1, each drought spell can thus be characterized by its time of occurrence, duration, minimum flow, and deficit volume (or severity) (Tallaksen, 2000).

The choice of type and magnitude of the threshold level is extremely important for the results of a drought study. Besides the option for a constant threshold value for all data over time (as applied in Figure 7.1) or for a variable threshold (e.g. fluctuating on a monthly or seasonal basis), the general magnitude of the threshold level is highly significant. A threshold level which is too low might lead to a high number of no-drought years making the few identified drought events statistically uncertain to evaluate. On the other hand, with a high threshold level the likelihood for a series of small single drought events being combined into one severe multi-year drought (drought lasting longer than a year) increases.

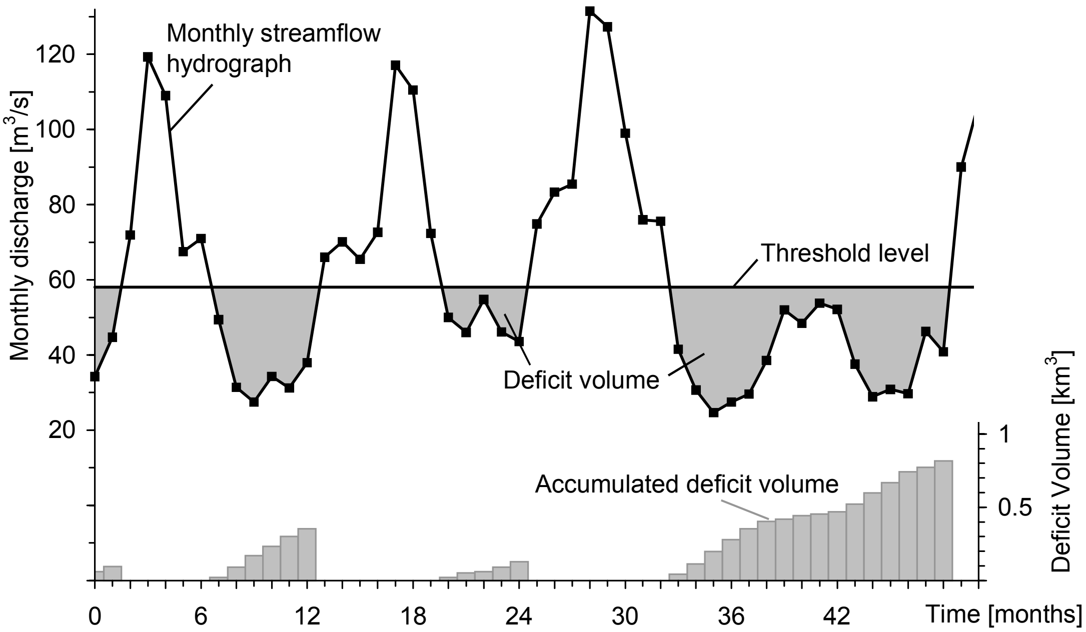

Figure 7.1: Definition of drought events and deficit volumes.

The general objective of drought frequency analysis is to relate the magnitude of a drought to its frequency or probability of future occurrence. One approach for this type of analysis is to first calculate all deficit volumes and then to select the highest deficit volume per year (annual maximum series) or the most severe drought events over time. To derive a basin's drought frequency distribution, the such selected droughts 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 (Tallaksen, 2000).

7.2.2 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 low flow calculations are highlighted:

Water use. All calculations carried out within this drought 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, droughts are determined by mid- to long-term low flows with slowly growing water deficits. Hence, for drought calculations the consumptive water use of households, industry and agriculture is considered to have a significant impact as during low flow periods water withdrawals can reach or even exceed the dimension of water availability. Therefore, not only the actual river discharge is analyzed in this chapter, but the effect of consumptive water use is discussed separately.

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 low flow 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.

Wetlands, lakes and reservoirs. For the occurrence of a drought, the storage and retention of water in lakes, reservoirs and wetlands plays 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 for all freshwater storage as no further data on reservoir control or retention behavior is available. As a consequence, WaterGAP will locally underestimate the possible human influence of drought mitigation.

Groundwater and baseflow. Applying a heuristic approach, WaterGAP 2.1 partitions the total runoff from land into fast surface and subsurface runoff and into slow groundwater runoff. The groundwater storage is modeled via a simple linear storage approach leading to groundwater discharge or baseflow. The baseflow component is strongly relevant for any low flow calculations as in particular for long dry spells there is only minimum contribution through fast surface or subsurface runoff (induced by precipitation) expected. The accuracy of the baseflow modeled by WaterGAP, however, is not fully evaluated yet as WaterGAP was originally developed for estimating long-term averages where the temporally explicit calculation of the baseflow component was only of secondary interest. Therefore, in Section 7.2.4 an attempt is presented to evaluate WaterGAP's ability to model low flow situations.

