Water and Climate: A Global Perspective

Joseph Alcamo, Michael Märker, Martina Flörke, Sara Vassolo

Center for Environmental Systems Research
University of Kassel

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Water and Climate:

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University of Kassel, 34109 Kassel, Germany
Tel. 0561 804 3266, Fax.0561 804 3176
Internet: http://www.usf.uni-kassel.de

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INTRODUCTION

The Dialogue on Water and Climate was launched in December, 2001 at the Bonn Global Water Conference with the goal to "raise awareness and develop coping and adaptation strategies that reduce climate-associated vulnerability at the regional, national, and community levels." While others will address the community-level aspect of these topics, here we provide a global perspective on climate and water resources. From this broad perspective we aim to provide water managers and other stakeholders with new understanding about the global connections between climate change, impacts on water resources, and society's vulnerability to these impacts.

The principal instrument used in this report for the analysis of water resources is the WaterGAP model (*Water* - *G*lobal *A*ssessment and *P*rognosis) developed at the Center for Environmental Systems Research of the University of Kassel, in cooperation with the National Institute of Public Health and the Environment of the Netherlands (Alcamo et al. 2003). WaterGAP is one of the few models with global coverage that computes both water use and availability on a river basin scale (see Appendix for more information). In this report we first use WaterGAP to analyze the impact of current climate variability on water availability[1]. Next we use it to examine the impact of climate change scenarios on future water availability. We then analyze future trends in water withdrawals from households, factories, power plants and irrigated farms, and compare them to changes in water availability using various indicators of "water stress". Finally, we identify "critical regions" where changes in water availability and withdrawals may be particularly important. Taken together, these analyses highlight the important changes in climate, water availability and water use that are likely to occur throughout the world in the coming decades.

[1] In this report we define "water availability" as total river discharge, which is the sum of surface runoff and groundwater recharge.

TODAY'S CLIMATE VARIABILITY

Although society has always lived with large year-to-year and decade-to-decade variations in climate, only recently have scientists begun to recognize the regularity of these variations. An important example is the El Niño-Southern Oscillation cycle (ENSO), a periodic large scale warming of the equatorial Pacific. ENSO is of particular interest because it illustrates the nature and impacts of inter-decadal climate variability.

A typical El Niño event leads to extremely dry and wet periods in Latin America and other parts of the world. Here we have analyzed the impacts on water availability of the 1982-1983 El Niño, one of the strongest events of this type recorded in the 20th century (Map 1). During this event, water availability was more than 25 percent below its long term (1961-90) average level over large parts of Indonesia and southeastern Asia, and more than 50 percent lower in parts of Australia and northeastern Brazil. Much higher than normal runoff was experienced in parts of southern Brazil, southern China and the USA, for example. These variations in availability are a great challenge to the adaptive capacity of the societies where they occur.

The cold extreme of the El Niño-Southern Oscillation cycle is the La Niña phenomenon, related to lower than normal sea surface temperatures in the tropical Pacific. The La Niña period of December - February in 1988 showed wetter than normal conditions for Indonesia, southern Africa, south and southeastern Asia as well as for parts of northern and central Latin America. Drier than normal conditions occurred in eastern and southern Latin America, large parts of Australia and the Midwest of the US. During this event, floods in Bangladesh and droughts in the Midwest of the United States were reported [2].

[2] See http://www.pmel.noaa.gov/tao/elnino/nino-home.html

A CHANGING CLIMATE

Estimates of future climate change depend on many factors including the trend of greenhouse gas emissions and the climate model used to make these estimates. The usual approach to assess the impact of climate change is to estimate the trend of emissions, and then to input these emission trends into climate models. The climate models then estimate future temperature, precipitation and other climate variables on a global grid.

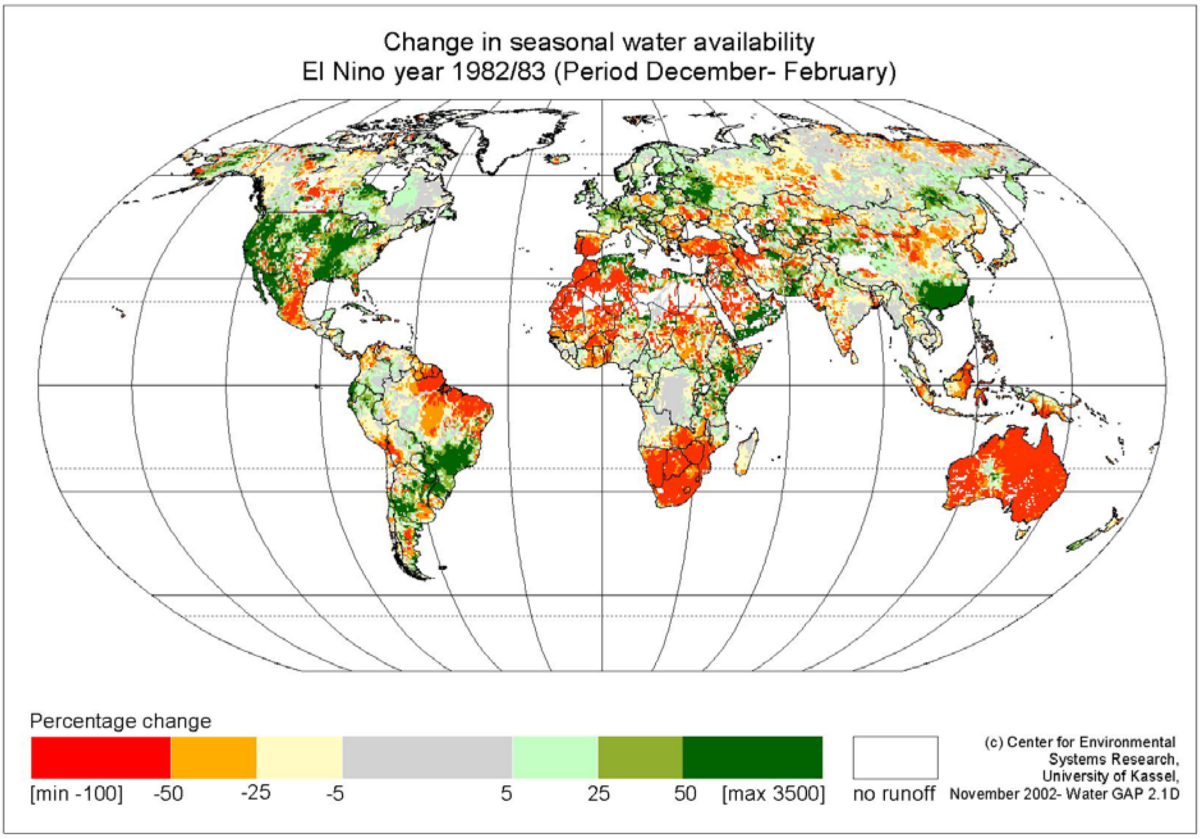
To assess the impact of climate change in this report we examine two different greenhouse gas emission scenarios, and results from two different state-of-the-art climate models. The two emission scenarios we analyze are “A2” and “B2”, which are a subset of the scenarios developed by the Intergovernmental Panel on Climate Change (IPCC, 2000). Both scenarios assume a future regionalized world, with the A2 scenario emphasizing economic values, and the B2 scenario environmental values. In the A2 scenario, greenhouse gas emissions continue to increase beyond 2100 and are overall substantially higher than the B2 scenario. The two climate models used in this report are the HadCM3 model of the Hadley Center in Great Britain (Pope et al., 2000) and the ECHAM4 model of the Max Planck Institute of Climatology in Germany (Roeckner et al., 1996).

