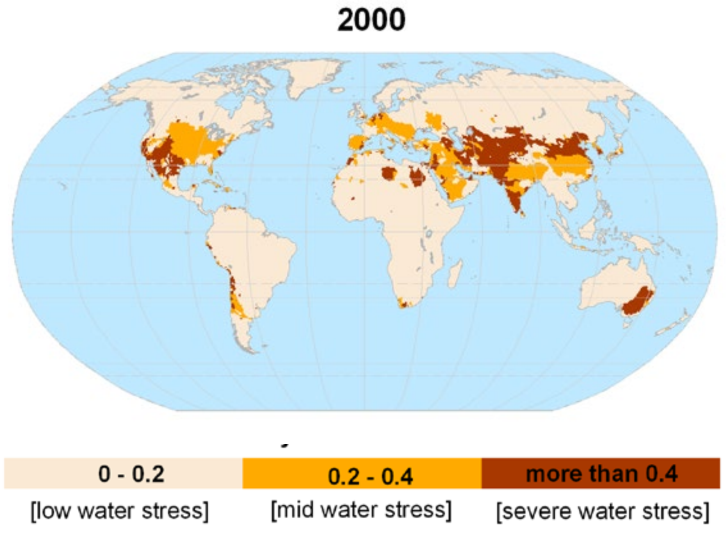
Water and Global Change

Technical Report No. 46

THE DEVELOPMENT OF GLOBAL SPATIALLY DETAILED ESTIMATES OF SECTORAL WATER REQUIREMENTS, PAST, PRESENT AND FUTURE, INCLUDING DISCUSSION OF THE MAIN UNCERTAINTIES, RISKS AND VULNERABILITIES OF HUMAN WATER DEMAND



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Title:	The development of global spatially detailed estimates of sectoral water requirements, past, present and future, including discussion of the main uncertainties, risks and vulnerabilities of human water demand
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Organisations:	CESR, University of Kassel, Germany
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Content

1. Introduction

This Technical Report analyses the past, current and future demand of water for the agricultural, domestic, and industrial sectors. Spatially detailed scenarios of population and economic activity from WP2.1 and climate data sets from WP1 and WP3 are used to calculate scenarios of future water use for human and economic activities that investigate the impact of demographic and economic changes, new water-saving technologies, competition for water from other sectors, and climate change. Spatial downscaling of past (from statistical data) and projected water-related activities provide locations and estimates of water use, moreover, hot spots of water abstractions become visible. Based on information from WB3, the main uncertainties, risks and related vulnerabilities of the water requirements for human and economic activities are assessed. Spatially explicit information is given for past, present and future water withdrawals and consumption for all sectors in form of gridded data sets which were made available to WATCH partners.

Scenarios on the future of domestic and industrial water uses are based on projected economic developments and population and urbanisation trends provided by WP partners. Assumptions regarding water use efficiencies were taken from other global scenario assessments, i.e. UNEP's – Global Environment Outlook (GEO-4, Rothman et al. 2007) or the Millennium Ecosystem Assessment Carpenter et al. 2005, Alcamo et al. 2005).

Studies of domestic water use have confirmed that consumption and vulnerability of people to the availability of water varies significantly between income and age groups. Scenarios of domestic water use are formulated on the basis of current trends and projected economic development, and forecasted population distributions and urbanisation trends. This Technical Report continues the work performed in tasks 2.3.1 and 2.3.2 and reported in Technical Report No. 17; this is done through the addition of future projections of domestic water demand.

Water demand for industrial uses is rapidly increasing and taking a larger and larger share of global freshwater resources. This Technical Report describes past, current and future developments of water abstracted in the manufacturing and thermal power production sectors taking into account changes in economics, thermal electricity production and water-saving technologies. Historical and today's freshwater demand was already described in Technical Report No. 23. Here, projections are added following different pathways into the future.

Agricultural production activities require a huge amount of water, and globally 70% of the total water withdrawn is used in this sector. Future developments analysed in this report take into account only climate change and efficiency improvements.

For calculating past, current and future water stress the withdrawals-to-availability ratio is used (w.t.a.), an indicator widely used in global or large-scale studies (Alcamo et al. 2007, Alcamo and Henrich 2002, Vorösmarty et al. 2000, or Cosgrove and Rijsberman 2000).

2. Methodology and Data

In order to attain the goals of this study (estimating future water use on a global scale), we decided to combine a scenario approach and a modelling approach. The scenario approach was chosen to describe possible futures with quantitative data of water use. However, two alternative scenarios were used according to the WATCH project, namely the SRES A2 and B1 scenarios. The modelling approach was selected to quantify past, current and future water use in a consistent way.

Modelling approach

In order to quantify past, present and future water use the WaterGAP model (Alcamo et al. 2003, Döll et al. 2003, Flörke and Alcamo 2004) has been applied. WaterGAP is used to compute both water use and availability on a global scale. It consists of two main components: a Global Hydrology Model to simulate the terrestrial water cycle and a Global Water Use Model to estimate water withdrawals and consumption. The Global Water Use Model consists of five sub-models to determine both the water withdrawals and water consumption in the domestic, thermal electricity, manufacturing, irrigation, and livestock sectors. In this context, water withdrawals depict the total amount of water used in each sector while the consumptive water use indicates the part of withdrawn water that is lost to evapotranspiration, consumed by industrial products or humans. For most water use sectors, only a small amount of water is actually consumed, whereas most of the water withdrawn is returned, probably with reduced quality, to the environment for subsequent use.

In this Technical Report future developments of water withdrawals are described, past and current water demand of the domestic and industrial sectors are documented in Technical Report No. 17 and Technical Report No. 23, respectively. Since agricultural water use (sum of irrigation and livestock water use) is also part of this study, the authors would like to refer to the model descriptions given in Döll and Siebert (2002), Alcamo et al. (2003), and Flörke and Alcamo (2004).

The Global Hydrological Model (Alcamo et al. 2003, Döll et al. 2003) is used to simulate the characteristic macro-scale behaviour of the terrestrial water cycle in order to estimate water availability. Herein, water availability is defined as the total river discharge, which is the sum of surface runoff and groundwater recharge. The effect of changing climate on runoff was taken into account via the impacts of temperature and precipitation on the vertical water balance.

Scenario approach

The scenario approach is used in this study to produce two main scenarios of water use according to the climate change projections following the SRES A2 and B1 scenario assumptions. In this context, the main drivers like population and GDP developments and thermal electricity production were provided by the project partner IIASA (IIASA 2009), shares of GVA (gross value added), technological changes and irrigation efficiencies were taken from GEO-4 and Millennium Ecosystem Assessment. In order to link the SRES A2 and B1 scenarios with further assumptions from the GEO-4 assessment, the SRES A2 scenario was combined with assumptions from the “Security First” and the SRES B1 scenario was linked to the “Policy First” scenario. Information on main drivers is given on a regional level in accordance to the GEO-4 regionalization and as defined by UNEP (Table 1, Figure 1).

Table 1 Regionalization used in this study.

Region	*SubRegion*	
AFRICA (AFR)	Northern Africa	1
	Central Africa	2
	Western Africa	3
	Western Indian Ocean	4
	Eastern Africa	5
	Southern Africa	6
ASIA AND THE PACIFIC (ASP)	South Asia	7
	South East Asia	8
	North West Pacific and East Asia	9
	Central Asia	10
	Australia and New Zealand	11
	South Pacific	12
EUROPE (EUR)	Western Europe	13
	Central Europe	14
	Eastern Europe	15
LATIN AMERICA AND THE CARIBBEAN (LAC)	Caribbean	16
	Meso-America	17
	South America	18
NORTH AMERICA (NAM)	North America	19
WEST ASIA (WAS)	Arabian Peninsula	20
	Mashriq	21