7.2.3 Drought calculations with WaterGAP

In order to derive today's and future drought 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. Monthly discharge values are applied. This temporal resolution is used as
   a) the month is the usual time unit for river flow drought studies as it is long enough to eliminate all less significant, arbitrary or artificial daily extremes, and short enough to represent single drought events, and
   b) WaterGAP is based on monthly climate data, hence it can be expected to provide reliable results at this time scale.
2. A drought event is defined to start when the discharge falls below the threshold value and to end when the discharge exceeds the threshold. The deficit volume (or severity) of a such identified drought event is calculated by accumulating the monthly differences between threshold and actual discharge values over time.
3. The frequently used median of monthly discharges, here calculated from the time series 1961-90, is applied as a constant threshold value for all data over time (both for today's calculations and for the future). As this is a relatively high value (compared e.g. to Q60 or Q90, the discharge that is exceeded by 60% or 90% of all given values), drought events start soon on the falling hydrograph and the deficits reach rather high volumes. This, however, reflects that hydrological droughts can be understood as periods when streamflow is not sufficient to supply established uses under a given water management system (Demuth and Stahl, 2001), where any reduction from means can be considered problematic.
4. For the drought frequency calculations the annual maximum series of drought deficit volumes is chosen. Thus, for every year the highest occurring deficit volume is selected. With this simple approach, however, multi-year droughts might be picked more than once.
5. As drought calculations generally require long discharge series, the 30-year series 1961-90 is applied to calculate today's droughts (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).
6. In order to finally derive drought 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 only extrapolations up to 200-year droughts are analyzed as, when looking at the model and data uncertainties described above, any statements on more extreme events are not considered justified.

7.2.4 Evaluation of WaterGAP regarding drought assessments

For the evaluation of WaterGAP concerning its capability to assess droughts, 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 drought calculations derived from a model that is calibrated to long-term average discharge only. As time series for the comparisons the 1961-90 "climate normal" period is chosen. The drought frequency distributions are extrapolated from these data.

First, in order to assess the general performance of WaterGAP concerning the simulation of low 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 7.2). Based on monthly discharge values it is evaluated to what extent WaterGAP, in the long run, simulates the correct month with minimum discharge. For 22 stations WaterGAP showed correspondence within plus or minus one month to the GRDC stations, the maximum difference lying at five months (maximum possible difference: six months). WaterGAP is therefore believed to cover the overall regional trend, but fails at certain locations.

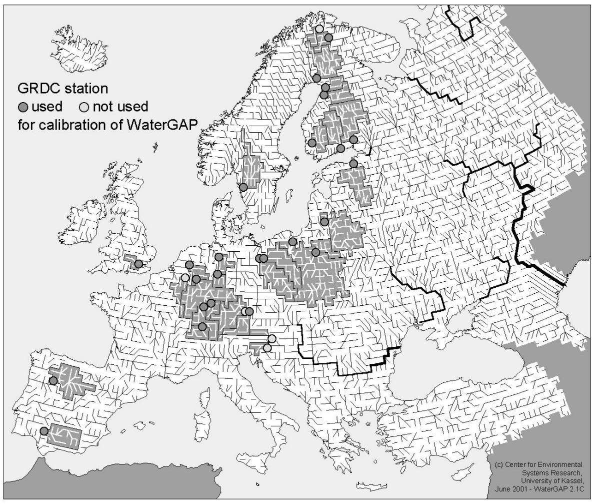

Figure 7.2: 30 GRDC stations selected for the evaluation of WaterGAP regarding seasonal low flow periods and drought frequencies.

Second, in order to judge the capability to compute basin characteristic drought frequency distributions, the accuracy is evaluated to which WaterGAP calculations correspond to drought frequency distributions derived from discharge measurements. For this purpose, again the 30 GRDC stations shown in Figure 7.2 are selected.

Figure 7.3 presents a comparison of monthly Q90 values, derived from GRDC observed and WaterGAP modeled monthly discharges. Q90, the discharge that is exceeded by 90% of all given values, is commonly used as one typical parameter for describing the low flow characteristics of a river basin. Figure 7.3 shows that the correlation of observed and modeled Q90 for the 30 selected stations is good, with a modeling efficiency of 0.92.

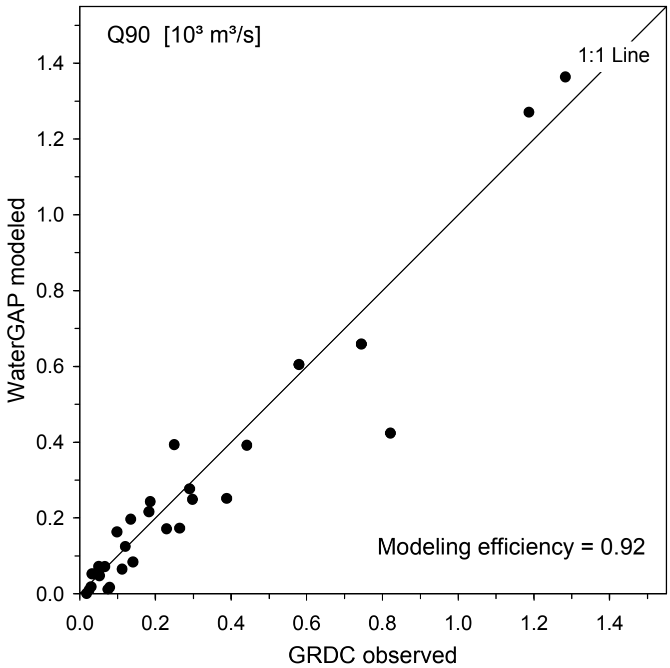

Figure 7.3: Comparison of GRDC observed and WaterGAP modeled monthly Q90 values for 30 selected European stations, period 1961-90.