In Maps 3 and 4 we show changes in annual precipitation in the 2020s and 2070s, respectively, for the A2 scenario as interpreted by the HadCM3 climate model (compared to the climate normal period). Climate models generally compute that most of the world becomes more humid under climate change (partly because of increased evaporation of the oceans), and this is also shown in Maps 3 and 4. Typical increases in annual precipitation are in the order of 5 to 25 percent over many regions (relative to its average during the climate normal period of 1961 to 1990).

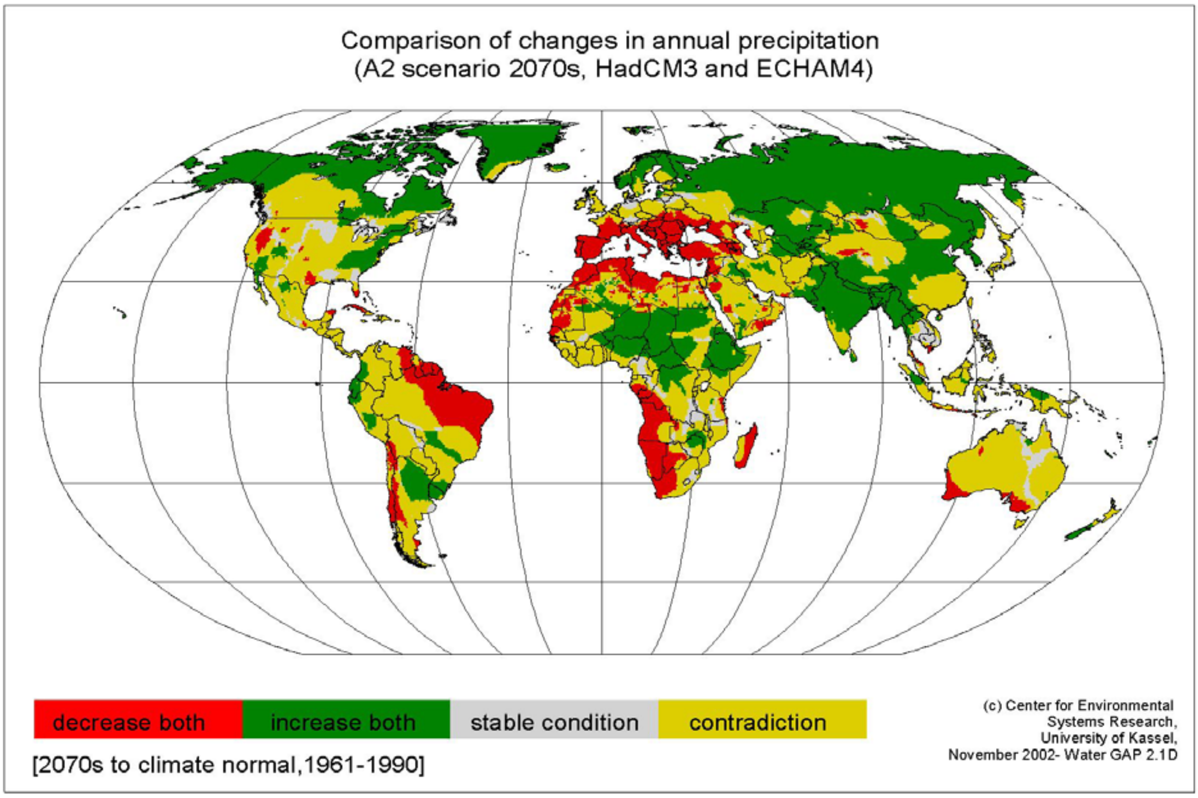
But not all regions have increased precipitation. Decreases in precipitation occur over the Middle East, southwest Russia, the northern part of Latin America, and large parts of southern Africa and Australia. By the 2020s annual precipitation decreases in these regions by around 5 to 25 percent, and by the 2070s by more than 25 percent (Maps 3 and 4).

Regarding temperature changes, the HadCM3 climate model computes an increase in surface temperatures of about 0.5 to 7.7 °C in the Northern Hemisphere and about 0.9 to 5.6 °C in the Southern Hemisphere between now and the 2070s for the B2 scenario (not shown in maps). For the A2 scenario, the model computes an increase of about 0.8 to 8.8 °C and 0.9 to 6.1 °C for the Northern and Southern Hemispheres. The A2 scenario is expected to have somewhat higher temperature increases because it has higher greenhouse gas emissions.

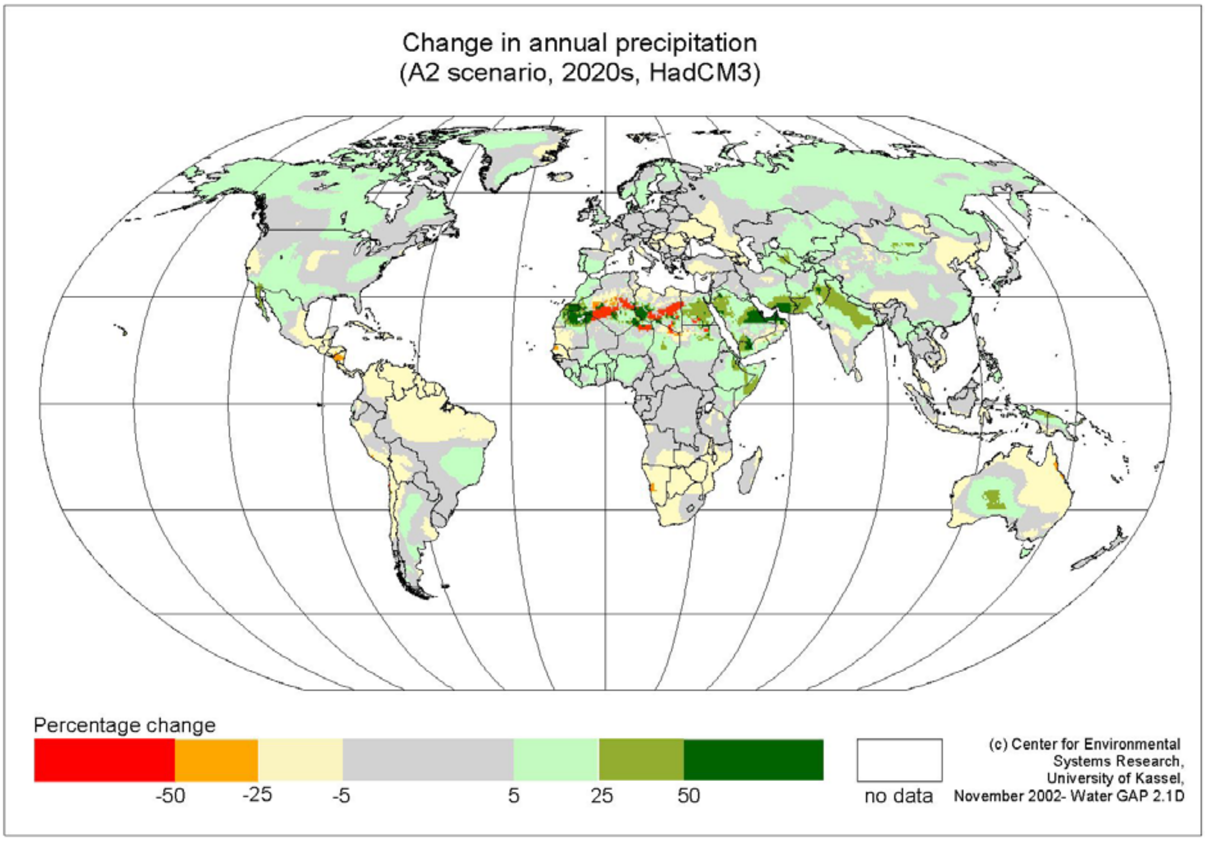
There are not only significant differences between scenarios, but also between results of the different climate models. Map 2 shows that the HadCM3 and ECHAM4 climate models give opposite results for the change in precipitation for much of the world (although the differences are often not large). On the other hand, Map 2 also shows that estimates are consistent for many regions. For example, both models predict decreasing precipitation in the already arid regions Southern Europe, the Middle East and northeast Brazil.



