3 PERFORMANCE OF WATERGAP AS COMPARED TO MESOSCALE MODELS: A CASE STUDY FOR THE ELBE AND ODER BASINS

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3.1 Introduction

Typically, for studies on the impact of global change on water resources, basin-specific approaches and mesoscale models are applied. The derived results are thus appropriate for the basin under investigation. When looking at inter-basin problems, however, or for informing political decisions at the scale of a country or the European Union, an integrated assessment of larger regional units is required. EU-support for irrigated agriculture, for example, should aim for an EU-wide optimization of efficient water use, which demands for studies on the differences in water availability across Europe. But the spatial integration of various river basins, which is necessary for this purpose, as well as the possibilities for comparisons are limited if different approaches and/or models are applied for the individual basins. To address this problem, macroscale models with continental or global coverage are being developed. Yet, their basin-specific results are coarse and the uncertainties induced by these models are not sufficiently known. When finally thinking of a combined application of models at different scales, the various model concepts to describe the hydrological processes, set up and optimized for different temporal and spatial resolutions, lead to individual effects and model behavior making an interpretation of the derived results ambiguous.

Although the problem of scaling is considered by numerous hydrological studies, comparisons of model results from micro- to macroscale for the same or nested areas are rare. Such comparisons can support developers and users of different model systems to learn from each other, to validate their individual results and to gain new knowledge. Furthermore, it can be determined, what quality and amount (resolution) of expensive data is necessary or sufficient in order to deliver a result at a certain level of reliability.

In response to these arguments, the joint cooperation project “Impact of climate and land-use and its change on water availability and flood events in Europe” (financed by the German Federal Ministry for Research and Education, BMBF), with the project partners Potsdam Institute for Climate Impact Research (PIK), GKSS Research Center Geesthacht (GKSS) and Center for Environmental Systems Research at the University of Kassel (GhK), aimed for comparisons of three hydrological models, each developed for a different spatial and temporal resolution. The macroscale model WaterGAP (GhK) performs its computations at a comparably coarse spatial resolution (0.5° longitude x 0.5° latitude) for the entire land surface of the globe. The watershed model ARC/EGMO (PIK) and the high-resolution, detailed modeling system GESIMA/SEWAB (GKSS) are applied on mesoscale levels (at flexible spatial resolutions, typically in the order of 5 km x 5 km or lower).

In this chapter, results of the comparative study are presented. The spatial and temporal distributions of selected hydrological variables of the three models are analyzed. The comparisons are limited to certain time periods and to the two basins of the Elbe (or Labe) and Oder (or Odra) rivers.

Assuming that the mesoscale models "better" represent reality than the macroscale one, the first objective of the model comparisons is to provide a general evaluation of the WaterGAP model and thus to estimate its scope and limits. This is achieved in particular by analyzing the results for a subbasin of the Elbe (the Saale watershed), for which WaterGAP is not calibrated. A second objective is to estimate the uncertainties that are due to the less detailed and supposedly less reliable input data of WaterGAP. Here, the impact of the most dominant model input *precipitation* is investigated by applying the precipitation data of the higher-resolution model ARC/EGMO to the WaterGAP model and analyzing the effects.

3.2 Overview of the applied models

3.2.1 WaterGAP (GhK)

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.

3.2.2 ARC/EGMO (PIK)

The mesoscale hydrological modeling system ARC/EGMO can be applied to watersheds of variable extent and allows studies on the total water balance (i.e. not only certain hydrological processes). It was applied for the entire German part of the Elbe basin for the period 1982 to 1995. ARC/EGMO uses a GIS-supported approach to derive the modeling parameters from commonly available basin characteristics (e.g. land use, vegetation, soil, geology). ARC/EGMO is directly coupled to the GIS ARC/INFO and allows to subdivide the watershed under investigation into variable units: basic units (smallest modeling areas), hydrotopes (aggregated basic units, based on criteria of hydrological similarities), classes of hydrotopes (spatially independent aggregation of the same hydrotopes) and further user defined zones. ARC/EGMO thus meets the requirements of hydrological regionalization, including efficiently applicable methods of disaggregation and aggregation. The temporal resolution is in the range of hours or days. A more detailed description of the model is given in Krysanova et al. (1996) and Pfützner et al. (1997).