Figure 7.4 presents the annual maximum deficit volumes for the Rhine river basin at station Rees as derived from GRDC observed data and from WaterGAP model results (for comparison: the 1961-90 mean monthly discharge is 6.3 km^3). The example represents a 'typical' fit within the data of the 30 stations, not the best and not the worst. The general behavior of the Rhine basin is reproduced well with some exceptions like for the years 1964 or 1977. Here, WaterGAP underestimates the drought severity, most likely because the threshold value is exceeded some months earlier in the WaterGAP results than in the GRDC data. The Rhine river at Rees drains about 160 000 km^2 including considerable areas with strong human influence (abstractions, reservoir management, etc.), which additionally has to be taken into account when judging the disagreements of observed and modeled data in Figure 7.4.

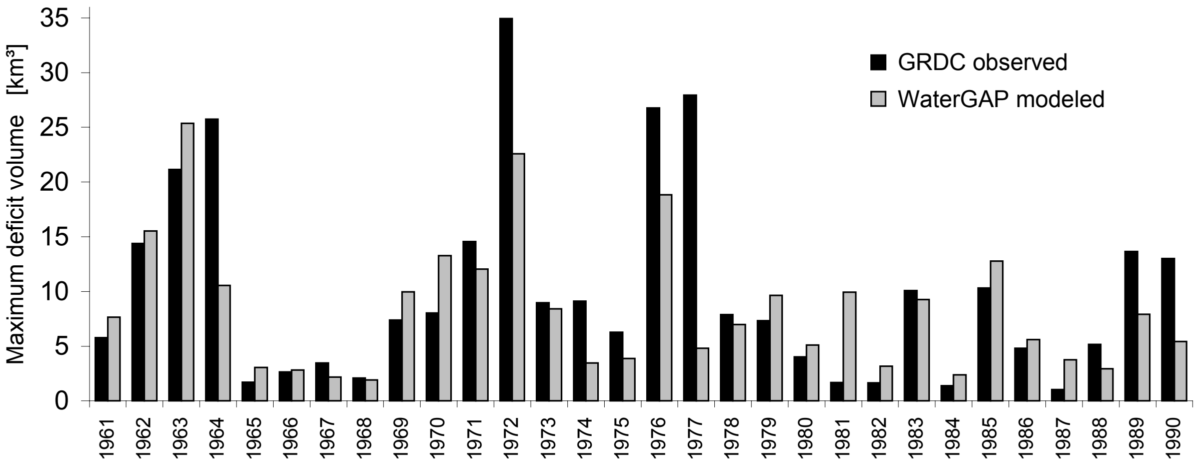

Figure 7.4: Comparison of GRDC observed and WaterGAP modeled annual maximum deficit volumes for the Rhine river at station Rees (160 000 km^2).

Figure 7.5 shows the drought frequency distributions of the Rhine river at Rees (i) as derived from the GRDC monthly discharge series, and (ii) as derived from WaterGAP 2.1 results. The agreement of the curves is satisfying, showing a difference of e.g. 8% for the 100-year drought.

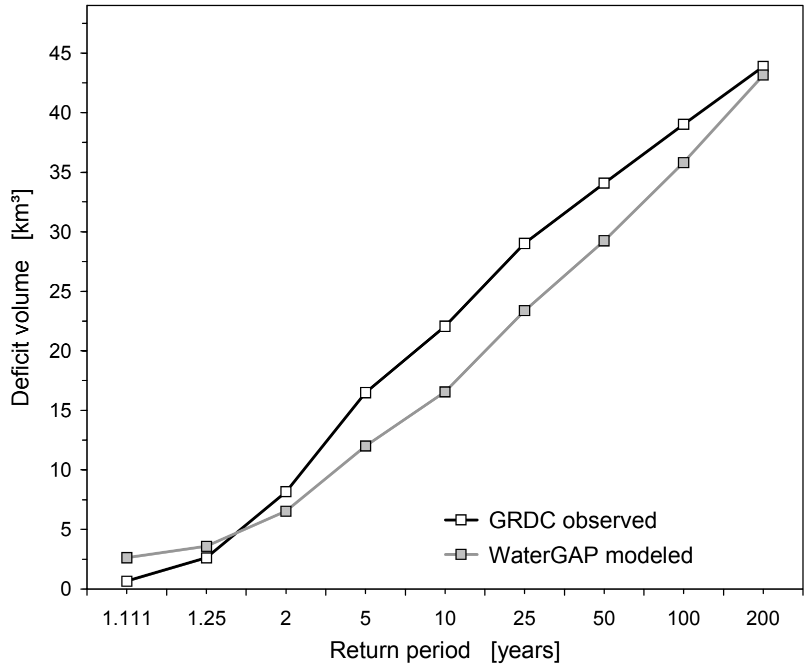

Figure 7.5: Drought frequency distributions for the Rhine river at station Rees (160 000 km^2), extrapolated from monthly discharge values for period 1961-90, Log-Pearson Type III distribution.

The 29 other selected European GRDC stations were investigated in the same manner. In Figure 7.6 only the drought deficit volumes with a return period of 100 years are extracted and analyzed. With a modeling efficiency of 0.86 the correspondence of drought frequencies derived from observed data and from model results is good, especially when considering all limitations and restrictions discussed above.