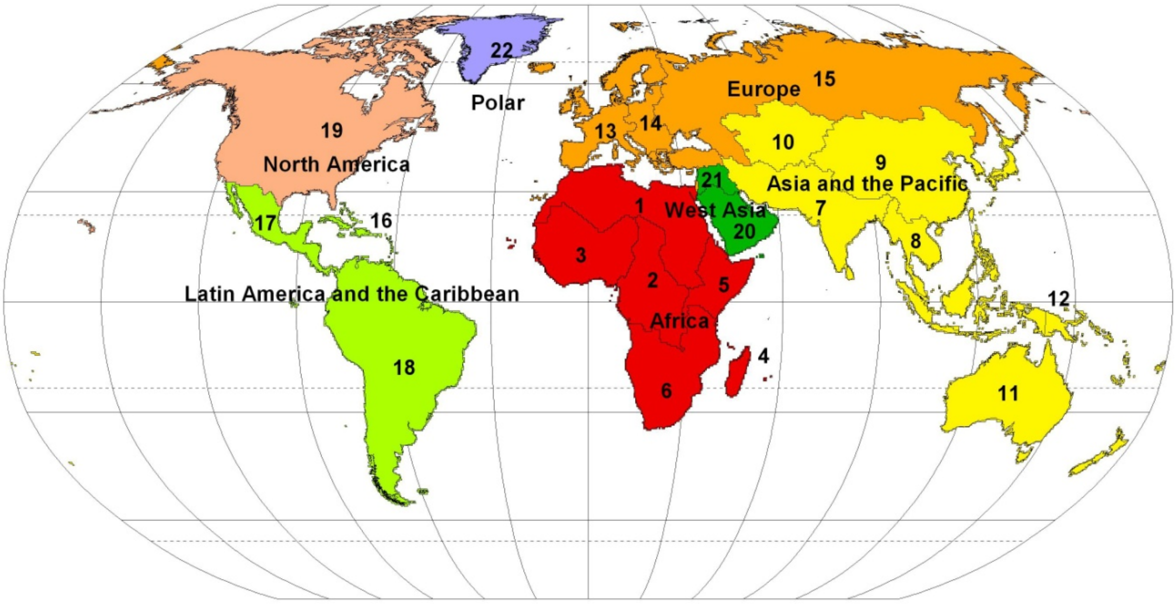

Figure 1 Map of defined regions and sub-regions (displayed as numbers; see Table 1).

Driving Forces

Scenarios should be based on coherent and internally consistent set of driving forces and assumptions about the key relationships which have a significant influence on the future water demand at the global scale. The core driving forces considered by the modelling approach are those incorporated in the calculations of the WaterGAP model as listed below.

a) Population: The number of future water users obviously determines the magnitude of water use in the domestic sector. Population assumptions are used in the WaterGAP model to compute water use in the domestic sector. Data on future time series of population were used from the IIASA's Greenhouse Gas Initiative (GGI) scenario database (IIASA 2009) and were based on the SRES A2 and B1 scenarios. Population developments according to the defined regions are shown in Figure 2.

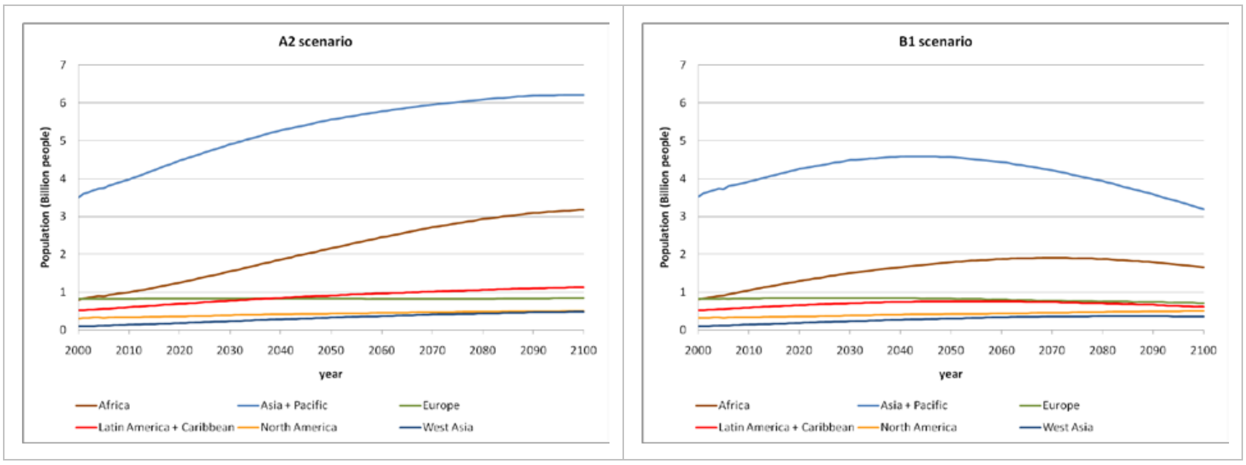

Figure 2 Population development for the SRES A2 (left) and B1 scenario (right) on a regional scale.

b) Per Capita Income (GDP/cap): Changing income is an important driving force of future water use. Per capita income is used in the WaterGAP domestic water use model to compute per capita water use in the domestic sector. Data on future time series of GDP were used from the IIASA's Greenhouse Gas Initiative (GGI) scenario database (IIASA 2009) and were based on the SRES A2 and B1 scenarios. Scenario projections of average income according to the defined regions are shown in Figure 3.

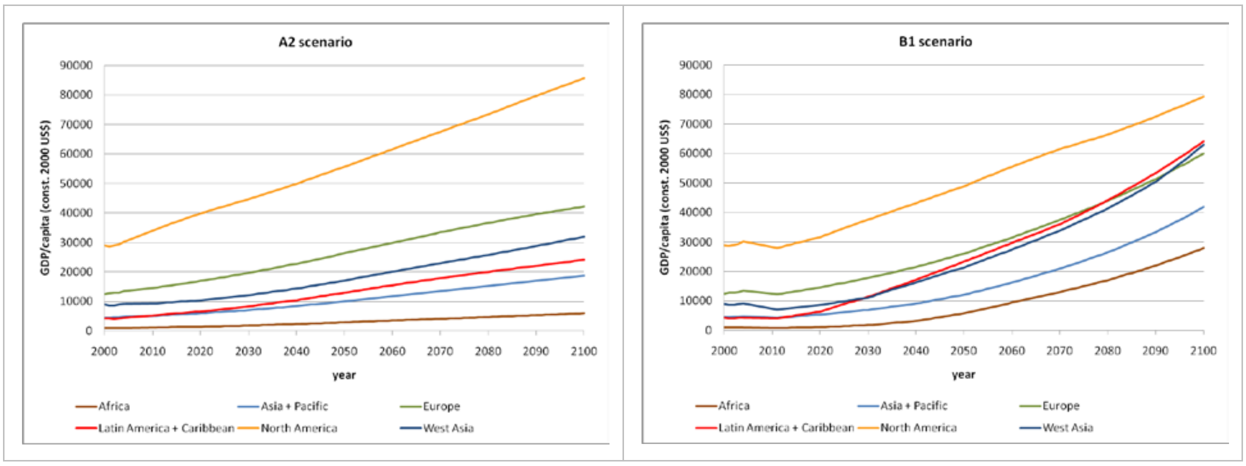

Figure 3 GDP per capita development for the SRES A2 (left) and B1 scenario (right) on a regional scale.

c) Gross value added (GVA): The magnitude of manufacturing output in a particular industry is an important determinant of water use by the manufacturing industry. The WaterGAP model uses assumptions of future manufacturing output to compute water use in the manufacturing industry sector. Projections of the share of manufacturing GVA as part of total GDP were assumed from GEO-4 and were based on the Security First and Policy First scenarios (Figure 4).

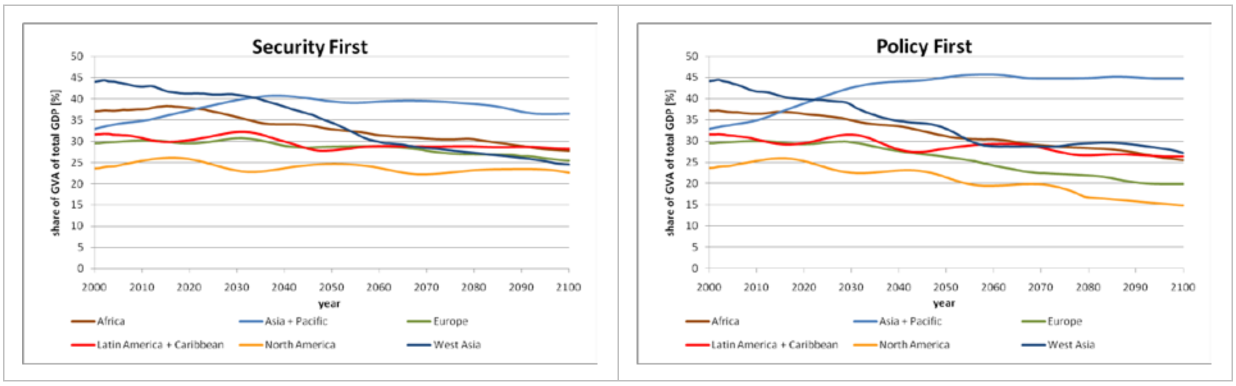

Figure 4 Future projections for shares of GVA as part of total GDP for Security First (left) and Policy First scenario (right) on a regional scale.

d) Thermal electricity production: The volume of water needed at thermal power plants is driven by the production of electricity at these facilities. The WaterGAP model uses assumptions about future thermal electricity production to drive calculations of water use in the electricity production sector. In this context, thermal power plants may burn fossil fuels, biomass or use nuclear energy to produce the necessary thermal energy. Data on future time series of thermal electricity production were used from the IIASA's Greenhouse Gas Initiative (GGI) scenario database (IIASA 2009) and were based on the SRES A2 and B1 scenarios (Figure 5).