3.2.3 GESIMA/SEWAB (GKSS)

GESIMA/SEWAB (plus routing scheme) represents an interactively coupled hydrologic-atmospheric modeling system. It has been calibrated and applied for the entire Oder basin for the period 1992 to 1993. The non-hydrostatic mesoscale model GESIMA is an atmospheric circulation model, which in particular is able to simulate small scale, locally induced circulation patterns in complex terrain. Coupled to the GESIMA model, the land surface scheme SEWAB calculates the lower boundary conditions given by the turbulent fluxes of sensible and latent heat, the latter being based on the one-layer concept for vegetation. Driven by climatic variables, SEWAB calculates the land surface runoff as input to hydrologic transport models, the interflow of the unsaturated zone and the baseflow. The time step of the simulation is in the range of minutes. A more detailed description of the modeling system is given in Kapitza and Eppel (1992), Eppel et al. (1995) and Mengelkamp et al. (1999).

3.3 Results

Figure 3.1 provides an overview of the study areas of the Elbe and Oder basins at the 0.5° resolution of the WaterGAP model. The German part of the Elbe basin covers approx. 96 000 km^2. The subbasin of the Saale river with its approx. 23 000 km^2 is at the lower spatial limit of WaterGAP for which extent and lateral flow directions can be represented in acceptable accuracy (Döll and Lehner, 2001).

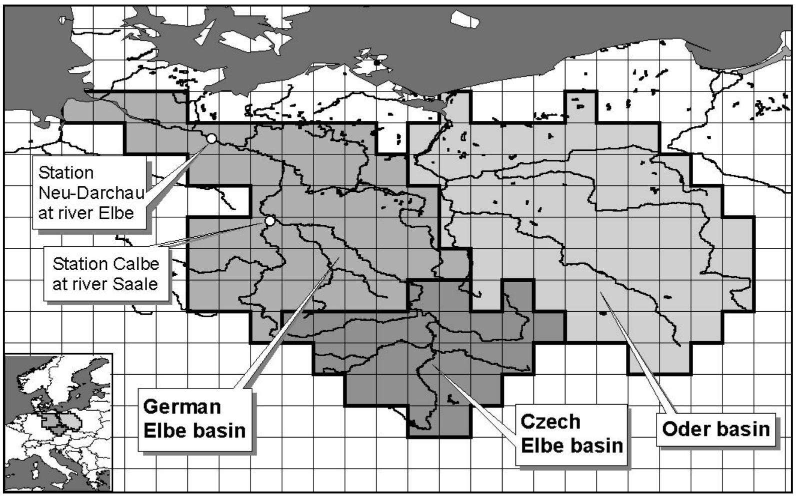

Figure 3.1: Elbe and Oder basins at the 0.5° spatial resolution of the WaterGAP model.

3.3.1 Spatial and temporal model comparisons

For the comparison of the three different hydrological models at various scale levels, the input data *precipitation* and *temperature*, and the model results *evapotranspiration* and *total runoff* are selected with the following characteristics:

- GESIMA/SEWAB: input data (BALTEX high resolution data, half-hourly values) and model results for the Oder basin upstream of station Gozdowidce, hydrological year November 1992 to October 1993

- ARC/EGMO: input data (PIK data, corrected precipitation, daily values, 5 km x 5 km spatial resolution, for further details see Haberlandt, 1999) and model results for the German part of the Elbe basin, period 1982 to 1995
- WaterGAP: input data (Climate Reserach Unit CRU data, uncorrected precipitation, monthly values, 0.5° x 0.5° spatial resolution, for further details see Chapter 2 and New et al., 2000) and model results for the entire basins of the Elbe and Oder rivers, period 1982 to 1995

In the following, the values of precipitation and temperature (input data) as well as evapotranspiration and total runoff (model results) are compared. The total runoff, resulting from the models' vertical water balances, is computed as sum of the components land surface runoff, interflow and groundwater recharge. The definitions of these runoff components, however, are not fully congruent in the models under investigation, hence the interpretation of this variable is limited.