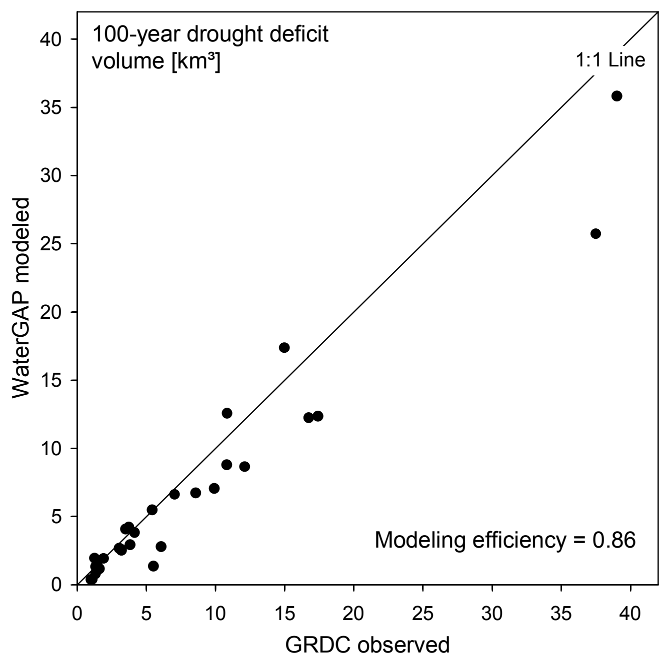

Figure 7.6: Comparison of GRDC observed and WaterGAP modeled 100-year drought deficit volumes for 30 selected European stations, period 1961-90.

Finally, Figure 7.7 shows, as an example, the drought situation for August 1976, calculated with the WaterGAP model. The deficit volumes are derived as described above (they represent the deficit volumes that have accumulated until the end of August 1976) and are then normalized to the long-term monthly average discharge. The summer 1976 is characterized in the literature as being exceptional for Europe, with severe droughts reaching from Scandinavia to France, affecting in particular Sweden, Denmark, The Netherlands, Northern France, England, Scotland and Ireland, later also spreading to Eastern Europe, while "the impact was worst in South-East England with supply restrictions" (Bradford, 2000). The good agreement of Figure 7.7 with the described situation increases the confidence in the chosen method and the applied threshold value.

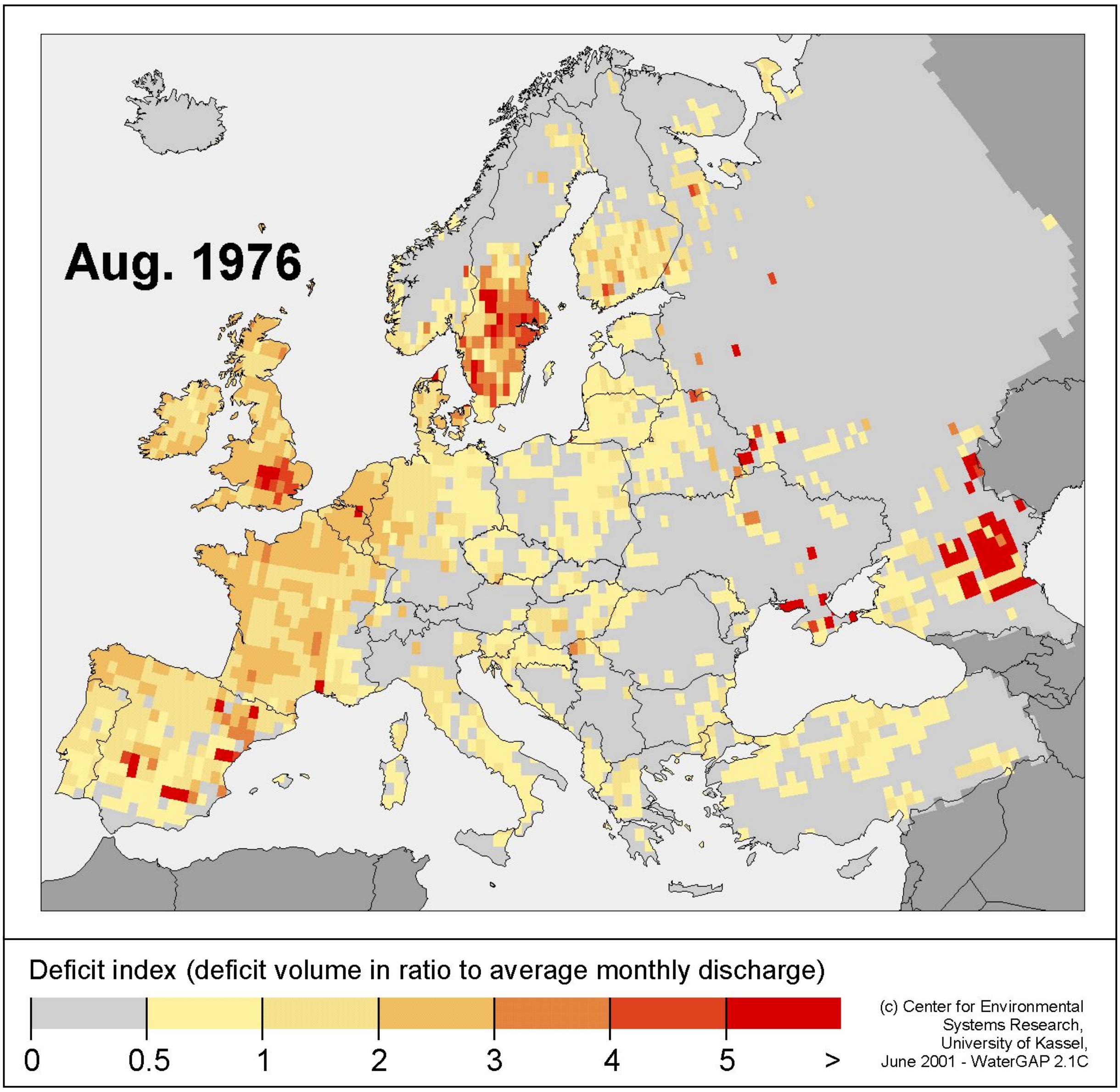

Figure 7.7: Drought situation in Europe for August 1976. The deficit index is calculated as ratio of accumulated deficit volume and 1961-90 average monthly discharge.