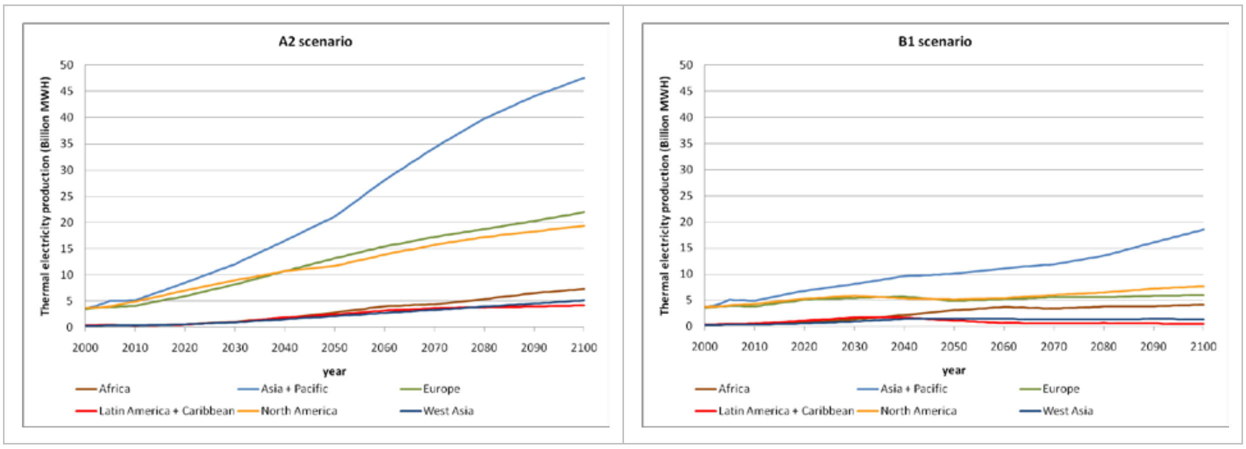

Figure 5 Development in thermal electricity production for SRES A2 (right) and B1 scenario (right) on a regional scale.

e) Type of cooling system: The type of cooling system in a power station (once-through or tower cooling) is an important determinant of the station's water use. This driving force is taken into account by the WaterGAP model to compute water use in the electricity production sector. Future assumptions were taken from GEO-4 and were based on the Security First and Policy First scenarios (Table 2).

Table 2 Assumptions for future type of cooling system.

Security First	Policy First
Proportion of tower-cooled versus once-through cooled: all new power plants in Europe are tower-cooled. The lifetime of a power plant is 50 years. No structural changes in the other regions	Proportion of tower-cooled versus once-through cooled: all new power plants are tower-cooled or air-cooled (Western USA, Africa). The lifetime of a power plant is 35 years.

f) Irrigated areas: An important driving force of irrigation water use is the extent of irrigated land. The WaterGAP model uses assumptions about the future coverage of irrigated area to compute water use for irrigation. In this study, no changes in irrigated area were assumed, i.e. the area was kept constant to the year 2000 (Siebert et al. 2007).

g) Climate change: Climate is an important driver of irrigation water requirements as well as for calculating water availability. The WaterGAP model takes the variables into account precipitation, temperature and radiation. Climate projections until the year 2100 were provided by project partners of WB 3 for three global circulation models and two emission scenarios, SRES A2 and B1, respectively.

h) Number of livestock: Water use by livestock in a country is obviously driven, among other factors, by the number of livestock. This driving force is taken into account by WaterGAP to compute livestock water use. Future projections follow A2 and B1 scenarios and were provided by IIASA.

i) Technological changes lead to improvements in water use efficiency: This driving force is particularly important because it tends to reduce water use whereas the preceding driving forces in most cases increase water use. The impact of technological change on improving water use efficiency is taken into account in all sectors. (See Table 3 and Table 4).

Table 3 Technological change rates as specified for the Security First and Policy First scenarios.

Security First	Policy First
Domestic: -0.1% per year until 2050, 0% per year thereafter in Latin America & Caribbean. All other regions 0.25% per year until 2025, 0% per year thereafter. Manufacturing: -0.1% per year until 2100 in Latin America & Caribbean. All other regions 0.25% per year until 2025, 0% per year thereafter. Electricity: -0.1% per year until 2100 in Latin America & Caribbean. All other regions 0.25% per year until 2025, 0% per year thereafter.	Domestic: 1% per year until 2025, 0.75% per year until 2050, 0% thereafter in Latin America & Caribbean. 1.25% per year until 2025, 0% per year until 2035, 0.75% per year until 2050, 0% thereafter in Europe and Central Asia. All other regions 1.25% per year until 2025, 1% per year until 2050, 0% thereafter. Manufacturing: 1% per year until 2025, 0.75% per year until 2100 in Latin America & Caribbean. 1.25% per year until 2025, 0% per year until 2035, 1.25% per year until 2100 in Europe and Central Asia. All other regions 1.25% per year until 2025, 1% per year until 2100. Electricity: 1% per year until 2025, 0.75% per year until 2100 in Latin America & Caribbean. 1.25% per year until 2025, 0% per year until 2035, 1.25% per year until 2100 in Europe and Central Asia. All other regions 1.25% per year until 2025, 1% per year until 2100.

Table 4 Rate of improvement of future project irrigation efficiencies until 2050; no improvement is assumed for the time period after 2050.

Country/region	Security First [% per year]	Policy First [% per year]
Canada	-0.11 for the first 25 years, -0.3 thereafter	0.5 for the first 25 years, 0.45 thereafter
USA	-0.2 over whole time period	0.5 for the first 25 years, 0.25 thereafter
Central America	-0.5 over whole time period	1 for the first 25 years, 0.45 thereafter
South America	-0.6 over whole time period	0.8 for the first 25 years, 0.5 thereafter
North Africa	-0.6 for the first 25 years, -0.2 thereafter	0.9 for the first 25 years, 0.1 thereafter
West Africa	-0.8 for the first 25 years, -0.3 thereafter	1.4 for the first 25 years, 0.5 thereafter
East Africa	-0.6 for the first 25 years, -0.3 thereafter	0.8 for the first 25 years, 0.4 thereafter
South Africa	-0.5 for the first 25 years, -0.2 thereafter	0.6 for the first 25 years, 0.5 thereafter
Northern OECD-Europe	-0.1 over whole time period	0.3 over whole time period
Eastern Europe	-0.15 over whole time period	0.5 for the first 25 years, 0.4 thereafter
Baltic Republics + Belarus	-0.1 over whole time period	0.5 over whole time period
Near East Countries	-0.1 over whole time period	0.45 for the first 25 years, 0.15 thereafter
India + South Asia	-0.8 for the first 25 years, -0.3 thereafter	0.65 for the first 25 years, 0.45 thereafter
China + CPC	-0.6 for the first 25 years, -0.3 thereafter	1.4 for the first 25 years, 0.45 thereafter
East Asia	-0.75 for the first 25 years, -0.3 thereafter	0.65 for the first 25 years, 0.45 thereafter
Oceania	-0.25 over whole time period	0.65 for the first 25 years, 0.15 thereafter
Japan	-0.1 over whole time period	0.45 over whole time period
Southern OECD-Europe	-0.7 for the first 25 years, -0.6 thereafter	0.85 for the first 25 years, 0.4 thereafter
Rest of the former SU	-0.6 for the first 25 years, -0.3 thereafter	0.55 for the first 25 years, 0.33 thereafter

3. Results

Water withdrawals are presented for the different sectors for the past (represented by the year 1960), present (represented by the year 2000) and future (represented by the year 2050) on a grid cell level (0.5 by 0.5 arc degrees) for the whole world. Society withdraws large volumes of water each year from the world's reservoirs, rivers, aquifers and other freshwater and saltwater sources. Major water users are households, factories, power plants and irrigation projects (see Figures 7, 8, 9 on water withdrawals by sector). In Figure 6 we show the sum of all water withdrawals on a grid cell basis. The units of the maps [mm/a] indicate how much water is withdrawn per unit area of a grid cell. In the year 2000 high water withdrawals occur as expected in densely populated areas such as Japan, Korea, coastal China, India, Pakistan, Western and Central Europe, and in North America, as well as parts of Latin America and Australia. Also in the high withdrawal categories are intensely irrigated areas of Northern China, Central Asia, the Middle East, and the Western United States. Some of the hot sports are already visible in the past (map for 1960), for example in Europe, North America, South and South-east Asia, and Australia. Water withdrawals, however, were less pronounced in South America and Africa.