Figure 3.2 presents a visual impression of the spatial distribution of the selected variables as used or calculated in the different models. The spatial units for the presentation are defined by the subcatchment zones of the ARC/EGMO model for the Elbe basin, and the grid cells of the GESIMA/SEWAB model for the Oder basin (unprojected), respectively. In order to make the visual comparison more uniform, the data of WaterGAP is transferred into the modeling units of the two other models. Therefore the values given in the 0.5° WaterGAP resolution are disaggregated (spatially weighed) into the smaller units (the original 0.5° cells of WaterGAP are superimposed in Figure 3.2 for additional information).

Looking at the spatial patterns of the selected variables for the Elbe and Oder basins, Figure 3.2 indicates that the overall structure is reproduced well in the macroscale resolution of WaterGAP. For example, ARC/EGMO and WaterGAP agree in higher precipitation and runoff values for the north-western area of the Elbe basin (long-term average 1982-95), while GESIMA/SEWAB and WaterGAP both show higher precipitation, temperature and evapotranspiration values for the western part of the Oder basin (year 1992/93).

For a better evaluation of the data quality in the context of this comparison, it should be noted that the resolution of some source data of the two mesoscale models is much higher than the resolution presented in Figure 3.2 (e.g. soil types or elevation data), whereas the initial data within WaterGAP are mainly derived from coarse global source maps. Structures which are "small" on the global scale are thus less reliably reproduced in WaterGAP. For the southernmost, mountainous part of the German Elbe basin, for example, precipitation, temperature and runoff differ considerably amongst WaterGAP and ARC/EGMO. The small scale increased runoff formation in the extreme south-western to south-eastern part of the Oder basin, on the other hand, is modeled by WaterGAP in good agreement to GESIMA/SEWAB.

