Preliminary assessment of IPCC-SRES scenarios on future water resources using the WaterGAP 2 model

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Abstract: In this study future climate impacts on water resources were assessed using the WaterGAP model. The model has been developed at the Center for Environmental Systems Research at Kassel University, Germany, in cooperation with the National Institute of Public Health and Environment of the Netherlands. The aim of the model is to provide a basis (i) to compare and assess current water resources and water use in different parts of the world, and (ii) to offer an integrated long-term perspective of the impacts of global change on the water sector. WaterGAP belongs to the class of environmental models which can be classified as 'integrated' because they seek to couple and thus integrate different disciplines within a single integrated framework. To estimate future climate impacts on water resources the driving conditions must be estimated. Recently, the Intergovernmental Panel on Climate Change published a set of scenarios describing changes in global greenhouse gas emissions up to 2100 (IPCC-SRES). These scenarios have been used by climate research centers as input to their climate models to calculate the future state of the global climate system. One of the scenarios, the A2 scenario, assumes a future regionalized world which puts special emphasis on economic values; another, the B2 scenario, assumes a regionalized world with an accent on environmental goals. In this paper we highlight the first results of a global assessment of current and future water resources using these new IPCC-SRES scenarios.

Keywords: *Global water resources; global assessment; modeling, climate change; IPCC Scenarios*

1. INTRODUCTION

Presently there is a growing need for water resources analyses on the global and regional scale because of the rising scientific and policy interest in environmental issues on this scale. The scientific side on one hand is keen interest in the analysis of large-scale impacts that climate change, land cover change, and other factors have on water resources (Arnell, 1996). On the other, policy side, governments and large international donor organizations are interested in assessing and setting global priorities for their support in water resources development. This interest raises new questions for water resource analysts and researchers:

1) What is the current and future pressure on freshwater resources due to withdrawals from different water sectors? 2) What river basins are under particular pressure, and how will this situation change under different scenarios of future water use? 3) How will climate change affect the availability of water in different parts of the world?

To address these questions we need new analytical tools for regional and global assessments of freshwater resources. The tool that has been applied in this study regarding these questions is the WaterGAP 2.1d model (**Water** – **G**lobal **A**ssessment and **P**rognosis). It is one of the few global models that is able to estimate both the availability and the consumtion of water at a river basin scale. The main goals of the model are to enable a comparison of the freshwater situation in different parts of the world and to provide a long term perspective (at least a few decades) on changes in global water resources.

In this study we use the model to assess future water availability and water withdrawals following the assumptions of the IPCC SRES scenarios A2 and B2 (Nakicenovic and Swart, 2000). Future precipitation and temperature for these two scenarios are estimated by climate models. Due to the uncertainties in the calculation of the precipitation, we compare the results from two different climate models ECHAM4 and HadCM3. Future water use from three different sectors (households, industry, and agriculture) are considered in the modeling procedures based on the development of the respective driving forces (population growth, economic development, climate change). Results derived for these model scenarios in terms of water availability and water use are presented and discussed for all combinations of results.

2. WaterGAP MODEL

The WaterGAP 2 model (WaterGAP from now on) consists of two modules – a Global Water Use module and a Global Hydrology module (Figure 1). The Global Water Use module takes into account basic socio-economic factors to estimate domestic, industrial, and agricultural water use. The Global Hydrology module incorporates physical and climate factors that lead to runoff and groundwater recharge (Figure 1). Under "water availability" we understand the annually renewable water resources within a river basin (i.e. the discharge from a river basin) (Döll and Lehner et al., 2001; Lehner and Döll, 2001; Döll et al., 2003).