7.3 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 low flow and drought frequencies does not suggest spatial compensation as an appropriate assumption.

Before actually looking at drought frequency distributions, a first example of the overall complexity of changing low flow characteristics due to climate or global change is presented in Figure 7.8. The influence of climate on low flows is not only induced via changes in the spatial distribution of precipitation amounts, but also via temporal changes in the precipitation pattern, or, where snow storage 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 lowest average runoff is likely to represent the main drought 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 (applying climate scenario results of the General Circulation Model (GCM) HadCM3; for a more detailed description of the GCM application see Chapter 4). For each raster cell of Europe the month with the lowest average discharge is visualized in Figure 7.8. The regional pattern basically indicates two characteristic types of low flow regimes:

a) The orange/red to green/purple colors represent areas with typical summer droughts, ranging from June to November. These areas comprise all maritime areas (Iberian Peninsula, Western France, Great Britain, Mediterranean countries), reaching as far as Central Europe (Germany, Czech Republic, Western Poland). Here, the discharge falls to minimum values at the end of summer, induced either by long dry spells without any precipitation (first countries) or by prolonged periods with high evapotranspiration (latter countries).

b) The dark blue to yellow colors represent areas with typical winter droughts, ranging from January to April. These areas comprise the Northern and some East-Central European countries, as well as the Alpine region. Here, precipitation is accumulated throughout the winter months as snow cover and the soils are frozen, hence baseflow falls to minimum values at the end of this period. (It should be noted here that, as described in Chapter 3, distinct uncertainties in WaterGAP's calculation of the snow balance were observed. This might in particular lead to errors concerning the minimum flows in East-Central Europe as for these areas seasonal winter and summer low flows are, according to the measurements, often in the same order of magnitude. A rough qualitative evaluation showed that in some of these cases WaterGAP tends to falsely calculate the lowest discharge in January instead of September.)

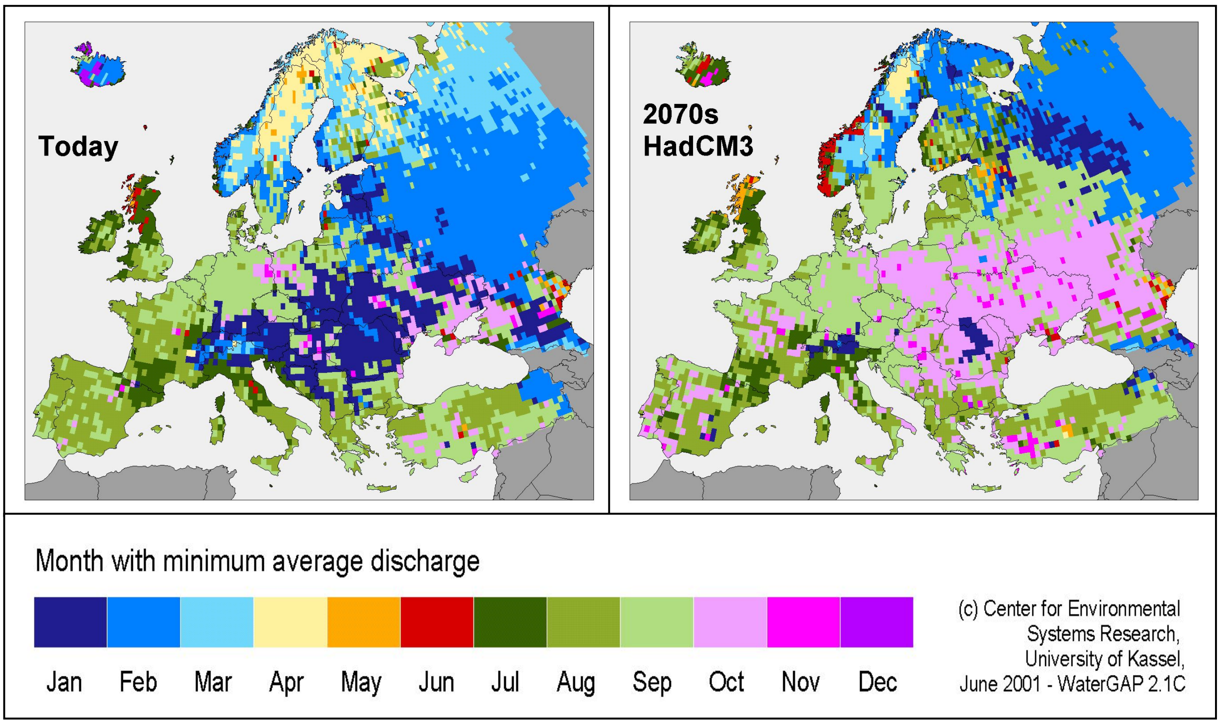

Figure 7.8: Month with minimum average discharge. Comparison of results calculated with WaterGAP 2.1 for today's climate (1961-90) and for the 2070s (HadCM3 climate model and Baseline-A water use scenario).