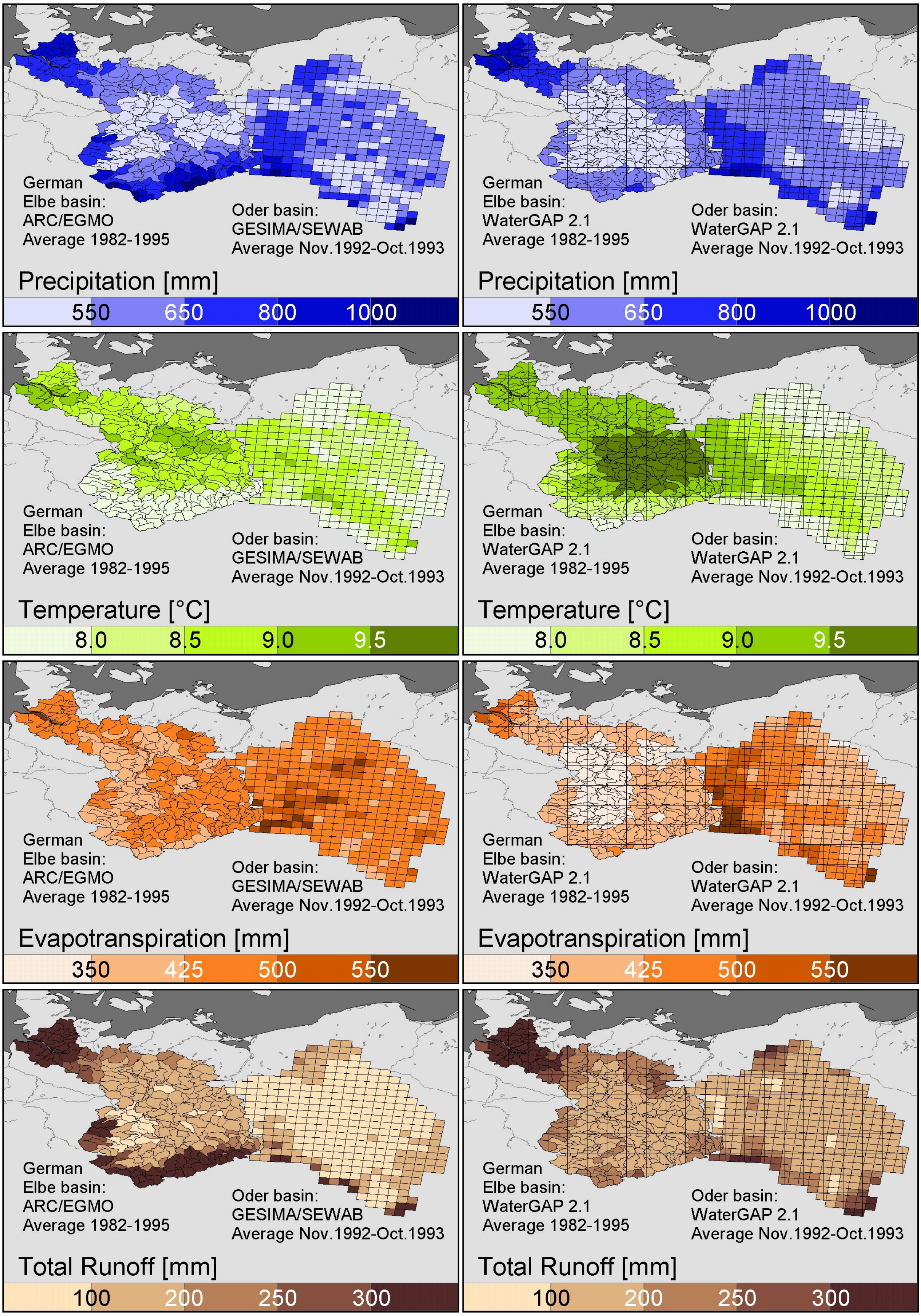

Figure 3.2: Comparison of the spatial distribution of various hydrological variables in models at different scale levels (for different time periods). Left column: models ARC/EGMO (German part of the Elbe basin) and GESIMA/SEWAB (Oder basin). Right column: WaterGAP 2.1, disaggregated.

Looking at the absolute values of the variables shown in Figure 3.2, the most obvious characteristics of WaterGAP are a generally higher temperature level, as well as lower evapotranspiration rates in the Elbe basin and a higher runoff balance in the Oder basin. The latter observation for the *Oder basin*, however, must be qualified to be less significant but rather incidental, as the selection of one single year has to be judged as an example only, lying at the temporal limit of reliable results within WaterGAP. For a better interpretation of the absolute values within the *Elbe basin* (and the subbasin of the Saale river), Figures 3.3 and 3.4 present further analyses of the investigated variables. The time series of 1982-95 are calculated as spatially weighed means over the respective basin areas.

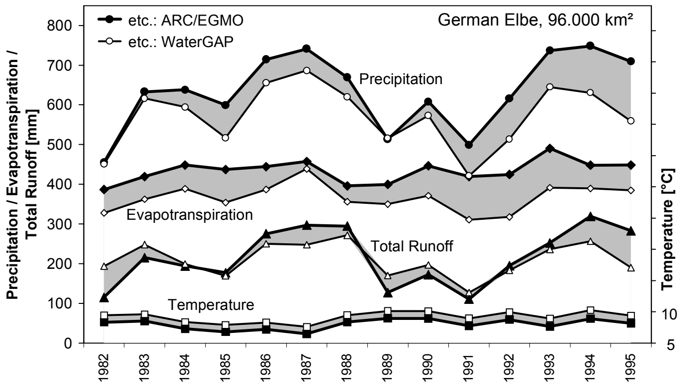

Figure 3.3: Comparison of precipitation, evapotranspiration, total runoff and temperature within the models ARC/EGMO and WaterGAP for the German part of the Elbe basin.

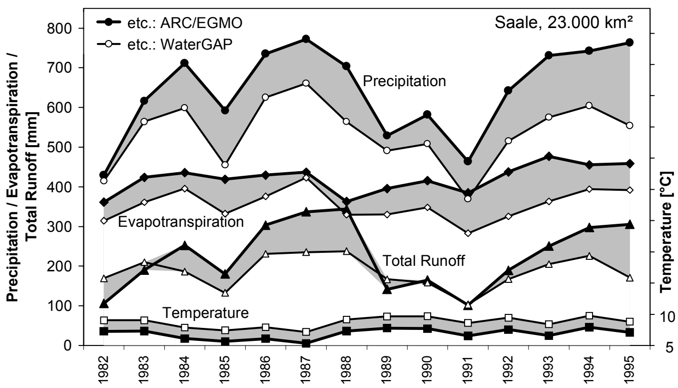

Figure 3.4: Comparison of precipitation, evapotranspiration, total runoff and temperature within the models ARC/EGMO and WaterGAP for the Saale basin.