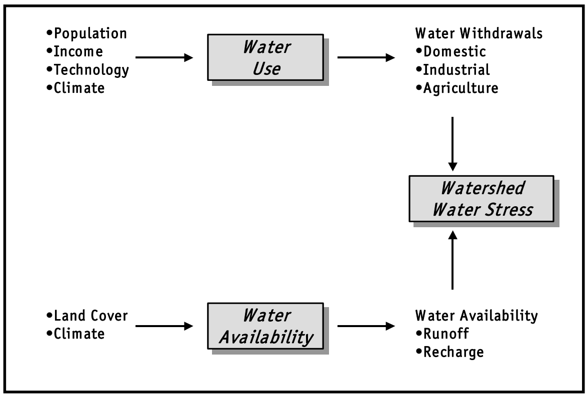


Figure 1. Conceptual scheme of WaterGAP 2

3. SCENARIO SETTINGS

Scenario analysis provides a useful tool for evaluating dynamic changes in society and environment. One of the first definitions describes scenarios as "hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points" (Kahn and Wiener, 1967). Therefore, scenarios lead to possible images of the future, but they should not be interpreted as predictions or forecasts. Rather, scenarios unfold their full potential when applied to enhance learning of complex systems, to highlight inter-connectedness of driving forces, and to identify critical issues. To guarantee meaningfulness, scenarios should be based on an internally consistent, reproducible, and plausible set of assumptions and/or theories of the key relationships and driving forces of change (IPCC, 2000).

In this paper we analyze two long-term reference scenarios of global change, the "A2 scenario" and the "B2 scenario. Scenario A2 foresees a very heterogeneous world with continuously increasing population, regional economic development, and slow technological change. Scenario B2 describes a world in which population increases but at a slower rate than in A2, economic growth is regionally oriented, technological change is somehow faster than in scenario A2, and there is a trend to environmental sustainability.

3.1 Climate Driving Forces

Climate as a driving force impacts all aspects of water availability as well as irrigation in the WaterGAP approach. Due to the uncertainties in the calculation of the precipitation, it is worth to compare future climates from various climate models. In this study we use results from two models: ECHAM4/OPYC3 from the Max-Planck Institute for Meteorology (Hamburg, Germany) and HadCM3 from the Hadley Centre for Climate Prediction and Research (Bracknell, UK).
With respect to climate we focus our analysis on three time slices: today, the 2020s, and the 2070s. A 30-year time series (1961 to 1990) of observed monthly precipitation and temperature values on a 0.5° degree global grid from New et al. (2000) depicts today's climate condition. To derive appropriate future scenarios, today's temperature and precipitation data are scaled using changes predicted by the two climate models.

3.2 Socio-Economic Driving Forces

The main driving forces for water use are country-level scenarios of population (households), electricity production (industry), irrigated area (irrigation), and number of livestock (livestock). Additionally, country-level scenarios for income play an important role in the determination of structural changes in the water use intensity for the households and industry sectors. Water use intensity in the irrigation sector depends on the types of crops grown and on the climatic conditions (Döll and Siebert, 2001). Furthermore, in all sectors water use intensity may be reduced by improvements in water use efficiency (technological changes).

Scenario data for ***population*** (distinguished between urban and rural population) are based on IMAGE 2.2 results for 17 world-regions (IMAGE, 2001). These data are used to scale country-level estimates from the United Nations (1998). In scenario A2 the global population increases to above 8.7 billion by 2025 and above 13 billion by 2075. In scenario B2 there is a less marked increase with global population growing to more than 8 billion by 2025 and more than 10 billion by 2075.

Income scenarios (given as Gross Domestic Product) are also based on results from IMAGE 2.2 for 17 world-regions. These figures are then down-scaled to country values assuming that all countries within a region follow the same trend as the region itself. Average income growth in all regions is somewhat low and very unevenly distributed in scenario A2. Globally, the income is predicted to increase by a factor of 1.5 by 2025 and of 3.5 by 2075. Under scenario B2, income growth is higher at the global level leading to an increase factor of 1.7 by 2025 and 3.7 by 2075.

Electricity production (measured in TWh) is based on IMAGE 2.2 results for 17 world-regions. These values are down-scaled to country figures assuming that all countries within a region follow the same trend as the region itself. Total electricity production increases in nearly all regions under both scenarios. However, the highest increase is expected to occur in scenario A2 except for the Asian region, whose increase is slower than in scenario B2. Globally, the total electricity production under scenario A2 increases by a factor of 2.1 by 2025 and 5.6 by 2075. Under scenario B2 the global total electricity production increases by a factor of 2.1 in 2025 and 4.1 in 2075.