In order to look into the future two different pathways were selected, the SRES A2 (linked to Security First) and B1 (linked to Policy First) scenarios. The A2 scenario shows a further increase in water withdrawals until the year 2050 whereas the B1 scenario results are either in the order of current withdrawals or even reduced. However, due an increase in GDP per capita an increase in water withdrawals is expected in Western and Eastern Africa under the B1 scenario conditions. Altogether, the A2 scenario (and Security First) is characterized by growing population and neglect of water conservation which push water withdrawals upwards. Yet, slower economic growth tends to slow the increase. On the other side, the B1 scenario (and Policy First) assumes widespread adoption of integrated water management strategies, with strong emphasis on demand management and conservation. These developments, together with slower population growth rates, lead to slower increases in overall water use.

Domestic sector

The domestic sector includes water abstracted for household use, small businesses and other municipal uses, which take high quality water directly from the municipal pipelines when it is available. Cities require large volumes of water with the majority used in households to cover the basic personal needs of urban dwellers. As can be imagined, the profiles of household water use in developing and industrialized countries are quite different. In developing countries they include water for drinking, cooking and bathing. In addition to these basic needs, the current Western lifestyle requires considerable extra amounts of water for washing clothes, dishes and cars. Many industrialized countries also have very substantial outdoor water demands for watering lawns and gardens, and for maintaining swimming pools. In arid climates outdoor water uses can make up a huge fraction of total water use. However, on the average the largest fraction of water used in industrialized countries is for toilet flushing, followed by clothes washing, showering and faucet use. The differences in personal requirements also lead to huge differences in the volumes of water used between countries – the average North American uses about 400 litres per person per day while the typical sub-Saharan African, around 10 to 20 litres per day. Figure 7 shows the water withdrawals for households per unit area as well as water withdrawals for supplying the needs of commercial businesses in cities and rural areas. These needs are much the same as household requirements – water use for toilets, kitchens, and sinks – but include additional uses for process water, large restaurant kitchens, and sometimes decorative landscaping. Today, household plus commercial uses account for approximately 10 percent of the total withdrawals of water in the world. Hence the most essential requirements for water – drinking, cooking, and hygiene – are covered by a relatively small fraction of the world's water withdrawals. The maps in Figure 7 show that the needs for households are more widespread over the world than water uses for other purposes. This is expected since people live in urban and rural areas and they require basic water services. In the year 2000, higher water withdrawals per unit area are found through much of Europe, South and Northeast Africa, large parts of Latin America and much of North America (mainly in the east). In some places such as India, Pakistan, China, and Northeast Africa the household use per person is lower than in industrialized countries, but population density is higher. Hence the water withdrawals per unit area are of the same order of magnitude as in industrialized countries. No water withdrawals occur in the polar and desert regions.

Especially in Africa and Latin America the situation in the past (1960) differs quite much from the year 2000 because less water was withdrawn for domestic purposes. This is due to the fact that most people lived in rural areas and not in cities and that the share of people with access to safe drinking water was very small compared to current conditions.

Domestic water withdrawals are expected to increase mainly in Asia and Africa under the A2 and B1 scenarios until 2050 as a result of further population growth and economic development (see Figure 2 and 3). Overall, water abstracted for domestic use is more pronounced under the A2 scenario compared to the B1 scenario since higher technological change rates dampen the further increase of water use intensities. This trend in the B1 scenario is supported by an increasing commitment of people to save water in households. Domestic water use as calculated for the A2 scenario is strongly influenced by neglecting water conservation.

Industry sector

Industrial water withdrawals include water used by manufacturing industries and cooling water for the thermal electricity production. Water is one of the crucial raw ingredients of manufacturing industries. Its most important use in manufacturing is for cooling, as in the quenching of molten iron in the iron and steel industry. Its next most important use is as “process water” in which it makes up an essential part of the product stream. In the paper and pulp industry, for example, water is used for transporting ground wood and pulp from one process to another, for washing the pulp, for removing bark from pulp wood, and for cooking wood chips to remove lignin. In some industries, particularly canning, distilleries and other agro-industries, process water is literally a raw ingredient of the beverages and other canned products.

Producing electricity at thermal power plants requires substantial amounts of water during every stage of the energy cycle from mineral extraction to delivery of the fuel to the power plants. But by far the greatest need for water comes from the cooling of turbines in the power plant. The amount of water required depends on the type and size of power plant, and especially on the type of cooling. The two main types are “once-through cooling”, in which water is used to cool the turbines and then discharged directly back to a waterway or pond, and “tower cooling” in which the turbines are cooled and the hot water is sent to a cooling tower, reused several times, and eventually discharged from the plant. One of the advantages of tower cooling is that water is discharged back to waterways at a much cooler temperatures, thereby protecting aquatic ecosystems and downstream water uses. Another advantage is that it allows the recycling of water within the power plant, and this means that tower cooling requires less than three percent of the water withdrawals of once-through cooling (per unit energy produced). Although tower cooling requires much lower withdrawals, it consumes twice as much water per unit energy as once-through cooling because much more water is evaporated in the cooling towers.

Figure 8 shows the volume of water withdrawn for industrial purposes per unit area. For the year 2000, these withdrawals are highest in northeast of North America, large parts of Europe, northern and central India, the eastern half of China, Japan, and in the Nile Basin in Africa. Because thermal power plants and big manufacturing industries are reliant on large sources of water, the areas of highest withdrawals tend to be more geographically concentrated than water uses of the domestic sector (compare Figure 7) which are more widespread. Nevertheless, most of the water withdrawn by thermal power plants is used and then returned to waterways without a major degradation of quality (except for thermal pollution caused by once-through-cooling). Hence their overall average impacts on downstream users are often smaller than that of manufacturers or municipalities which withdraw water, use it, and discharge it back to waterways with degraded quality.

In 1960 less water was withdrawn for industrial purposes compared to the year 2000 due to ongoing industrialisation driven by economic developments (see Figure 8). Industrial centres were located in north-eastern America, Central Europe, and northern India.

Future industrial water withdrawals are driven by the development of manufacturing gross value added and the production of thermal electricity production as well as changes in technology. Based on these assumptions future industrial water use was calculated for the A2 and B1 scenarios for the year 2050 (see Figure 8). The results show highest water withdrawals for the A2 scenario in North America, Europe, and Asia. In addition, high values are expected in Latin America along the western and eastern coastlines, the Arabian Peninsula, and parts of Northern and Western Africa. Contrary, the B1 scenario displays rather low industrial water withdrawals except for the main industrial centres in North America, Europe, India and China. Although GVA further increases and thus also the manufacturing water use, a strong reduction in thermal electricity production lower total industrial water uses globally. Improving efficiencies as well as structural changes in form of a shift in cooling system underpin the significantly faster progress to achieve environmental and human-well being goals.

Agricultural sector

Water used in the agricultural sector comprises irrigation water requirements and livestock water use. Livestock water use is very small compared to the amount of water abstracted for irrigation purposes therefore only irrigation water withdrawals are presented (Figure 9). The amount of water needed by irrigated crops depends on many factors the most important are the type of crop and cropping system, the irrigation approach and its level of technology, and the local climate and topography. On a per hectare and year basis, the water requirement for irrigation in arid areas is about 8000 cubic meters in Spain, and 10,000 in California. Obviously, in regions where the efficiency of irrigation is lower, more water is required. For example in Egypt the average requirement is between 15,000 and 20,000 cubic meters. Figure 9 depicts the irrigation water requirements on a per unit area basis. To a certain extent the highest water withdrawals are located in areas with the highest density of area equipped for irrigation. This includes Pakistan and northern India, northern China, and the Central Valley of California. On the other hand, water requirements are also high in areas with a lower density of irrigation projects that are subject to intense evaporation because of local climate conditions such as large parts of India and China, Central Asia, much of the western United States, parts of western Latin America and Brazil, Southern Europe, the lower Don and Volga in Russia. In all these areas irrigation can be expected to be the dominant user of water.

High irrigation water withdrawals were already visible in the year 1960, but irrigation has been intensified during the 40 years. Increasing agricultural activities occur in North America, Latin America, Eastern Europe, South Africa, and in South and East Asia.