In WaterGAP, the long-term fluctuations of all selected variables are in acceptable agreement to ARC/EGMO values. The absolute differences are clearly amplified for the smaller Saale basin. The precipitation input of ARC/EGMO generally exceeds that of WaterGAP which is explained by the fact that the PIK precipitation data are corrected and thus higher (see Section 3.3.2). In order to correctly simulate the long-term mean discharge (measured at station Neu-Darchau), the calibration of WaterGAP forces the underestimated precipitation to be compensated by an according reduction in evapotranspiration. Consequently, the resulting total runoff generation in WaterGAP shows good agreement with ARC/EGMO values. Generally, WaterGAP calculates a slightly smaller range of fluctuations and tends to produce lower runoff means than ARC/EGMO in years with high precipitation and vice versa.

Finally, Figure 3.5 presents seasonal regimes (long-term monthly averages for the period 1982-95) for the German part of the Elbe basin. Again, the overall shape of the annual regimes show good agreement between meso- and macroscale models. The precipitation values within the winter months found in the CRU data are up to 20% lower than in the PIK data. This clearly indicates the necessity for a correction of the CRU precipitation data compensating for wind and snow influences. The temperature values are, as also observed for the long-term (Figure 3.2) and annual values (Figures 3.3 and 3.4), generally higher in the CRU data than in the PIK data. The annual regime, however, is nearly parallel in both data sets. This observation can be attributed to the large-scale and thus uncertain interpolation between the relatively few measurement stations for the CRU data (e.g. a temperature station at low elevation will reflect the regional pattern well, but with a systematic excess).

WaterGAP clearly tends to underestimate the evapotranspiration compared to the values of ARC/EGMO, in particular for the months November to February and May to July. A general improvement of the evapotranspiration module within WaterGAP seems necessary, in winter particularly focussing on temperatures below 0°C.

The total runoff regime indicates problems in the treatment of the snow balance within WaterGAP. In January and February too much snow is accumulated, hence the total runoff in these months (basically rain and snowmelt minus evapotranspiration) is too low. Then, with beginning snow melt in March, the runoff rises abruptly. In the summer months WaterGAP shows a generally higher total runoff generation than ARC/EGMO. This might be partly influenced by different definitions of the processes leading to groundwater recharge in the two compared models (ARC/EGMO allows for capillary rise and thus a negative groundwater recharge within the balance). But it also strongly reflects the lower summer evapotranspiration in WaterGAP: the soils stay wetter and more incoming precipitation is transformed into runoff. Normally, the discharge in the summer months should be dominated by baseflow rather than runoff, which is realized in ARC/EGMO but not simulated in WaterGAP to the same extent.

The observations for the subbasin of the Saale river are comparable (again with slightly amplified extremes) and are therefore not presented separately.

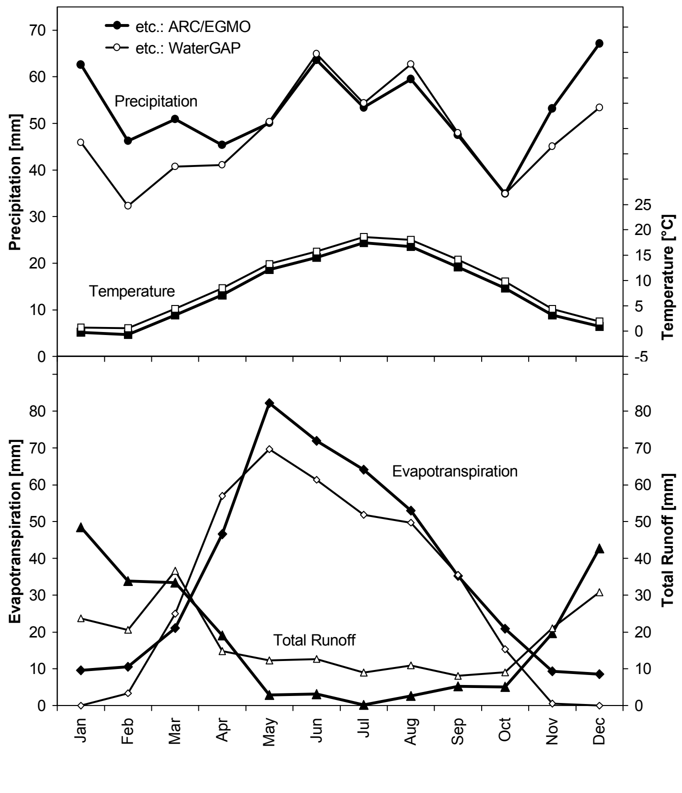

Figure 3.5: Comparison of seasonal precipitation, temperature, evapo-transpiration and total runoff regimes within the models ARC/EGMO and WaterGAP for the German part of the Elbe basin: long-term monthly averages for the period 1982-95.