The ***irrigated area*** is seen to be one of the most critical determinants of water stress and two contrasting views prevail on whether the trend in irrigated agriculture expansion will continue or bend. However, the assumptions for the scenarios A2 and B2 consider that the irrigated area will remain more or less constant along the whole period of calculation. The ***number of livestock*** is assumed to slightly increase by 2025 and remain constant from then on for both scenarios.

Structural changes are driven by the wealth grow and the consequent change in lifestyle (households), changes in the proportion of water use from different types of power plants and manufacturers (industry), or changes in the types of crops grown (irrigation).

The assumptions for structural changes in the A2 scenario reflect the emphasis on economic values and are based on the "business as usual" scenario of the World Water Vision (Alcamo et al., 2000). Water intensity in the household sector follows historical trends - average water use intensity first sharply grows along with income growth and eventually stabilizes at higher income levels. In the industry sector, water use intensity decreases with growing income and levels off at higher national incomes. For the irrigation sector, although no changes in the types of crops grown is assumed, water use intensity is still altered by changing climate conditions.

The assumptions for structural changes in the B2 scenario reflect its emphasis on environmental values and are based on the "Values and Lifestyle" scenario of the World Water Vision. In both the household and industry sectors, water intensity is two-thirds below the curve of the A2 scenario. Additionally, it is assumed that each person would have access to a minimum of 14.6 m^3 per year (40 l per day) in non-industrialized countries and of 29.2 m^3 per year (80 l per day) in industrialized countries. For the water intensity in industry, it is assumed that for each MWh total electricity produced in a year, at least a volume of 3.5 m^3 would be necessary. For the irrigation sector, although no changes in the types of crops grown is assumed, water use intensity is still altered by changing climate conditions.

Technological changes complement structural changes and usually lead to improvements in the efficiency of water use, and thus to a decrease in water use intensities. The assumptions regarding technological changes also draw on the World Water Vision scenarios.

In the A2 scenario water use intensity decreases at its historical rate of about 2 per cent per year in both the households and industry sectors, but slows down over time to a value of 1 per cent per year. Additionally, it is considered that the water intensity for households will not exceed the current value for the United States (214 m^3 per year and person) in any country. Concurrently, improvements in irrigation efficiency continues to decrease the water intensity in irrigation by 0.3 per cent per year, but this improvement slows down over time to a value of 0.15 per cent.

In the B2 scenario current rates of improvement in water use efficiency (2 per cent per year) do not slow down, but are maintained throughout the scenario period. Improvements in irrigation water use efficiency are as in scenario A2.

4. RESULTS

4.1 Changing Climate

Different greenhouse emission scenarios will produce different levels of climate change. Due to the fact that these emissions are higher in scenario A2 than in B2, the climate models tend to compute a higher level of climate change under A2 than under scenario B2. Climate models tend to estimate a more humid world under scenario A2 (mainly because of increased evaporation of the oceans) and thus, precipitation increases over most of the land area. However, some large areas experience a decrease in precipitation. The changes in precipitation (either increases or decreases) compared to the present situation (1961-1990) are already significant in many regions for the 2020s and become more intense by the 2070s. Figure 2 shows the changes in precipitation for the 2020s (top) and the 2070s (bottom) computed by the HadCM3 climate model under the A2 scenario settings. There are not only significant differences between scenarios, but also between the results from different climate models. Figure 3 shows that the HadCM3 and the ECHAM4 climate models give opposite results for the change in precipitation for much of the world.