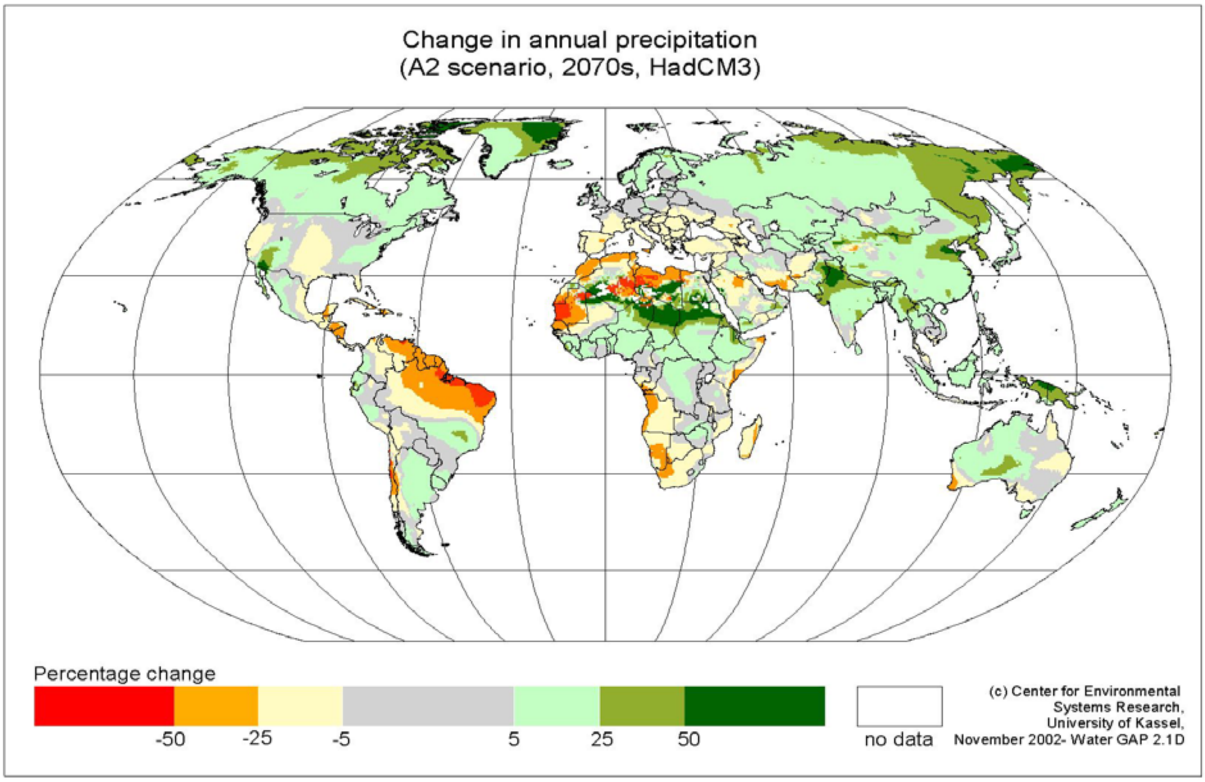
Map 1: Changes in water availability during the El Niño event 1982/83, period December – February. Computed by the WaterGAP model.



Map 2: Comparison of changes in annual precipitation in the 2070s for the A2 emission scenario computed by the HadCM3 and ECHAM4 models.



Map 3: Change in annual precipitation between the 2020s and the climate normal period. Computed by the HadCM3 model (A2 emission scenario).



Map 4: Change in annual precipitation between the 2070s and the climate normal period. Computed by the HadCM3 model (A2 emission scenario).

CHANGING WATER AVAILABILITY

Climate change will significantly affect water availability over large regions. An increase or decrease in precipitation will tend to raise or lower the volume of river runoff. Meanwhile, the expected increase in air temperature will tend to intensify evapotranspiration everywhere, and hence decrease runoff. These two effects interact differently at different locations to give a net increase or decrease in runoff.

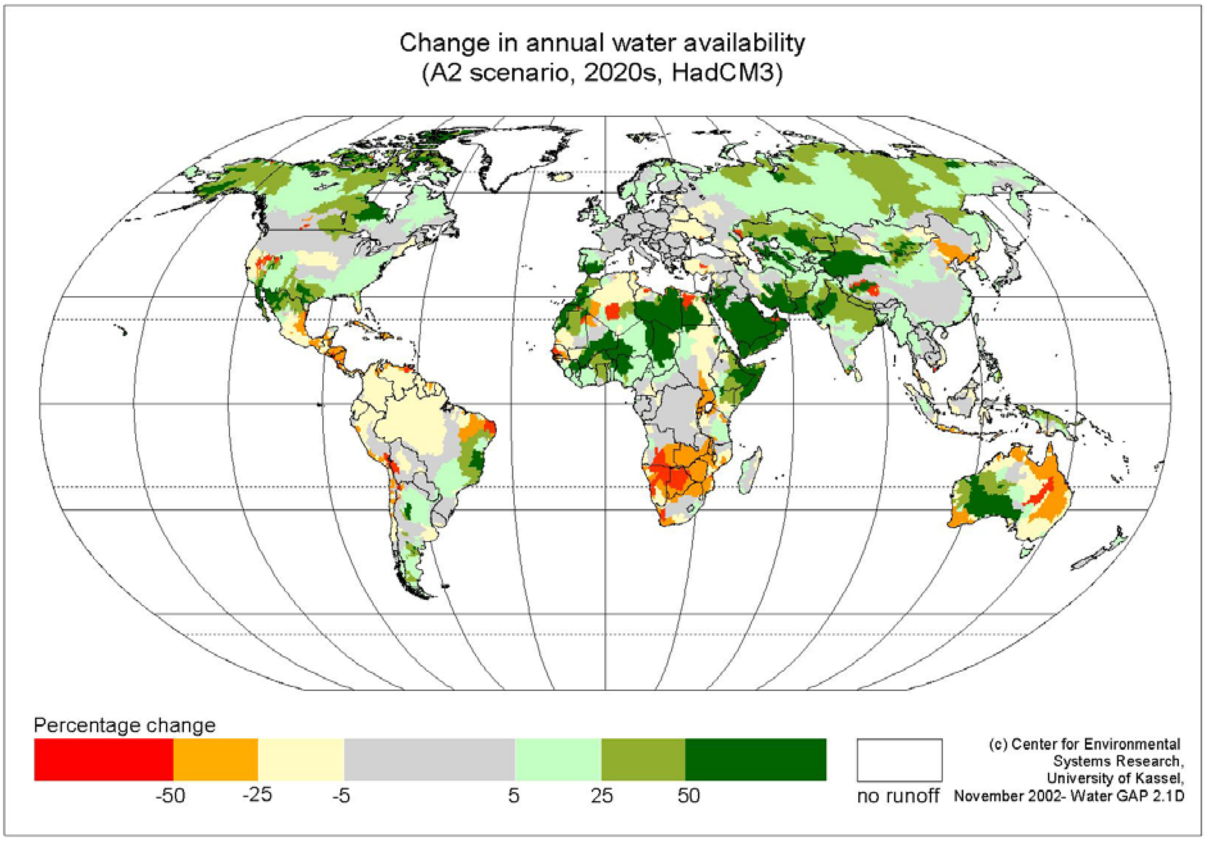
Under both the A2 and B2 scenarios much of the world will experience an increase in annual water availability. Results for A2 as interpreted by the WaterGAP model are shown in Maps 5 and 6. By the 2020s water availability could increase by at least 5 percent over much of the land area of the world, and more than 50 percent over large parts of Africa and Asia (relative to its average during the climate normal period of 1961 to 1990) (Map 5). By the 2070s water availability could be more than 25 percent greater over much of the world's land area (Map 6). At the same time, water availability could decline where precipitation declines and/or where temperature increases, as in the Middle East, southwest Russia, over a large portion of northern Latin America up through Mexico, and in large parts of southern Africa and Australia (Map 5). By the 2070s, already dry areas such as the Middle East, northeast Brazil, and southern Africa could experience a 50 percent or larger decline in water availability (Map 6).