Irrigation water requirements are expected to increase in the A2 scenario till 2050 as a result of climate change and neglect of irrigation improvement. The climate change effect is less pronounced in the B1 scenario but irrigation efficiency improves continuously leading to a decrease in water abstractions for irrigation purposes. However, highest water withdrawals are most likely in South and East Asia and the Nile Basin.

Most important water use sector

Figure 10 shows the most important water use sector per river basin, distinguishing domestic, manufacturing, thermal electricity production, and agricultural sectors. In view of the most important water user in the year 2000 a mixed picture emerges with large shares on agriculture, followed by electricity production, households and manufacturing. Water used in the agricultural sector is most prominent in Asia, Africa, North America, and Latin America while the electricity production sector is the main water user in Central and Eastern Europe, Canada, eastern US and Arabian Peninsula. Domestic water use is dominant in Central Africa and along the northern coastline of Latin America. Manufacturing water use is the most important sector only in Scandinavia and south-west Canada.

The map visualizing the situation in 1960 looks similar to the year 2000 and the order of most important sectors is the same. Only in some river basins the most important water user changed, e.g. in Central Africa or northern region of Latin America, and Australia.

Yet by looking ahead into the future the picture may tremendously vary: in an A2 world the most important water user is expected to be the industry sector (sum of manufacturing and electricity production) followed by agriculture and domestic sectors. Water used for thermal electricity production dominates in North America, Eastern Europe, Latin America, Arabian Peninsula, and parts of Africa and Australia. The second most important water user will be the agricultural sector, mainly occurring in Asia, Southern Europe, parts of Africa, and western regions of North America. Manufacturing water use, however, is important in Northern and Central Europe and Central Africa. Remaining regions in Africa and Latin America are dominated by domestic water use.

A different picture is drawn under B1 scenario assumptions where the agriculture sector is expected to be the most important water user almost all over the world. All river basins in Asia, huge parts of Europe, Africa and North America as well as Australia will be dominated by agricultural water withdrawals. The domestic sector will be ranked second, especially important in Central and Western Africa and Latin America. Northern Europe, parts of North America and East Africa are likely to be dominated by manufacturing water use in the future.

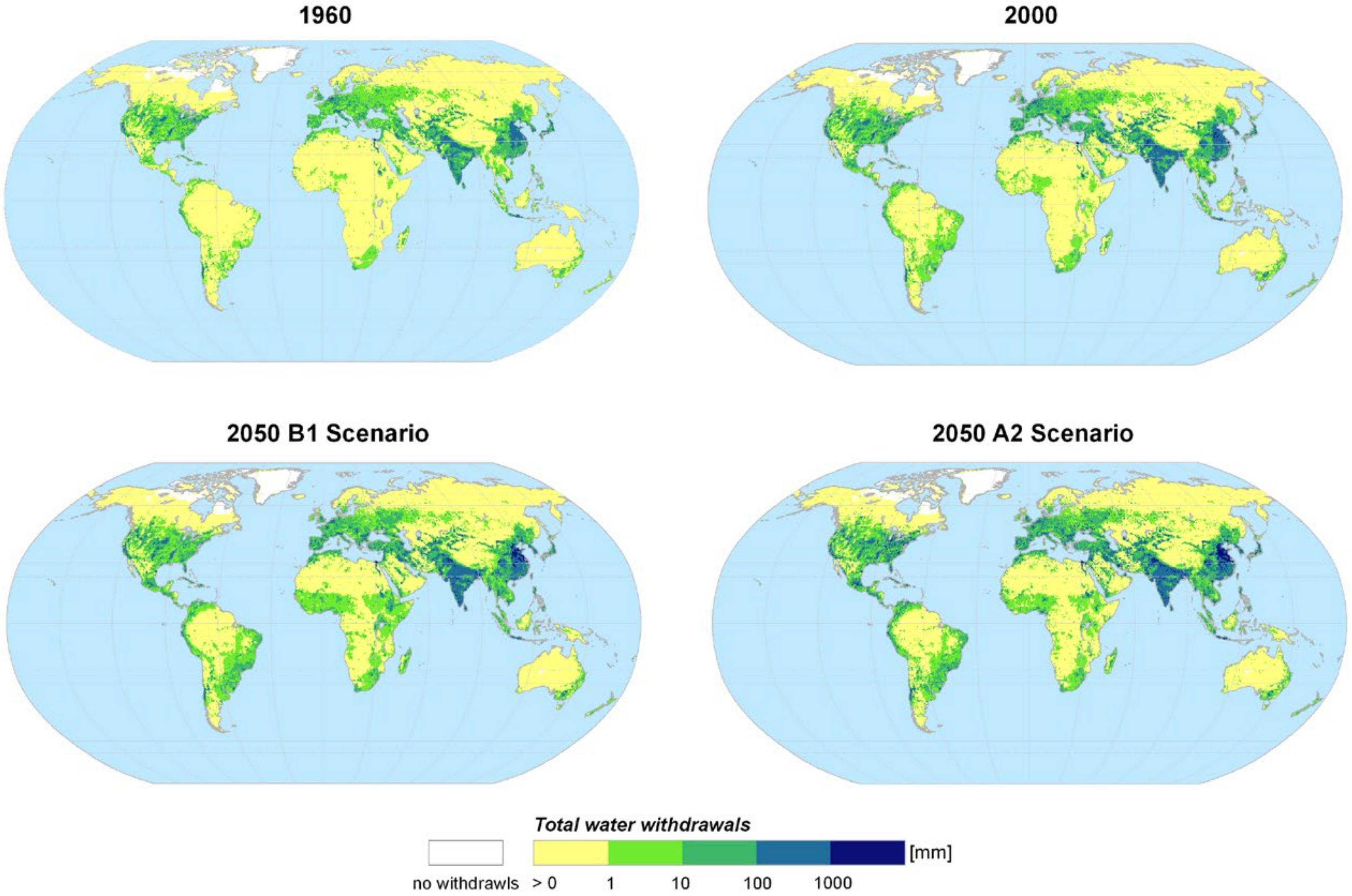

Figure 6 Past, present and future total water withdrawals.