3.3.2 Macroscale modeling using mesoscale precipitation data

In order to estimate the influence of the spatial and temporal resolution of the input data on the calculations within the macroscale model WaterGAP, two parallel simulations are performed with the WaterGAP 2.1 model for the Elbe basin:

a) applying the macroscale precipitation data that is normally used in WaterGAP (CRU data, uncorrected precipitation, monthly values, 0.5° x 0.5° spatial resolution, for further details see Chapter 2 and New et al., 2000), and

b) applying the precipitation data that is normally used in ARC/EGMO, given in spatially and temporally higher resolution (PIK data, corrected precipitation, daily values, 5 km x 5 km spatial resolution, for further details see Haberlandt, 1999).

The PIK data, available for the German part of the Elbe basin, are first aggregated into the 0.5° spatial resolution and are then imported as daily values into WaterGAP. In order to compare the two runs independently, the WaterGAP model is calibrated separately for the two sets of precipitation data using the discharge measurements at station Neu-Darchau. Generally, the daily precipitation data at higher resolution are assumed to be the more correct data. The resulting WaterGAP modeled discharge values are presented in Figures 3.6 and 3.7 for the decade 1982-91, both as annual series and as seasonal regime for the Elbe basin (station Neu-Darchau) and the subbasin of the Saale river (station Calbe). As a reference, the measured discharges are shown for the same period.

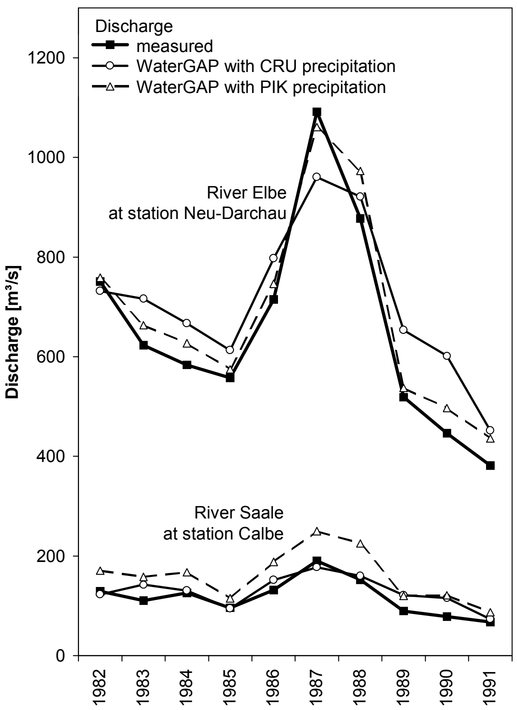

Figure 3.6: Annual discharge series 1982-91 for the Elbe and Saale basins: measured and calculated with different WaterGAP simulations.

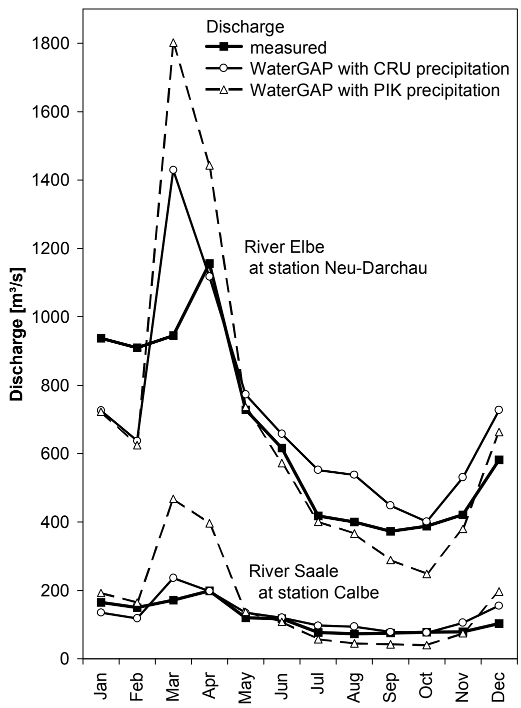

Figure 3.7: Seasonal discharge regimes 1982-91 for the Elbe and Saale basins: measured and calculated with different WaterGAP simulations.