Not only average water availability but also the frequency of its extremes will be affected by climate change. It is obvious that more frequent low and high runoff events could have great consequences on the future level of water security, and on the strategies needed for the management of water resources. Map 7 shows that many humid regions in northern Europe, western India, northern China, and Argentina may experience very high river discharges more frequently. At the same time, arid regions in Southern Europe, Turkey, the Middle East, parts of the United States and northern Latin America may encounter a higher frequency of extremely low flow conditions.

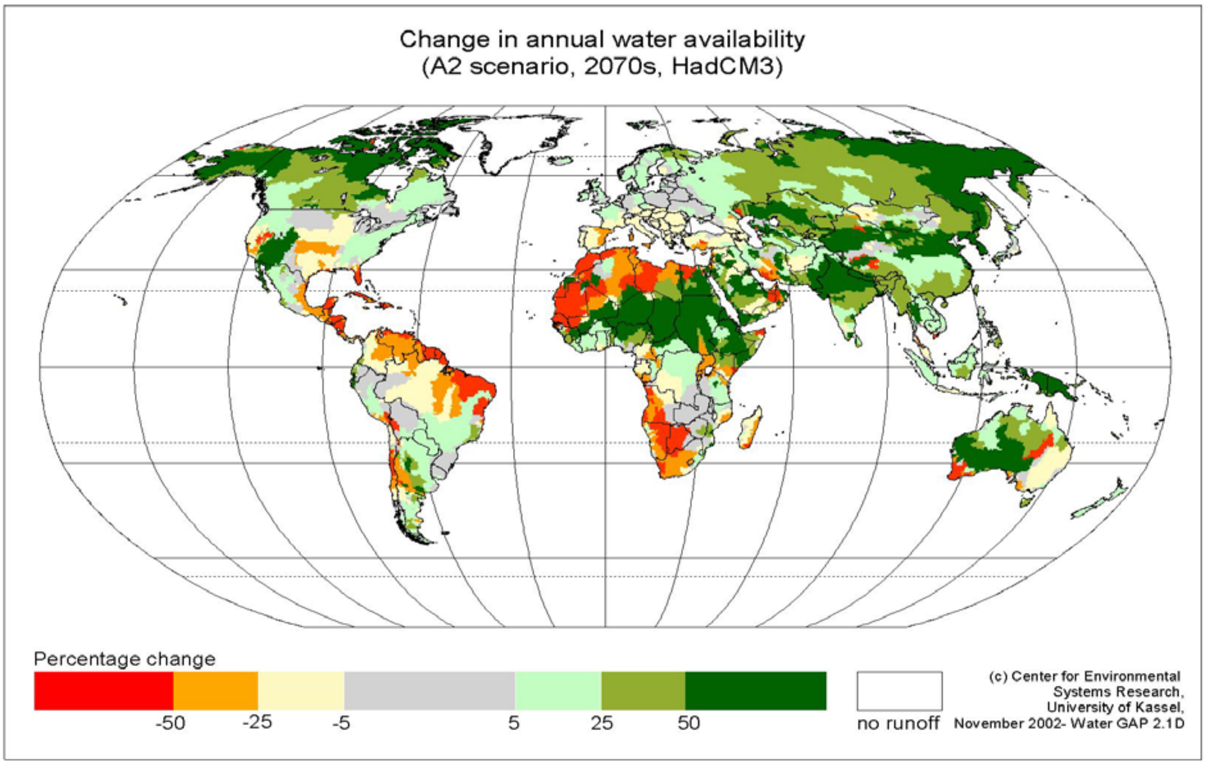
CHANGING WATER USE

Based on previous studies, it seems inevitable that not only water availability, but also the use of water by households, industry and agriculture may significantly change in the future. A better understanding of where these changes will occur will also help us to better understand the future world water situation.