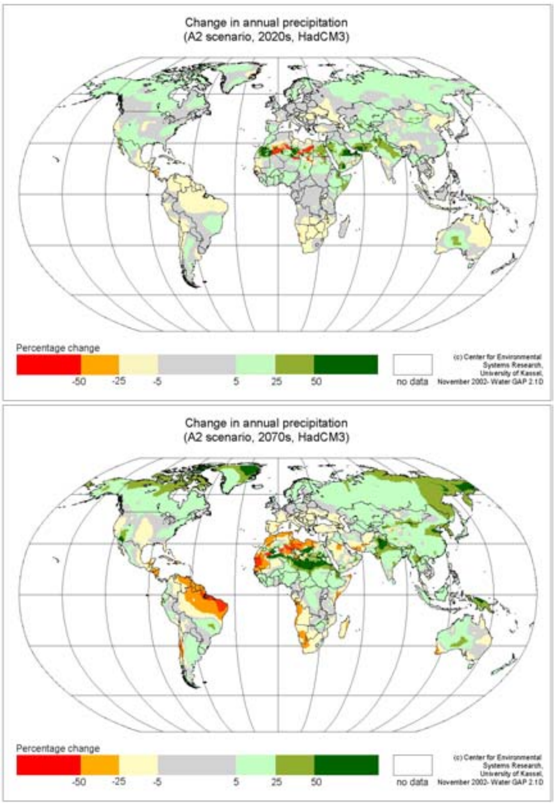
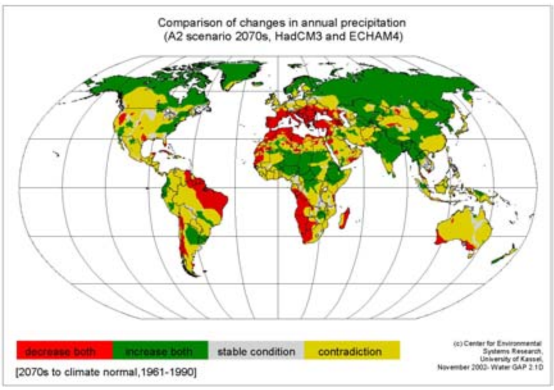


Figure 2. Changes in precipitation for 2020s (top) and 2070s (bottom) in relation to the current situation (1961-1990) computed by the HadCM3 under the A2 scenario settings.

However, these differences are often not large. On the other hand, Figure 3 shows consistent estimates for many important regions. For example, both models predict less precipitation in the arid regions of Southern Europe, the Middle East, Southwestern Africa, parts of the Andean regions, and Northeast Brazil.

Figure 3. Comparison of changes in annual precipitation for the 2070s for the A2 emission scenario



computed by the HadCM3 and ECHAM4 climate models

4.2 Changing Water Availability

WaterGAP computes future water availability (2020s, 2070s) based on the scenario settings presented in Chapter 3. In order to highlight the uncertainties in the climate input we show results based on HadCM3 and ECHAM4 model.

Here we present the changes in annual water availability, which represents the river runoff plus groundwater recharge. Climate change will significantly affect water availability in a direct way by changing long term patterns of precipitation and temperature. An increase or decrease in precipitation will proportionally raise or lower the volume of river runoff. Meanwhile, the expected increase in air temperature will tend to increase evapotranspiration everywhere, and hence decrease runoff. These two effects interact at different locations to give a net increase or decrease in runoff under climate change. Figure 4 shows the changes in water availability as computed by WaterGAP. These results are presented for the 2020s and 2070s using climate input from HadCM3 for scenarios A2 and B2. In both the A2 and B2 scenarios, much of the world will experience an increase in annual water availability. However, some large regions that already now experience water scarcity will have decreasing runoff. These include the Middle East, Northeast Brazil, and Southern Africa. Increases are computed especially for the Northern Hemisphere (Siberia and Canada), parts of Western Australia, the Sahel region, parts of the Middle East, and Northern India.

4.3 Changing Water Withdrawals

In order to assess the future state of water resources it is essential to estimate not only water availability but also water withdrawals. In this study we compute water withdrawals under current conditions and future conditions. Current conditions correspond to the situation in 1995, since this is the latest year for which comprehensive data on water use are available Annual water withdrawals in the different sectors are computed with the WaterGAP model based on the main driving forces related to population, income, and electricity production. Water withdrawals for irrigation are calculated using the results from the climate models as described above and the 1995 distribution of irrigated areas remaining unchanged.