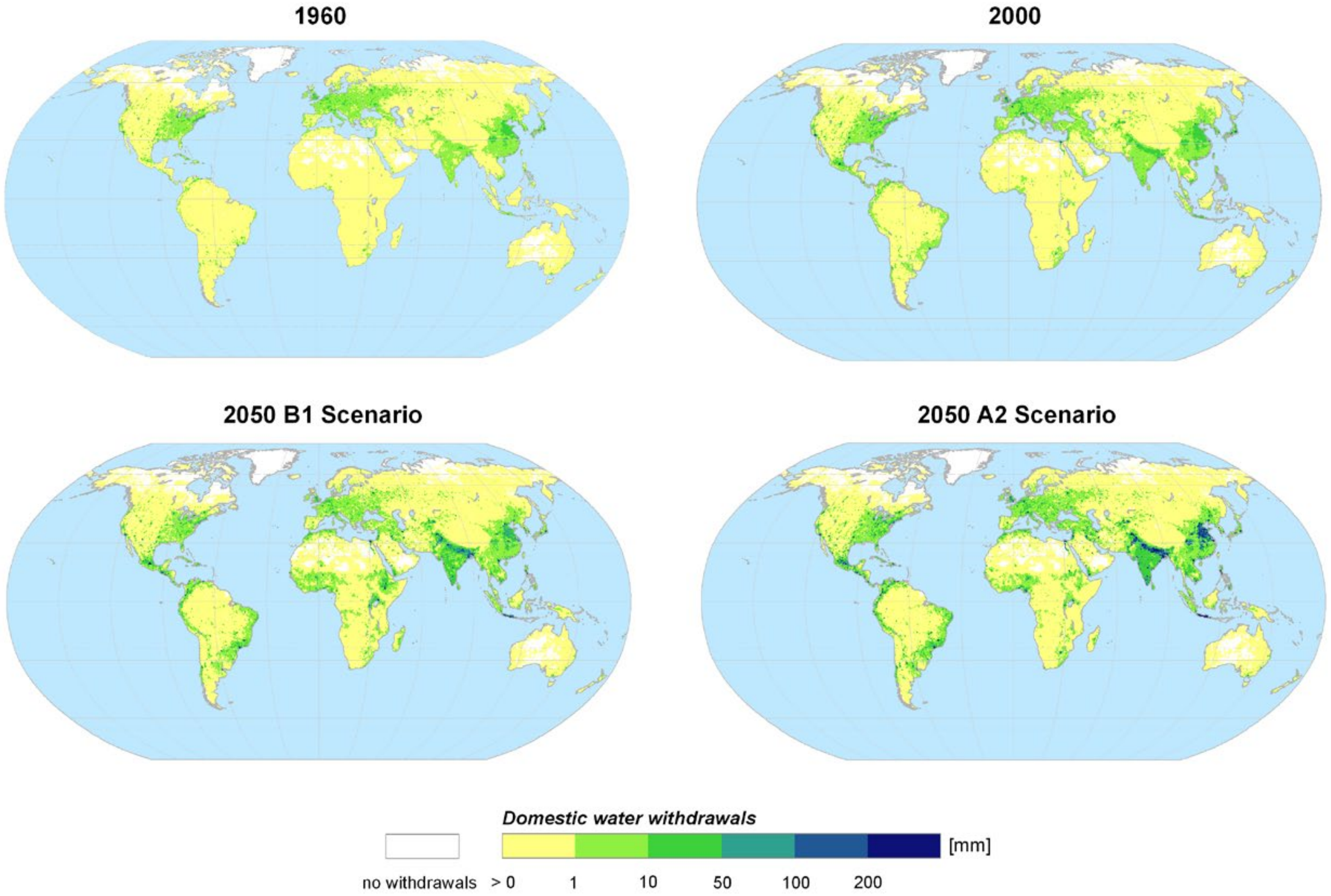

Figure 7 Past, present and future water withdrawals in the domestic sector.

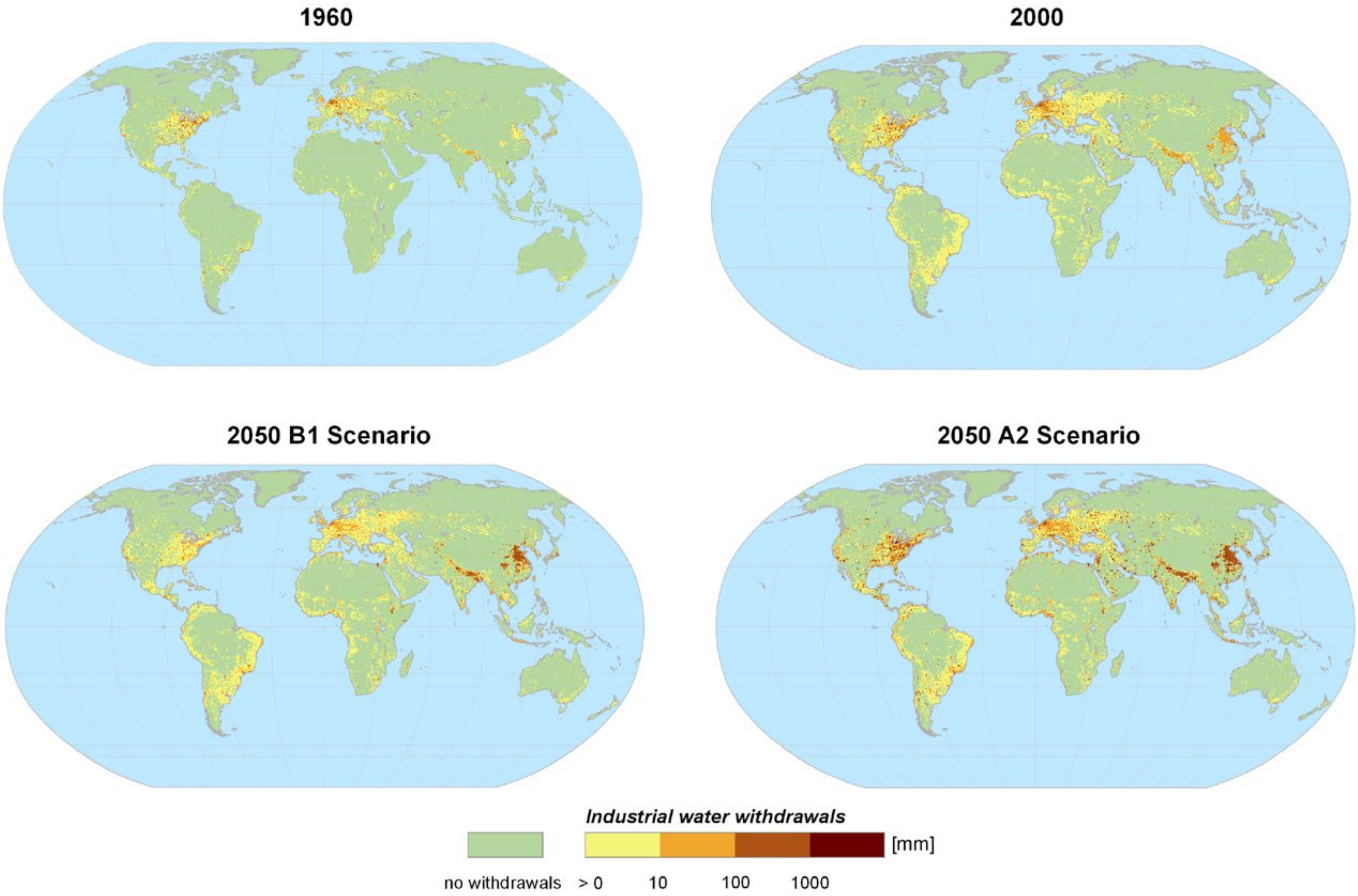

Figure 8 Past, present and future water withdrawals in the industry sector.

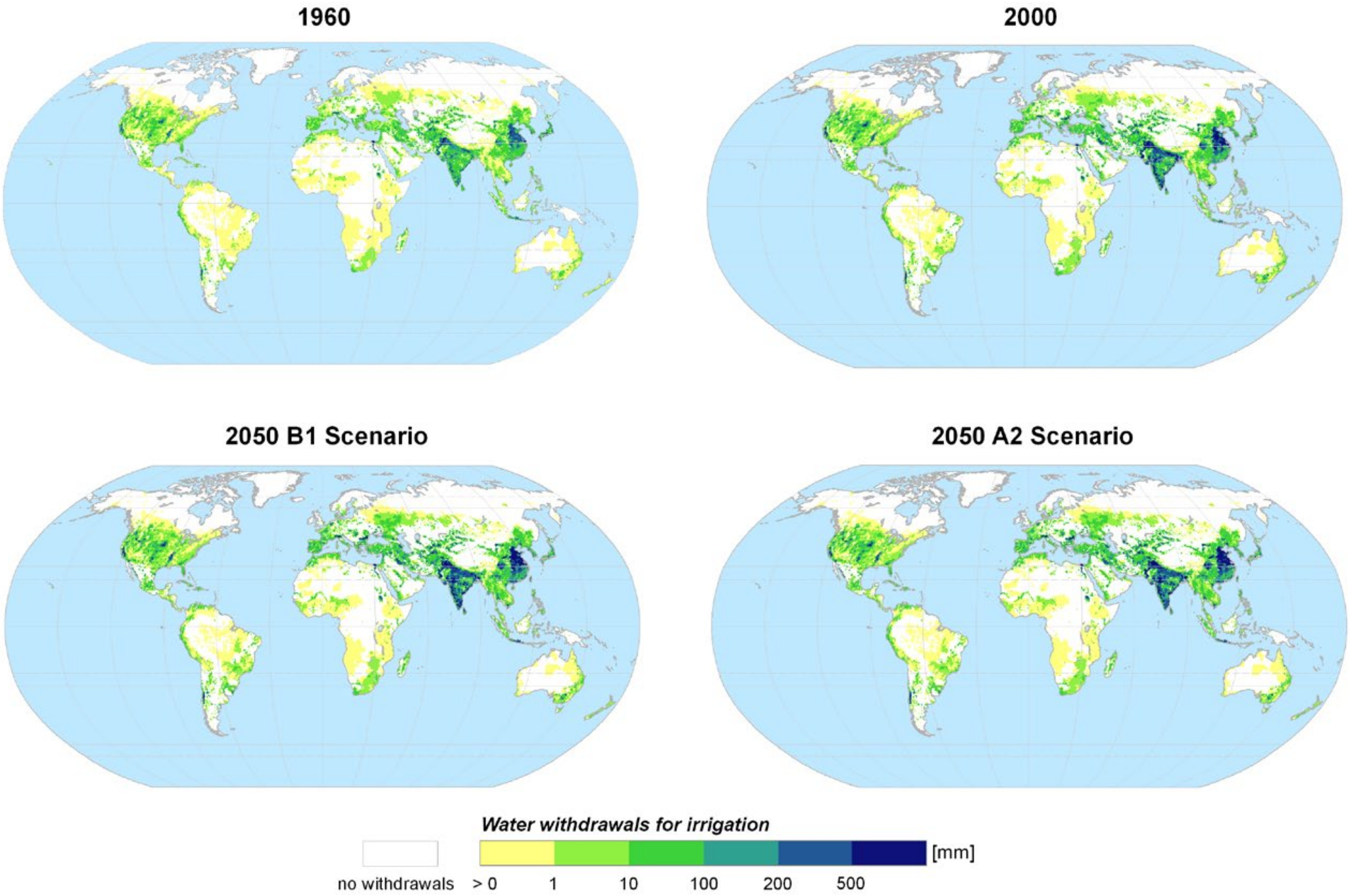

Figure 9 Past, present and future water withdrawals for irrigation purposes.