In the 2070s, the impact of climate change on the temporal low flow behavior is basically restricted to areas characterized today by winter droughts. For the Northern European regions (Scandinavia, Russia) a shift is simulated towards the minimum average discharge occurring one or two months earlier, still reflecting winter drought conditions. This can be explained by a general rise in temperature in the HadCM3 scenario for these areas, inducing an earlier date of snowmelt. The East-Central European areas, however, as well as some maritime (Western Norway, Iceland) or Alpine regions reflect a change in their low flow regime from winter towards summer drought characteristics (shift from January/February to June/July or October). This suggests an impact on the overall low flow regimes (though not necessarily the drought severity) of the affected basins to which typical water demand structures of society and environment have to adapt. (Again, WaterGAP's uncertainties within the snow module should be noted. The shift within East-Central Europe from winter to summer droughts might also be caused by generally higher temperatures leading to less snow influence and therefore differing WaterGAP simulations. Yet, this problem is not sufficiently analyzed or solved.)

In the next step, for all European cells drought frequency distributions were derived applying WaterGAP results for today and for future scenarios. An example is presented in Figure 7.9. The deficit volumes of the cells' individual 100-year droughts were derived for present conditions (today's water use and climate 1961-90) and for the 2070s (HadCM3 climate model and Baseline-A water use scenario), and the relative change is visualized (Figure 7.9, left). Additionally, for a more detailed evaluation of the relevant processes, the isolated impact of the change in water use is simulated. Therefore, a WaterGAP run was performed applying the Baseline-A water use scenario for the 2070s for the industrial and domestic water use sectors (for a more detailed scenario description see Chapter 4), while as climatic input today's (1961-90) data is used. Consequently, the irrigation water use stays unchanged as no change in irrigated area is assumed.

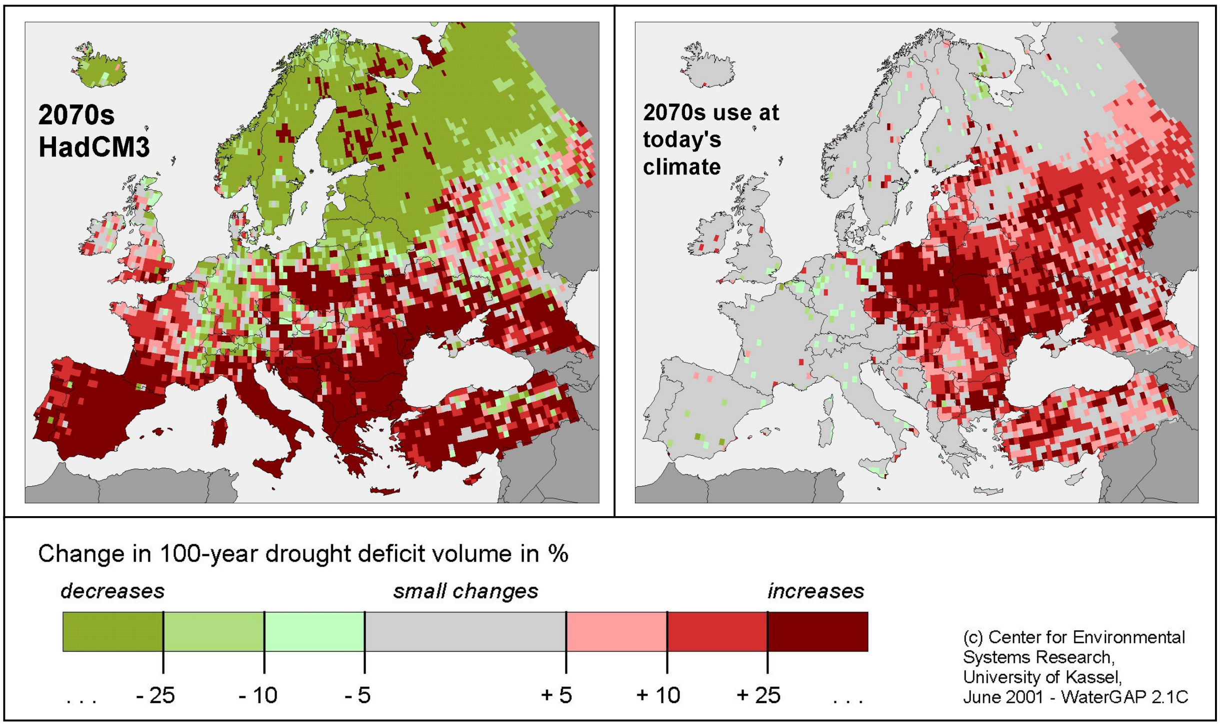

Figure 7.9: Change in magnitude of 100-year droughts. Left map: Comparison of results calculated with WaterGAP 2.1 for today's climate and water use (1961-90) and for the 2070s (HadCM3 climate model and Baseline-A water use scenario). Right map: Comparison of results calculated with WaterGAP 2.1 for today's climate and water use (1961-90) and for the 2070s (Baseline-A water use scenario at today's climate).

The left map of Figure 7.9 shows strong increases in the 100-year deficit volumes for large areas in Southern Europe as well as for parts of Western (Iberian Peninsula, Western France, Southern Great Britain) and East-Central Europe (Southern Poland, Hungary, Bulgaria, Romania, Moldova, Ukraine, Southern 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 decreases in average annual river discharge (Parry, 2000).