Figure 5 illustrates the changes in total water withdrawal for the 2020s and 2070s computed with the WaterGAP model. The climate used was computed by the HadCM3 model for the emission scenarios A2 and B2. As expected, under the scenario A2 assumptions the withdrawals increase in large parts of the world, due to population

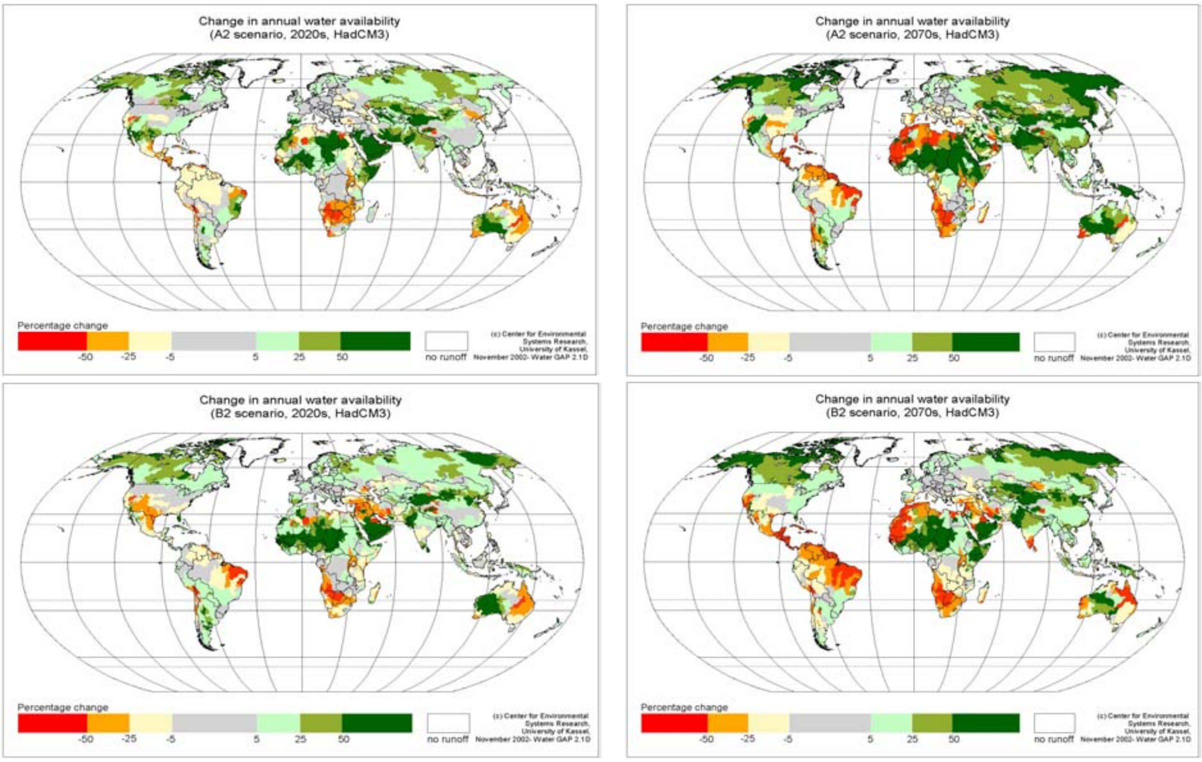


Figure 4. Changes in annual water availability for 2020s (left) and 2070s (right) in relation to the climate normal period. Computed by WaterGAP using HadCM3 climate. The upper graphs correspond to the A2 emission scenario and the lower graphs to the B2

growth and socio-economic progress. In the more environmental oriented B2 scenario more stable conditions are computed, with decreases in water withdrawals over large parts of the world (entire Northern Hemisphere and Australia). Only the Sub-Sahara Africa and India tend to have large increases in water withdrawals.

5. DISCUSSION AND CONCLUSIONS

In this study the WaterGAP model was applied to assess current and future situation of water resources using the IPCC SRES scenarios A2 and B2. Both scenarios assume a future regionalized world. The A2 scenario has special emphasis on economic development whereas the B2 scenario gives an special accent to the environment. current situation (climate normal 1961-1990) calculated with WaterGAP. Climate input computed by the HadCM3 model for the emission scenarios A2 (upper graphs) and B2 (lower graphs). Due to the high uncertainties in the calculation of precipitation, two different climate models are employed. However, Figure 3 shows that these two models deliver the same trends in precipitation for large parts of the world.