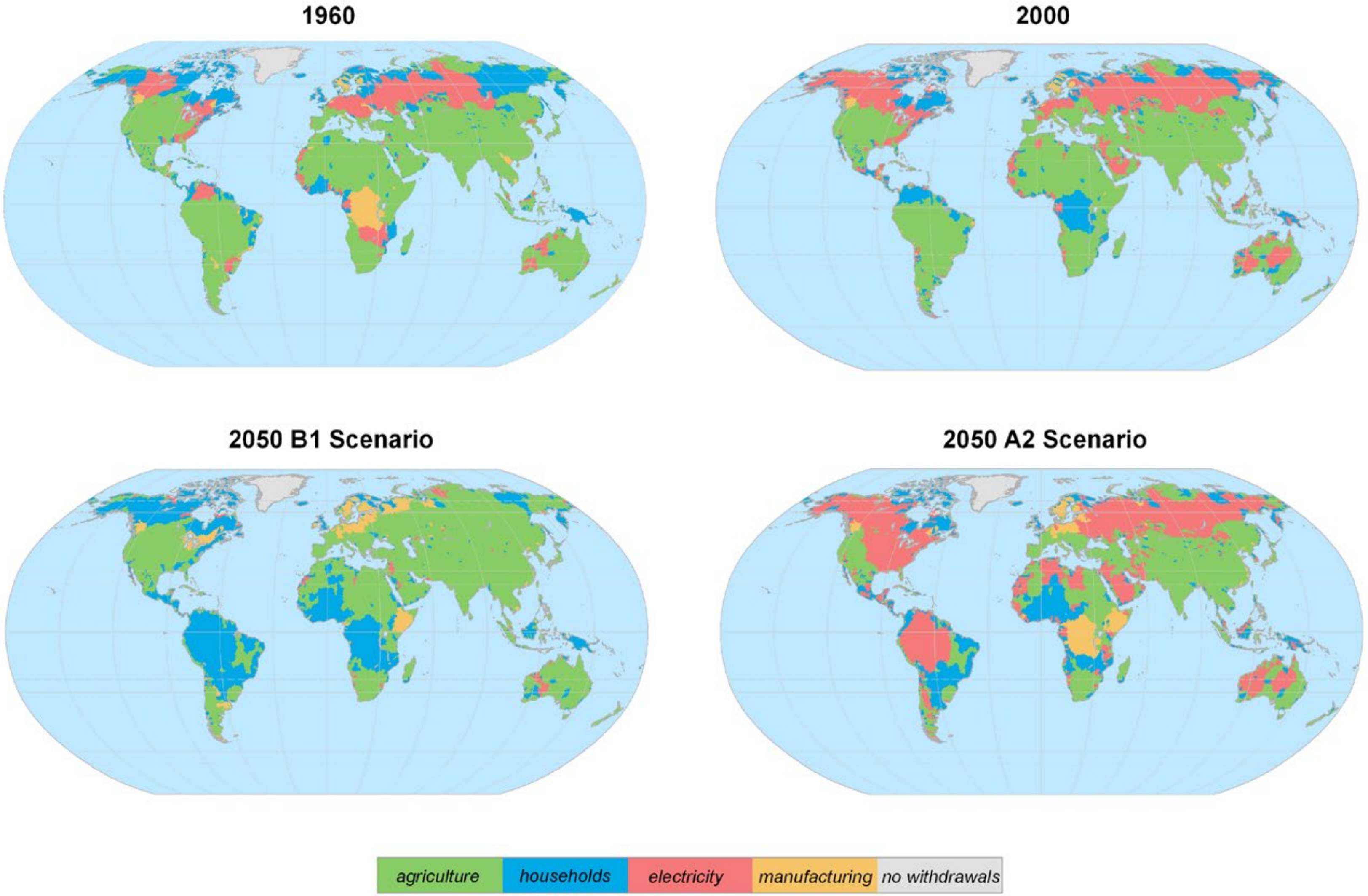

Figure 10 Most important water use sector per river basin as calculated for the past, present and future.

4. Uncertainty and Vulnerability

Uncertainty

Observed climate and hydrological characteristics are used to constrain climate model projections and for model calibration and validation. Here, a high degree of agreement between model simulations and observations considerably increases the confidence in the models' capability to make future projections. However, all observations suffer from measurement errors, they are not spatially and temporally homogenous, consistent and complete. Differences between observational data sets could be very large (McAvaney et al. 2001). In addition, very often observations cannot be used directly, as the applications they were established for require much lower precision than needed for climate change estimations and projections (Wunsch et al. 2007). With regards to climate change projections three main sources of uncertainty can be distinguished:

- The projections of anthropogenic emissions are maybe the largest single source of uncertainty, because neither the quantity of these emissions nor the response of the climate system to this forcing is known. Projections concerning the first variable require many assumptions about future population, socio-economic development and technical changes and their relationships and feedbacks (e.g., Wigley et al. 1996; Nakicenovic and Swart 2000).
- Climate models are the most credible tools available to construct consistent future climate change projections. Yet, they are source of considerable uncertainties due to incomplete, missing or incorrect representation of some processes and poorly constrained parameters (e.g., Katz 2002; Murphy et al. 2004).
- Model uncertainties can be partly resolved, using ensembles of simulations of one model with different scenarios and initial conditions or ensembles of simulations of different climate and hydrological models, forced with different scenarios. Projections based on the use of multi-model ensembles are considered to be more reliable than projections produced by single models alone, as a multi-model average or median simulates past and present climate features better. It should be noted, however, that a multi-model ensemble may share common systematic errors (Lambert and Boer 2001,) because entire processes are omitted and there are gaps in understanding of the physics or models may compensate errors in one process or parameterization with errors in other processes or parameterizations (e.g. Murphy et al. 2007), simulating as a result realistic present climate. Therefore, these possible not-quantified uncertainties have to be taken into account in addition to quantified ranges in order to avoid overestimation of the capability of current state-of-the art models to make future projections.

In order to address uncertainty related to climate change projections in WATCH, bias-corrected transient time series of precipitation and temperature were generated for the time period 1958 to 2100 (see Technical Report No 22, Piani et al. 2010 a, b, Hagemann et al. 2011). Based on the outcomes of the WATCH Forcing Data (WFD) future climate change projections were bias-corrected, respectively. In particular, WATCH provides climate information obtained through running multiple (three) climate models ("ensembles") with the intention to improve the accuracy and reliability of climate projections. Here, the output is a range of future projections generated globally at 0.5 x 0.5 arc degree spatial resolution using three different Global Climate Models (GCMs) forced by the IPCC SRES A2 and B1 emission scenarios. To cover the uncertainty in climate related data the climate output from these GCMs was selected to drive the hydrological simulations used for identifying vulnerable regions (hot spots).

The future of the world's freshwater resources will be influenced by a combination of many important environmental, social, and policy drivers, such as global (incl. climate) change, population growth, land use change, economical and technological developments. One way to open the window into a future world, as also done here, is to utilise scenarios. They offer the possibility to develop plausible descriptions of how the future may unfold, based on a coherent and internally consistent set of assumptions about key relationships and driving forces. Scenarios provide alternative views of the future but they are ***not predictions*** nor should they be taken as the most likely of the numerous possible futures. At most, they draw pictures of a limited number of plausible futures, based upon a coherent and internally consistent set of assumptions about choices by key actors, the progression of social processes, and underlying system relationships (Robinson 2003). By using scenarios possible future developments can be explored and strategies to influence those potential developments can be tested.