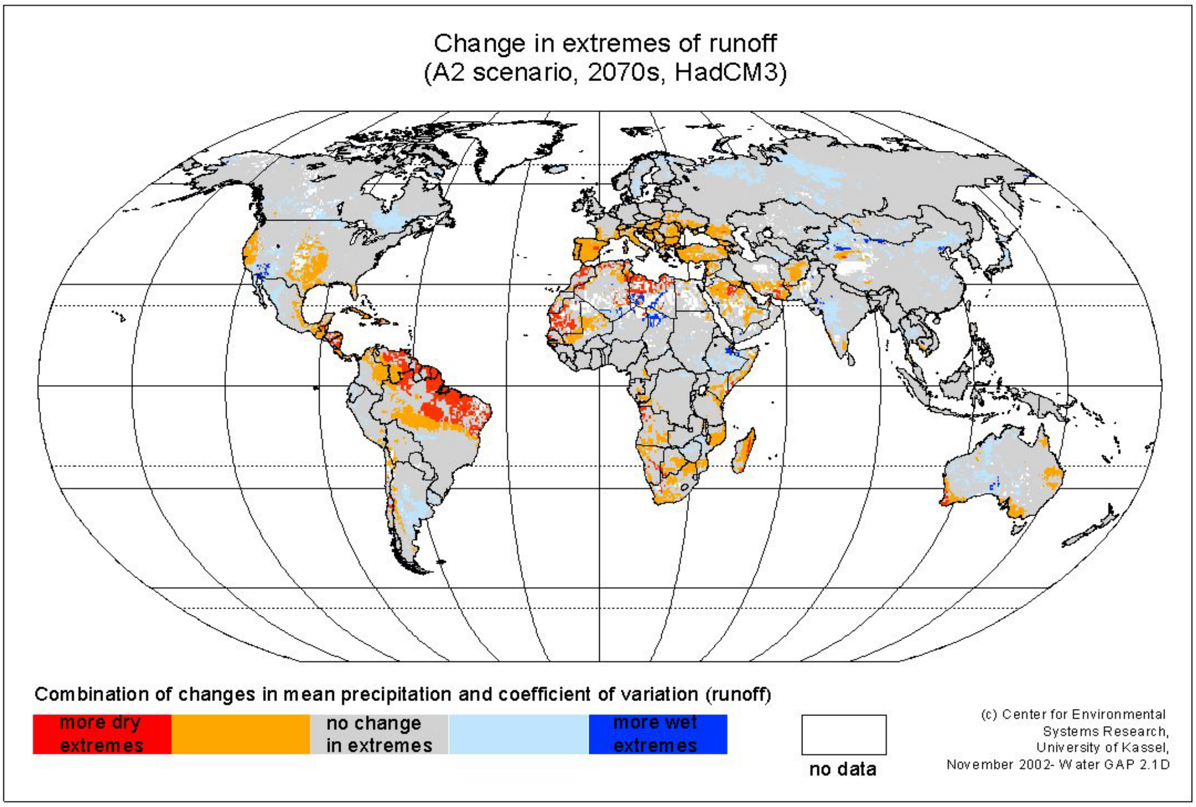
Here we present calculations of changes in water "withdrawal", which is the total volume of water abstracted from surface or groundwater sources for various uses. After taking into account changes in population, the economy and technology specified in the A2 and B2 scenarios, we estimate that water withdrawals will have a large net increase in developing countries and other parts of the world (Map 8). These calculations also take into account the impact of climate change on irrigation water uses. Under the B2 scenario with its lower population and higher GDP, water withdrawals are estimated to grow globally by 28 to 30 percent by 2025, relative to 1995. Under the A2 scenario, with higher population and lower GDP, the increase during the same period is estimated to be 53 to 54 percent. It is worth noting that the largest increases take place in river basins in the developing world as a result of their economic and population growth (Map 8). Of course, it is not clear that such a rapid growth in withdrawals is really achievable since it will require the rapid expansion of costly infrastructure for water supply (pumping stations, distribution pipes, etc.). Furthermore, some of the same river basins will have declining water availability due to climate change (Maps 5 and 6). These coinciding developments will result in higher costs for water supply infrastructure, stronger competition between water users, and perhaps a slowing of economic development in poorer countries.



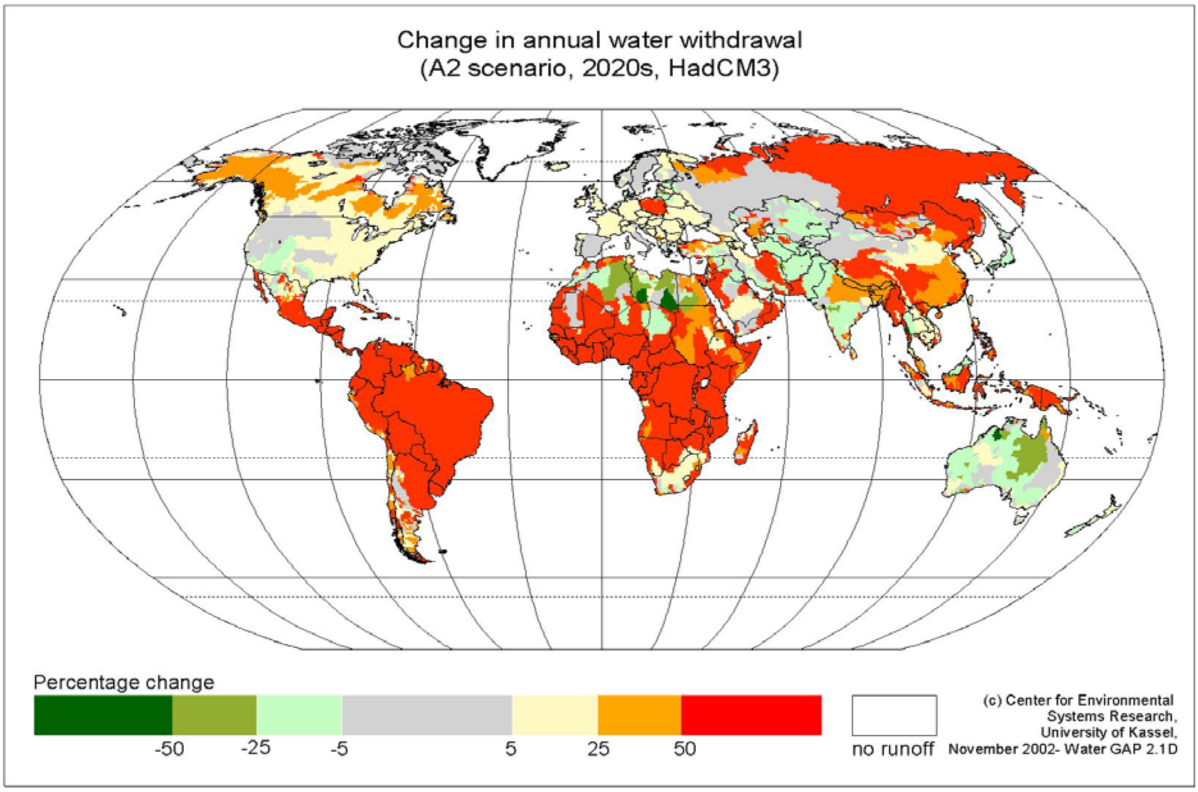
Map 5: Change in annual water availability between the 2020s and the climate normal period. Computed by the WaterGAP model (A2 emission scenario, HadCM3 climate model).



Map 6: Change in annual water availability between the 2020s and the climate normal period. Computed by the WaterGAP model (A2 emission scenario, HadCM3 climate model).



Map 7: Change in extreme runoff events. This map depicts the combination of changes in mean precipitation and the coefficient of variation of runoff. Computed by the WaterGAP model (A2 emission scenario, HadCM3 climate model). Orange indicates a decline between 5 and 25% in annual precipitation and in the coefficient of variation of runoff, and red a decline of more than 25%. Light blue indicates an increase between 5 and 25% in annual precipitation and in the coefficient of variation of runoff, and dark blue an increase of more than 25%.



Map 8: Change in annual water withdrawals between 2020s and 1995. Computed by the WaterGAP model (A2 emission scenario, HadCM3 climate model).

HIGH WATER STRESS IN THE DEVELOPING WORLD

The concept of "water stress" is often used for assessing changes in the world water situation. Water stress indicates the intensity of pressure put on water resources and aquatic ecosystems by users of these resources. Generally speaking, the larger the volume of water withdrawn, used, and discharged back into a river, the more it is degraded or depleted, and the higher the water stress. The higher the water stress, the stronger the competition between users.