Changes in precipitation will proportionally raise or lower the volume of river runoff. The expected increase in air temperature will tend to increase evapotranspiration everywhere, and hence decrease runoff. These two effects interact at different locations to give a net increase or decrease in runoff under climate change. WaterGAP results show that much of the world will experience an increase in annual water availability (Figure 4). However, some large regions that already show water scarcity at present will have decreasing runoff. These include the Middle East, Northeast Brazil, and Southern Africa. Increases are computed especially for the Northern Hemisphere (Siberia and Canada), parts of Western Australia, the Sahel region, parts of the Middle East, and Northern India.

Increases or decreases in water availability are particularly important in those regions where water is already now intensively used for households, industry, and agriculture. Hence, it is of great interest to assess where water use will increase in the future. Changes in water use will arise mainly from changes in population, economy, and technology, but also from changes in climate. WaterGAP results indicate that water use will have a large net increase in developing countries and some other parts of the world in the coming decades. Globally, total water withdrawals are estimated to grow only by 2 to 3 % by 2025, relative to 1995, under the B2 scenario mainly due to its lower population and higher GDP. Under A2 scenario, with higher population and lower GDP, the increase during the same period is estimated to be between 21 and 72 %. It is worth noting that the largest increases take place in river basins in the developing world as a result of their economic development and population growth (Figure 5).

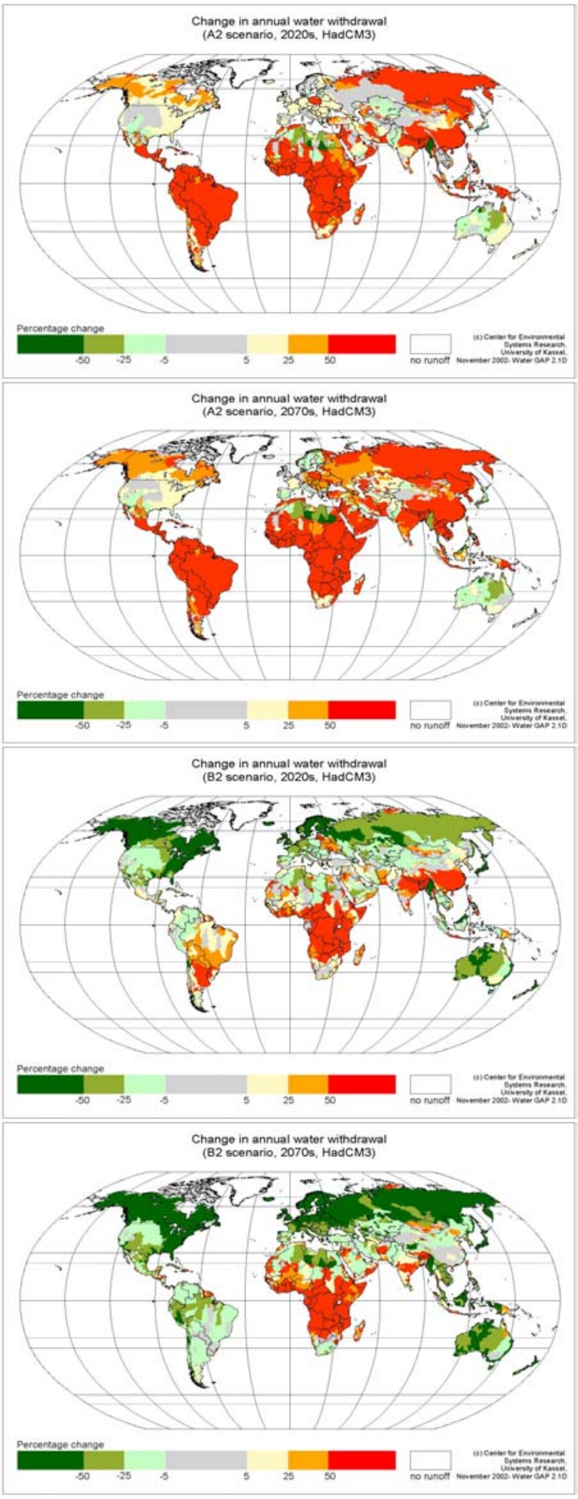


Figure 5. Changes in total water withdrawals for 2020s (top) and 2070s (bottom) in relation to the current situation (climate normal 1961-1990) calculated with WaterGAP. Climate input computed by the HadCM3 model for the emission scenarios A2 (top graphs) and B2 (bottom graphs).

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