Besides a general decrease in the precipitation amounts, the change in temperature is assumed to have a significant impact via its effect on the evapotranspiration rates. It should be noted, however, that the chosen threshold value (here: the median of monthly discharges 1961-90, both for today and for the future) strongly influences the calculations. This leads, in the applied case, to deficit volumes in the range of one or a few mean monthly discharges (in km^3). A lower threshold value would result in significantly lower deficit volumes, which would also affect the relative changes. Another aspect of the chosen threshold value becomes apparent in Scandinavia. Here, some red cells suggest a rise in the 100-year drought severity, where in fact the average discharges increase that much, that throughout most years the threshold value is exceeded, leaving only a few years with deficit volumes other than zero. The statistical frequency distributions derived for these singular data are not valid any more and deliver meaningless results.

A look at the right map of Figure 7.9 shows the isolated impact of a change in domestic and industrial water use (at today's climate). The distinct spatial zoning into Western (no change) and Eastern Europe (strong change) reflects the scenario assumptions described in Chapter 4 (generally strong increases in water use for Eastern European countries due to increased economic activity, less increase or decrease for the Western European countries). The influence of population density and classification (rural or urban) leads to variations within a country (e.g. Northern vs. Southern Russia). A transboundary (international) effect is noticeable when looking at the Elbe river basin (Czech Republic and Northern Germany). The increase in deficit volumes induced by rising water use in the Czech Republic is passed on throughout the complete Elbe river course and thus affects Northern Germany (the clearly distinguishable red cell-line in Northern Germany represent the Elbe river course in WaterGAP's routing scheme).

The comparison of both maps in Figure 7.9 indicates that the worsening in 100-year drought severity amongst Western European countries is primarily caused by climate change. For Eastern Europe, the change in water use plays an important role for the future low flow regimes. Here, the superimposed climatic changes worsen the situation in the southern regions, but have a meliorating effect for the northern areas as higher low flows balance the increased water demand.

A rise in the amount of a 100-year deficit volume can equivalently be interpreted as a higher frequency of recurrence of the low flow event that marks today's 100-year drought (compare Figure 7.10). As the latter is the more commonly used approach, it is adopted in Figure 7.11, where an overview is presented of the results applying two different GCMs (each with Baseline-A water use scenario) at two different time slices (for a more detailed description of the scenarios see Chapter 4).

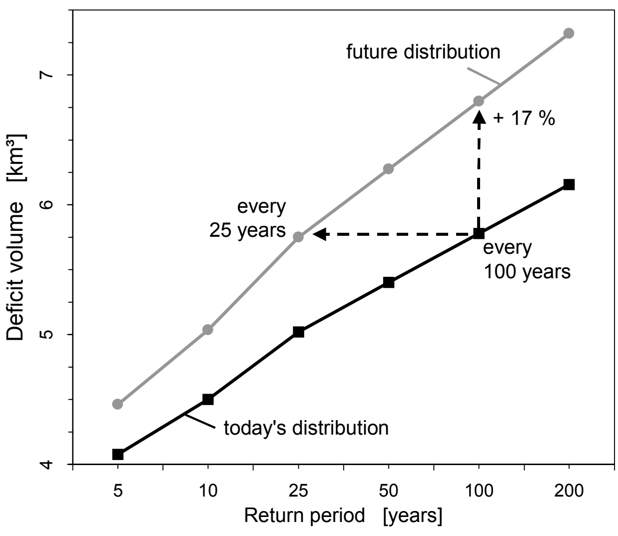

Figure 7.10: Characteristic values to describe a change in drought frequency distributions.