A commonly used measure of water stress is the annual "withdrawals-to-availability ratio" (w.t.a.) (Map 9). This indicator has the advantage of being transparent and computable for all basins, although it is an oversimplification of the processes of water scarcity. As a threshold for "severe water stress" it is common to use a w.t.a. ratio of 0.4 [3]. In poorer countries, a level of severe water stress indicates an intensive level of water use that likely causes the rapid degradation of water quality for downstream users, and absolute shortages during droughts. Also, in both developing and industrialized countries, severe water stress indicates strong competition for water resources during dry years between municipalities, industry, and agriculture.

Map 9 shows that many regions will be in the severe water stress category under the A2 scenario in the 2020s. This includes much of northern and southern Africa, the Middle East, Central Asia, northern China, the western United States, and the west coast of Latin America.

A disadvantage of using the w.t.a. and other aggregated indicators is their "smoothing" of differences between locations. Hence, it is wise practice to compare results for different indicators. In Map 10 we present results for the alternative indicator "consumption-to-Q90 ratio". "Consumption" is the average monthly volume of water that is withdrawn, used, and then evaporated and thus not available for downstream users. The "Q90" flow is a measure of the monthly river discharge that occurs under dry conditions. The monthly discharge of the river is higher than the Q90 value 90 percent of the time, or conversely, it is lower 10 percent of the time. When the ratio of consumption to Q90 is at or above one, there is a high risk that nearly all the flowing water resources in a river basin are at least temporarily consumed.[4]

In Map 10 we show the consumption to Q90 ratio for the same scenario and time period as for the w.t.a. above. Some of the critical areas in North America, Latin America and Africa are critical regions both here and in Map 9. However, Map 10 shows smaller impacted areas in Europe and China as compared to the w.t.a. indicator. This is because water use in these areas is dominated by the domestic and industry sectors which tend to have lower consumption levels than the irrigation sector.

Up to this point we have identified critical regions of the world where the level of water use is high relative to its availability. Now we focus on the special subset of regions where water stress is not only high, but also increasing because of declining water availability (due to climate change) or growing water withdrawals (because of economic and population growth or climate change). These regions, shown in Map 11, include the Andean areas of Chile, Bolivia and Argentina, the Limpopo and Orange river basin in southern Africa, large areas around the Mediterranean Sea, coastal areas of the Arabian Peninsula, the Euphrates and Tigris river basins, parts of the Huang Hu basin in China, and the southern parts of India. Also parts of North America and Europe are in this category. The pressure on water resources in these critical regions may be especially high in the coming decades.

As might be expected, the estimate of impacted regions is very scenario-dependent,

[3] Water stress is divided into "low" (w.t.a. ratio lower than 0.2), "medium" (w.t.a. ratio between 0.2 and 0.4), and "high" (w.t.a. ratio larger than 0.4). These values were selected by the World Water Commission (Cosgrove and Rijsberman, 2000) and a Consortium of U.N. organizations (Raskin *et al.*, 1997) based on expert judgment.

[4] Note that this indicator does not take into account factors such as water storage, the seasonal variability of water use especially for irrigation, or the irregular spatial distribution of water users.

showing smaller areas under the B2 than the A2 scenario because B2 has lower water withdrawals. However, some regions always appear as critical regardless of the scenario. These include small parts of central Mexico, the Middle East, parts of central and south-eastern India, the Limpopo River, sections of the Orange River in South Africa, parts of the Bolivian Andes and sections of the Algerian coastal zone.

MEGACITIES AND WATER

While the above analyses have given us an overview of the critical regions of the world, it is also worthwhile to take a more detailed look at the situation in the world's largest cities. Of course, providing water for the millions living in these cities is already an institutional and technical challenge, but here we address the special question – What prospects do these cities have for expanding their water supplies in the face of climate change and other factors?

In Map 12 we show the water stress situation within a 200 km radius of the world's megacities[5]. While it is no surprise that water stress is severe in the river basins where the cities are located, this map shows that it is also severe in nearly all of the basins surrounding the cities. In the 2020s even Lagos with its humid climate is surrounded by basins under severe water stress. These results illustrate the difficult situation facing these cities if they need to expand their water supply. It also suggests that future urban growth might be limited by water scarcity.

SUMMING UP

This report has presented a brief overview of the possible impact of climate change on global water resources. We have seen that the regular variability of climate, as in the ENSO cycle, leads to large inter-decadal variations in the availability of water resources. We have also seen that most climate scenarios expect a wetter world, and higher average runoff. Nevertheless some already dry regions may become even drier.

But climate change will not only cause average changes in runoff - We also expect it to lead to a higher frequency of low flows in some parts of the world, and high flows in others. And complicating this picture will be growing demands for water from households, industries and agriculture, especially in developing countries.

In this report we have combined the above factors together in a consistent analysis of the water situation in different parts of the world. This analysis has helped us to identify certain "critical regions", where climate change and increasing water use may exert more pressure on water resources than in other regions. Many of these critical regions will need the help of the international community to develop strategies for coping with these changes. And without a good strategy, water scarcity may become yet another barrier to sustainable development.

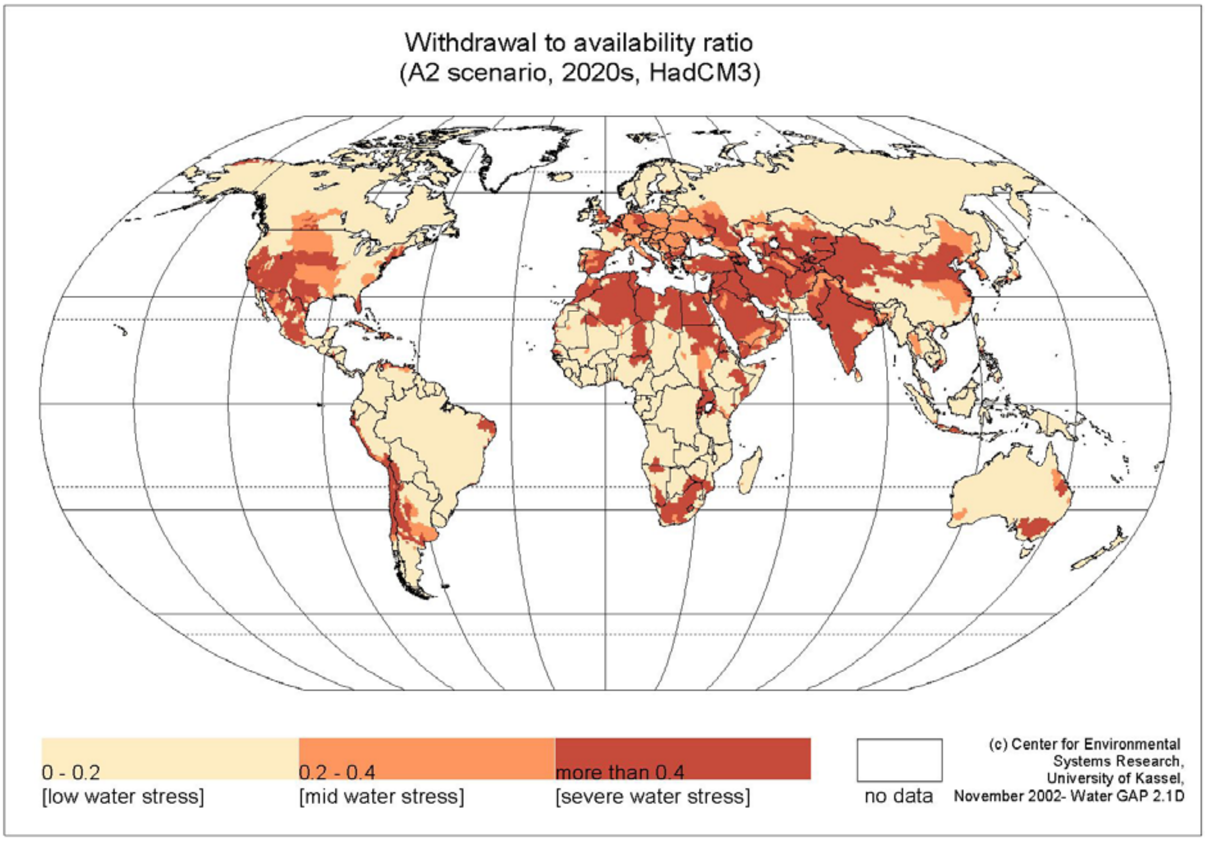
ACKNOWLEDGEMENTS

The authors express their appreciation to William Cosgrove, Pavel Kabat, and Henk van Schaik for their support of this study. The authors are also grateful to Petra Döll for her review of this report.