For the annual values (Figure 3.6), the implementation of the PIK precipitation data at spatially and temporally higher resolution clearly improves the quality of WaterGAP's discharge simulation when looking at the complete Elbe basin. For the subbasin of the Saale river, however, for which WaterGAP is not calibrated, the discharge is generally overestimated when applying PIK precipitation. This can be explained by the higher precipitation amounts within the PIK data due to their correction (see Section 3.3.1 and Figures 3.2 to 3.5). WaterGAP seems unable to counter this higher precipitation input by increased evapotranspiration in this “small” subbasin.

For the seasonal regimes (Figure 3.7), the precipitation input at higher resolution leads to an intensification of the discharge extremes, both for the high and low flow periods. This, in general, does not improve the macroscale discharge simulation. The clear overestimation of discharge in March and April can again be attributed to problems in the snow module of WaterGAP (see Section 3.3.1 and Figure 3.5): too much snow accumulation in winter is followed by an amplified melting in spring. With the higher (corrected) winter and spring precipitation the incorrect freezing-and-melting process is even more over-accentuated. In summer, on the other hand, the lowered discharge values (at nearly unchanged precipitation input, see Figure 3.5) must be attributed to an evapotranspiration rate which is now overestimated. This effect can be explained as combined result of an incorrect winter evapotranspiration and WaterGAP's calibration: In order to calculate the correct long-term discharge, the calibration forces the model to counteract the increased (corrected) annual precipitation by increased evapotranspiration; but as evapotranspiration in winter is generally simulated too low (see Section 3.3.1 and Figure 3.5), the evapotranspiration rate is overtuned to an extent at which in summer enough additional water is evapotranspirated to balance the overestimated winter discharge. This observation indicates that both the processes of freezing-and-melting and winter evapotranspiration have to be improved in the WaterGAP model.

3.4 Conclusions

Based on the presented comparisons, the capability of the macroscale model WaterGAP to simulate precipitation-runoff processes for watersheds at different spatial and temporal extents can be evaluated. Bearing the objectives of macroscale modeling in mind, WaterGAP is able to estimate long-term averages, annual series and their fluctuations for large regions to an acceptable degree of accuracy. Clear quantitative discrepancies to the compared higher-resolution models exist when looking at single annual values, monthly values or smaller areas. It has to be considered, however, that the values of evapotranspiration and total runoff derived from ARC/EGMO and GESIMA/SEWAB are also model results, which, although calculated at higher resolution, include uncertainties themselves (e.g. comparisons between ARC/EGMO and GESIMA/SEWAB showed clear differences in their respective evapotranspiration rates).

Quantitative differences within the input data of the investigated models ARC/EGMO and WaterGAP significantly influence the calculations. For example, the tendency of lower precipitation input in the macroscale model WaterGAP due to uncorrected data leads to a subsequent underestimation of the respective evapotranspiration rates.

The comparative study provided indications, rather than a proof, that macroscale long-term simulations within WaterGAP are improved by implementing precipitation data at a higher spatial and temporal resolution. When looking at the seasonal regime, however, this trend is not reflected. As a reason for the latter, problems within the snow module of WaterGAP and within the calculation of evapotranspiration, in particular in the winter period, were identified. Both the process of freezing-and-melting and winter evapotranspiration calculations have to be improved in WaterGAP.

As a general result of the presented comparisons of hydrological models at different scale levels the domain of suitability of the WaterGAP model can be verified. For detailed, temporally and spatially restricted watershed studies the macroscale model WaterGAP reaches its limits of quantitative accuracy. For applications to assess the long-term regional impact of climate change, however, the input data generally contain a high level of uncertainty. Therefore, WaterGAP appears as adequate for many questions of climate impact research as mesoscale or watershed models and has the added advantage that it efficiently delivers spatially extensive, consistent and comparable results. For comprehensive, integrated studies a concerted application of models at various scale levels is recommended.

3.5 References

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