Vulnerability

In order to identify vulnerable regions where the fulfilment of human water demand is at risk or may become at risk in the future the concept of “water stress” is used. With this approach the average conditions of water resources can be easily compared. Here, water stress is a measure of the amount of pressure put on water resources and aquatic ecosystems by the users of these resources, including households, industries, thermal power plants and agricultural users. For calculating past, present and future water stress the withdrawals-to-availability ratio is used (w.t.a.). This indicator has the advantage of being transparent and computable for all river basins and has been used in several studies, for example Alcamo et al. (2007), Alcamo and Henrich (2002), Vorösmarty et al. (2000), or Cosgrove and Rijsberman (2000). Generally speaking, the larger the volume of water withdrawn, used, and discharged back into a river, the more it is degraded and/or depleted, and the higher the water stress. At the same time, increasing water stresswill intensify the competition for water between society’s users and between society and ecosystem requirements (Raskin et al., 1997; Alcamo et al., 2003a). A drainage basin is assumed to be under low water stress if w.t.a. ≤ 0.2; under medium water stress if 0.2 < w.t.a. ≤ 0.4 and under severe water stress if w.t.a. > 0.4.

Water stress includes both, the pressure on water resources caused by climate change, in the sense that climate change could lead to reduced average water availability, and by the impacts of socio-economic driving forces, i.e. leading to increased water abstractions. Total and sectoral water withdrawals are comprehensively described in section 3 and hydrological model runs were carried-out forced by climate input developed within the project. Here, the average water resources available in drainage basins for the past, present and future were calculated over the long-run, i.e. for the 1960s (represented by the time period 1956-1985), present (represented by the time period 1971-2000), and 2050s (represented by the time period 2036-2065).

Among its other characteristics, water is a transportable substance. It can be distributed and made available to users at some distance from its source. But most of the runoff generated within a drainage basin is distributed and used within the same basin because the alternative – pumping water over the hills and mountains on its edges – is usually technically too difficult and/or expensive. Freshwaters within a basin are often stored in reservoirs and distributed within a basin by gravity flow. Hence a part of a drainage basin with more runoff can compensate for another part of the basin with less runoff, and the total discharge over drainage basin area is an approximate measure of the water available to the population in the basin.

Figure 11 shows the withdrawals-to-availability ratio for the river basins of the world. Water stress is divided into “low”, “medium” and “severe” classes according to commonly-used thresholds given before. In principal river basins classified to be under “severe water stress” are mainly located in regions where total water withdrawals are highest and/or in arid areas. For the year 2000, this includes large parts of India, Northern China, Central Asia, a few river basins in North Africa and Europe, Western Latin America, a large part of the Western United States, Northern Mexico, and south-east Australia. 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 a level of severe water stress indicates strong competition for water resources during dry years between households, industry and agriculture.

Less river basin area was under severe water stress in the year 1960, as expected. Nevertheless, severe water stress occurred in Northern China, Southern India, Central and South Asia, a few river basins in North Africa, Texas and California, and Western Latin America.

When analysing global change impacts on water stress up to the medium time scale (~2050) the differences between climate scenarios forced by different emissions scenarios are relatively small since the different emission pathways into the future start to diverge in the second half of the century. Moreover, at this time scale a meaningful combination with socio-economic scenarios is advisable to span a variety of possible futures. In order to address internal climate variability as well as model uncertainties ensemble simulations were carried-out.

The six maps in Figure 11 present the computed water stress maps for the two socio-economic scenarios (A2 and B1) under the CNCM3-A2 climate (upper right), CNCM3-B1 climate (upper left), ECHAM5-A2 climate (middle right), ECHAM5-B1 climate (middle left), and IPSL-A2 climate (lower right) and IPSL-B1 climate (lower left). All scenarios show stressed areas under the 2050s scenario conditions. By comparing the left side and right side maps it is clearly evident that the number of river basins under severe water stress is much larger under the A2 scenario than under the B1 scenario developments. In this context, the area in the severe water stress class increases tremendously in the A2 scenario compared to the B1 scenario as a result of the increasing water withdrawals. On the other side, decreasing water withdrawals as expected in the B1 scenario lead to reduced water stress and hence less river basins in the severe water stress class.

However, the spatial pattern of water stress, i.e. the future location of water stress, depends on the GCM employed for water availability calculations. When comparing the A2 driven scenario results as based on three different GCMs (right side scenario maps) it becomes obvious that the results for water stress are in good agreement for most parts of the world except for Africa. Especially on this continent the disagreement is quite high, reaching from almost no water stressed river basins (CNCM3-A2 scenario) to large parts being in the severe water stress class like Northern and Eastern Africa (IPSL-A2 scenario). Taking into consideration the regions of agreement rising water stress is more likely in Asia, Europe, and North America. For the B1 scenario (left side scenario maps), the GCM related results disagree not only in Africa as in the A2 scenario but also in North America. As stated for the A2 scenario, the number of water stressed river basins on these continents is lowest for the CNCM3-B1 scenario and highest for the IPSL-B1 scenario.

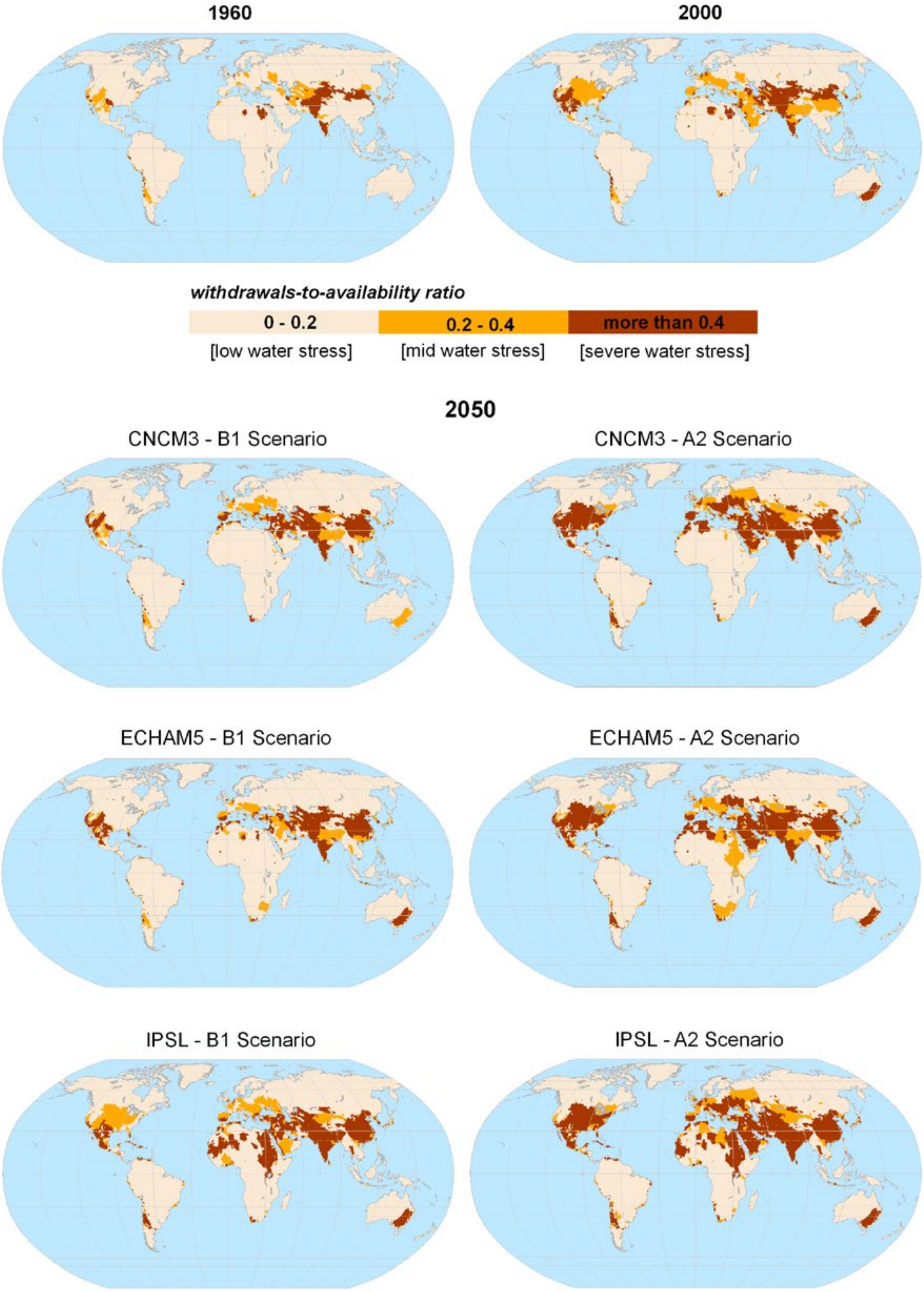

Figure 11 Water stress for the past, present and future. Future climate input was calculated by three different GCMs.

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