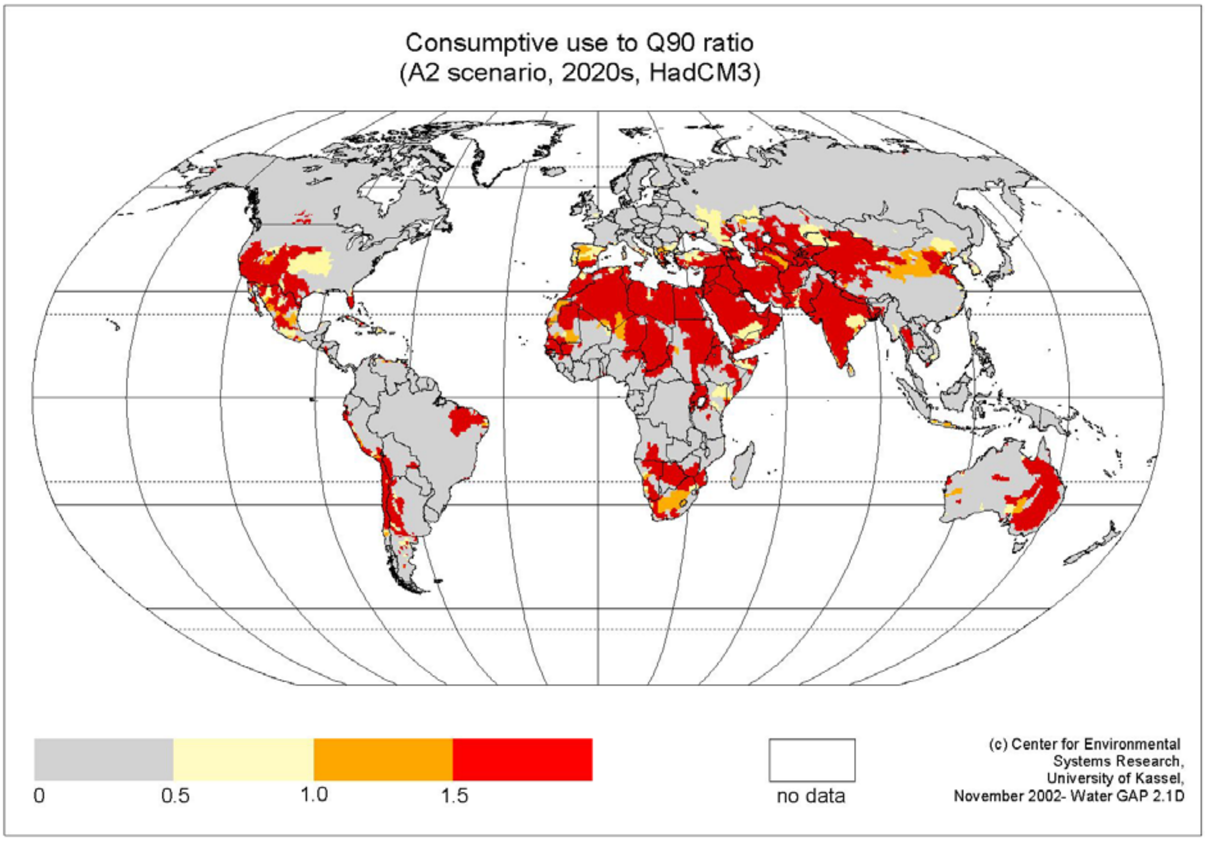
FURTHER INFORMATION

More information about the global perspective to climate and water can be obtained by consulting the web-site of the Center for Environmental Systems Research, University of Kassel, Germany
http://www.usf.uni-kassel.de
and the Water and Climate Dialogue
http://www.waterandclimate.org

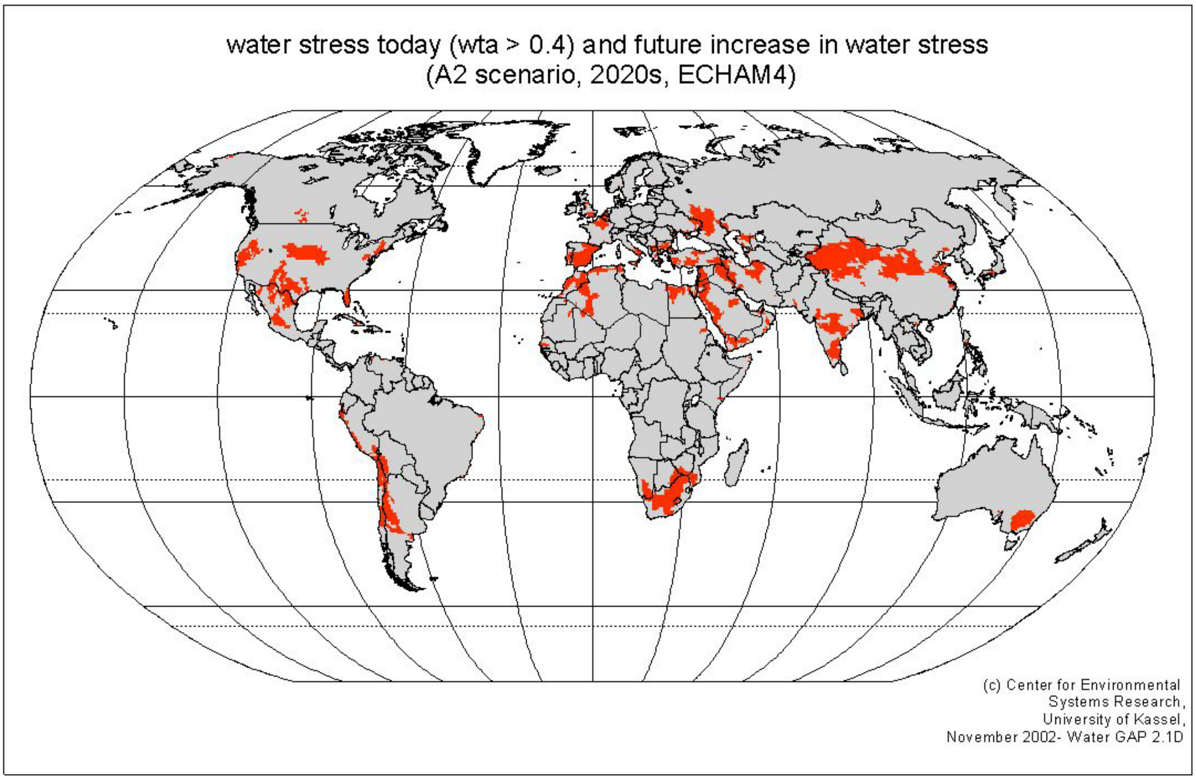
[5] These are the 20 largest megacities defined in UNEP (2002).