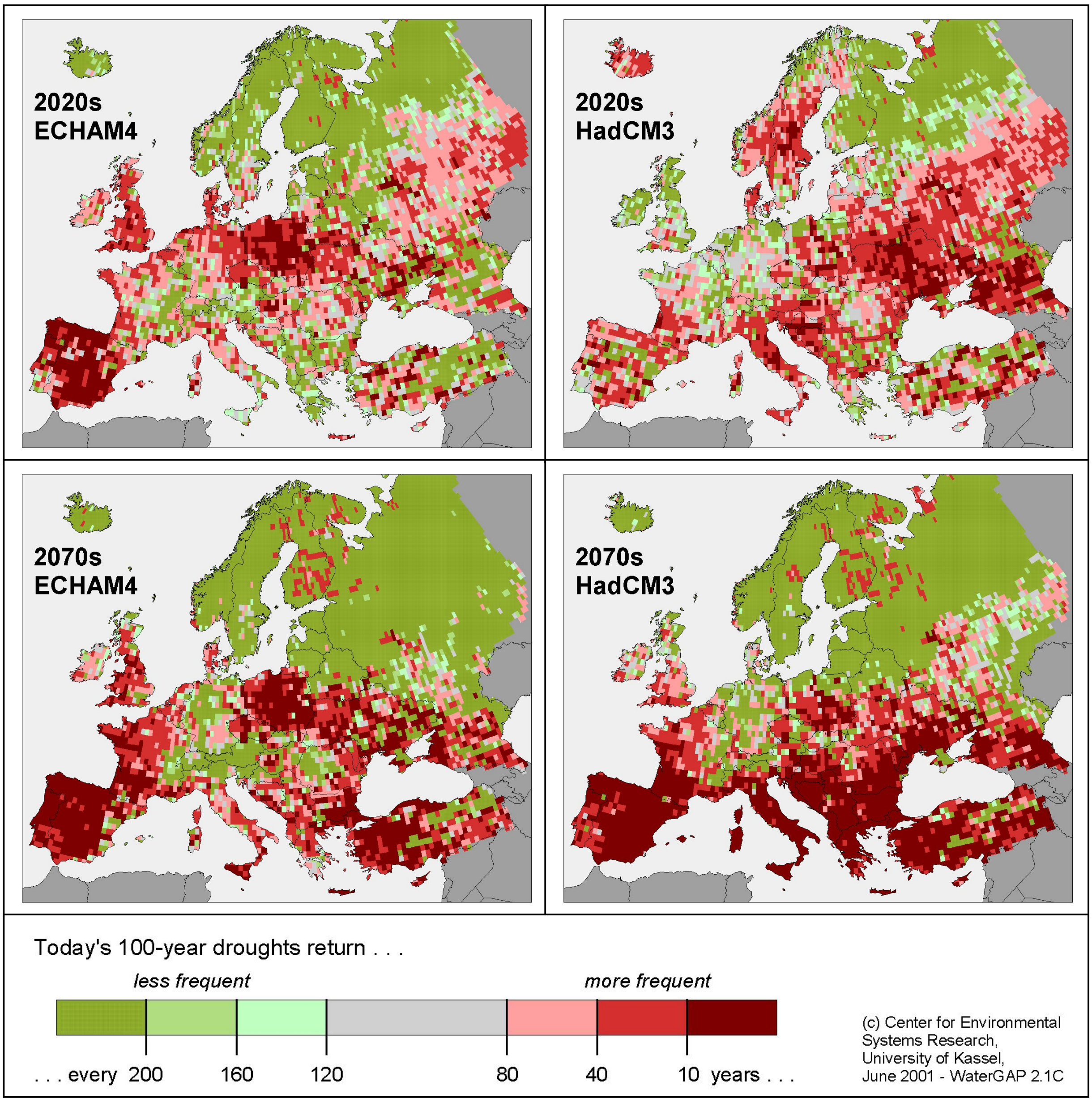

Figure 7.11: Change in occurrence of 100-year droughts. Comparisons of results calculated with WaterGAP 2.1 for today's climate and water use (1961-90) and for the 2020s and 2070s (ECHAM4 and HadCM3 climate models and Baseline-A water use scenario).

Due to the applied classification in Figure 7.11, the 2070s HadCM3 results show increasing (or decreasing, respectively) drought frequencies for basically the same regions as discussed in Figure 7.9 (left map). This implies that an increase of the 100-year deficit volume 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.

Both climate models agree in their estimates of more pronounced changes for the 2070s, where a 100-year drought of today's magnitude would return more frequently than every 10 years in parts of Spain and Portugal, Western France, the Wisla basin in Poland, and Western Turkey. The results of both ECHAM4 and HadCM3 are contradictory in several regions for their respective 2020s and 2070s (e.g. Southern Italy, Balkan Southern Russia for

ECHAM4, Scandinavia, Bulgaria for HadCM3). For the 2020s, ECHAM4 and HadCM3 lead to opposite results in Scandinavia. In the 2070s, Great Britain, Italy, Greece, the Balkan region and large areas in East-Central Europe develop a different drought severity according to which of the two climate models is applied, but commonly tend towards higher drought frequencies. Only a few areas like Southern Finland and Northern Russia show a consistent decrease in drought frequencies throughout both climate models and both time slices. Still, for the 2070s Scandinavia, Lithuania, Latvia, Estonia, Northern Belarus and Russia, most of Germany and the Alpine region generally tend towards an improvement of the drought risk situation.

7.4 Conclusions

This chapter looked into a concept of how to analyze the impacts of climate and global change on future low flows and river drought frequencies on a European scale. As an attempt to evaluate the applied global integrated water model WaterGAP with respect to drought assessments, the model's low flow calculations were first analyzed in order to determine to what extent they correspond to drought frequencies derived from measured discharge. For 30 selected European stations WaterGAP showed a satisfying overall correlation to the observed data within acceptable bounds. Still, improvements both in the WaterGAP model (e.g. in baseflow and evapotranspiration calculations) as well as in the methodological concept (e.g. choice of the threshold value, differentiation in summer and winter droughts) are desirable.

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

The drought frequencies react sensitively both on climate and water use changes. The scenarios generally imply a change in drought frequencies for almost all regions of Europe. North and smaller parts of Central Europe (Germany, Alps) show a decreasing trend in future drought frequencies. The regions most prone to a rise in hydrological drought frequencies are Southern Europe, i.e. Portugal, Spain, Western France and Western Turkey, as well as parts of East-Central Europe, i.e. the Wisla basin in Poland, with increases of 100-year deficit volumes of over 25% (today's 100-year droughts would return every 10 years). Also areas like Great Britain, Italy, Greece, the Balkan region and large areas in East-Central Europe show indications for a rise in drought risk.

A separate analysis, looking at the impact of a change in water use only, indicated that the direct anthropogenic influence on future droughts through water consumption is of the same order of magnitude as the simulated impact of climate change. In particular, the supposed strong increases in water use for Eastern European countries due to increased economic activity can cause or intensify severe drought events in these areas in the future.

In order to qualify the presented findings, one should not forget the limits of drought risk assessment on a global scale. The calculations are inherently uncertain as the involved processes are complex and difficult to predict. In particular, "the analysis of river flow drought suffers from the effects of artificial influences in many cases (urbanisation, effluents, abstractions) which makes drought severity calculation difficult" (Tate and Gustard, 2000).

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