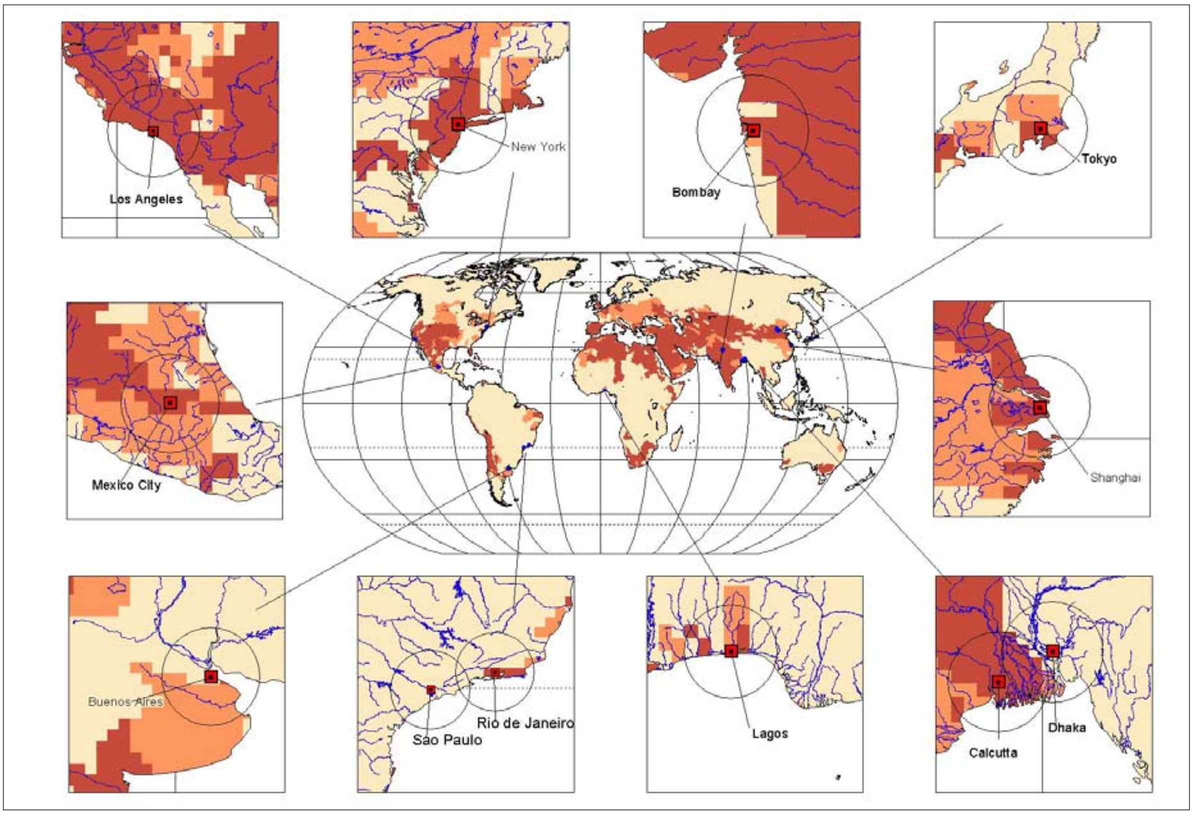
Map 9: Withdrawal to availability ratio in the 2020s. Computed by the WaterGAP model (A2 emission scenario, HadCM3 climate model).



Map 10: Consumption to Q90 ratio in the 2020s. Computed by the WaterGAP model (A2 emission scenario, HadCM3 climate model).



Map 11: Regions currently under "severe water stress" (w.t.a. greater than 0.4) and with increasing water stress between 1995 and 2020s. Computed by the WaterGAP model (A2 emission scenario, ECHAM4 climate model).



Map 12: Water stress in the 2020s in and around the world's 20 largest megacities. Computed by the WaterGAP model (A2 emission scenario, ECHAM4 climate model).

APPENDIX. COMPUTING GLOBAL WATER RESOURCES WITH THE WATERGAP 2 MODEL

The principal instrument used for the global analysis of water withdrawals, availability and stress in this report is the WaterGAP model (*Water* - *G*lobal *A*ssessment and *P*rognosis) developed at the Center for Environmental Systems Research of the University of Kassel, in cooperation with the National Institute of Public Health and the Environment of the Netherlands (Alcamo et al., 2003). WaterGAP is one of the few models with global coverage that computes both water use and availability on the river basin scale. The aim of WaterGAP is to provide a basis both for an assessment of current water resources and use, and for an integrated perspective of the impacts of global change on the water sector. WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use Model.

The Global Hydrology Model estimates water availability by simulating the characteristic macro-scale behavior of the terrestrial water cycle. In this context we define “water availability” as the total river discharge, which is the combined surface runoff and groundwater recharge. In a standard global run, the discharges of approximately 10,500 rivers are estimated. Discharge is computed on a global geographic grid from daily water balances of the vegetation canopy and soil. These water balance computations are driven by precipitation, temperature, and other climate data. A water balance is also performed for open waters, and river flow is routed through a global flow routing scheme. Runoff calculations have been tuned to annual runoff data from a network of stations covering approximately 50 percent of the earth’s terrestrial surface outside of the ice caps (Döll et al., 2003).

The Global Water Use Model consists of three main sub-models which compute water use for the domestic, industry, and irrigation sectors of 150 countries. WaterGAP computes water withdrawals in the domestic and industrial sectors at the country-scale by relating changes in population, national income, and electricity consumption to unit changes in the amount of water used in these sectors. These calculations also take into account the saturation of water demands at high incomes, as well as continuing improvements in water use efficiency due to technological change. Parameters of the model are derived by calibrating the model to a world-wide data base of historical water use trends from (Shiklomanov, 2000). Country-scale estimates of domestic and industrial water use are downscaled by the model to a geographic grid within countries by using demographic and other data. Water requirements for irrigated crops are computed on a geographic grid by taking into account the location of irrigated areas, local climate, and crop and management variables (Döll and Siebert, 2002; Döll, 2002).

Both water availability and water use computations cover the entire land surface of the globe, except Antarctica (spatial resolution 0.5°, i.e. 66896 grid-cells). A global drainage direction map with a 0.5° spatial resolution (Döll and Lehner, 2001) allows for drainage basins to be flexibly chosen; this permits the analysis of the water resources situation in all large drainage basins world-wide.

Results from the model have been used in many national and international studies, including a global water assessment of the German Advisory Council on Global Change (WBGU), in UNEP’s Global Environmental Outlook, and as part of the World Water Vision scenarios disseminated by the World Water Commission (see, for example, Alcamo et al., 2000; Henrichs and Alcamo, 2002; Alcamo and Henrichs, 2002).

For a detailed description of the model see Alcamo et al. (2003) and Döll et al. (2003).

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