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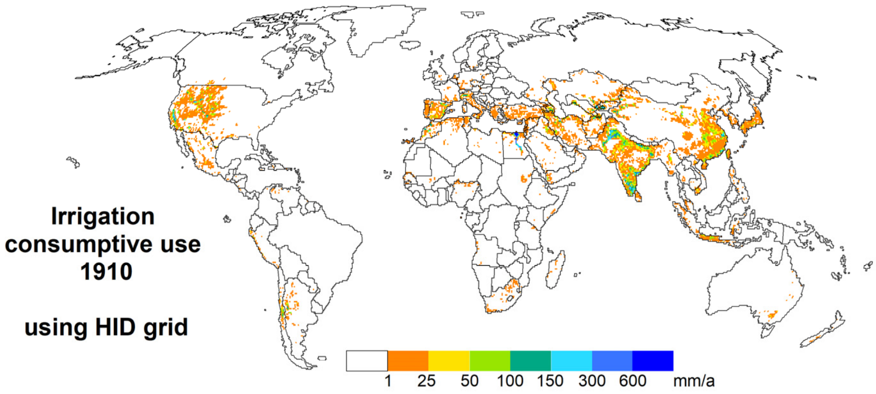
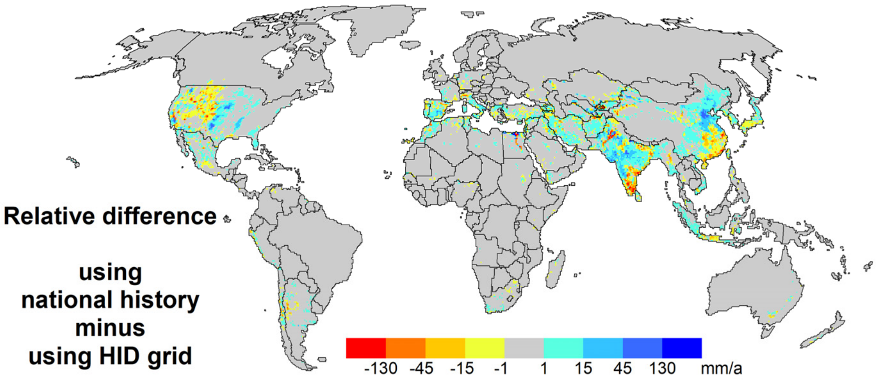
Global irrigation in the 20th century: Extension of the WaterGAP Global Irrigation Model (GIM) with the spatially explicit Historical Irrigation Data set (HID)





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Global irrigation in the 20th century: Extension of the WaterGAP Global Irrigation Model (GIM) with the spatially explicit Historical Irrigation Data set (HID)

Masterarbeit

zur Erlangung des akademischen Grades Master of Engineering im

berufsbegleitenden Weiterbildungsstudiengang Geoinformatik

Hochschule Mainz

Fachbereich Technik

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Betreuer:
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Bearbeitungszeitraum: 01. September 2016 bis 28. Februar 2017

Standnummer: 182

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Task assignment / Aufgabenstellung

Prof. Dr.-Ing. Fredie Kern
University of Applied Sciences Mainz
School of Technologies
Geoinformatics and Surveying

Master Thesis

Global irrigation in the 20th century: Extension of the WaterGAP Global Irrigation Model (GIM) with the spatially explicit Historical Irrigation Data set (HID)

Study Course: Geoinformatics (M. Eng.)

Thesis-ID Number / Standnummer: 182

for Mister Portmann, Felix Theodor (Student-ID/Matrikel-Nr. 913417)

Task assignment

The Global Irrigation Model (GIM) (Döll and Siebert, 2002; Siebert, 2002) is used within the framework of the global hydrological model WaterGAP (Müller Schmied et al., 2014) to calculate, with grid cell resolution of 0.5 degrees, monthly values of irrigation crop water use, as consumption (ICU) and water withdrawal (IWU), currently with the static Global Map of Irrigation Areas (GMIA). The model distinguishes cropping periods of rice and non-rice crops, each grown for 150 days, and up to two times a year. Based on these cropping periods of a reference climate period, ICU for consecutive years is calculated with monthly or daily climate forcing. Via country-specific national scaling factors for each year, historic development of maximum extent (“area equipped for irrigation”, AEI) and area actually irrigated (AAI) are superimposed on the results. Finally, dividing ICU by region-specific irrigation efficiencies results in IWU.

Main task of this Master Thesis is to refine the GIM in addition to the traditional conceptual mode using the country-specific national AEI scaling with a fixed reference year, a new mode using the newly available grid-cell specific AEI for 14 time slices between reference years 1900 and 2005 of the “Historical Irrigation Data set“ (HID) (Siebert et al., 2015). For the calculation of cropping periods, country-specific harvested area of irrigated rice and average climate has to be provided. Furthermore, cell-specific ratios AAI/AEI of year 2005 delivered with GMIA version 5 (Siebert et al., 2013a, 2013b) provide a spatially explicit estimate to possibly substitute the currently implicit country-specific national factors. This allows as secondary tasks (1) the comparison of results of the two modes for selected years (spatial pattern and water use totals for administrative units), (2) the testing the sensitivity of the results on cropping periods from different average climate, (3) the validation of the results with external subnational water use data available for the United States of America (USA).

The following steps have to be performed:

1. Refine GIM and redesign his implementation code and associated shell scripts
    a. Conceptual design of appropriate structure of code and scripts, depending on the input data and desired outputs
    b. Encoding in C^{++} and shell scripts
2. Input data preprocessing and discussion,
   e.g. aggregation from 5 arc-min to 30 arc-min
3. Analysis and presentation of results for selected years
4. Validation with external data for USA

Processing period: 01st September 2016 – 28th February 2017

Supervisors: Prof. Dr.-Ing. Fredie Kern
PD Dr. Stefan Siebert (University of Bonn)

Mainz, 01st September 2016

Place, Date
Prof. Dr.-Ing. Fredie Kern

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Abstract

The Global Irrigation Model (GIM) (Döll and Siebert, 2002) is used within the framework of the global hydrological model WaterGAP (Müller Schmied et al., 2014) to calculate monthly values of irrigation crop water use. Results are on a 0.5 degrees grid and include, consumption (ICU) and, via division by irrigation efficiencies, water withdrawal (IWU). The model distinguishes up to two cropping periods of rice and non-rice crops, each grown for 150 days, using a grid of area equipped for irrigation (AEI). Historical development of AEI and fraction of area actually irrigated (AAI) was previously considered via scaling of cell-specific results with country-specific factors for each year. In this study, GIM was adapted to use the new Historical Irrigation Data set (HID) with cell-specific AEI for 14 time slices between 1900 and 2005. AEI grids were temporally interpolated, and using the optional grid of AAI/AEI, results for years 1901-2014 were generated (runs "HID-ACT"). Thus, new installation or abandonment of irrigation infrastructure in new grid cells can be represented in a spatially explicit manner. For evaluated years 1910, 1960, 1995, and 2005, ICU from HID-ACT was superior to country-specific scaled results (run "HID-ACTHIST") in representing historical development of the spatial pattern. Compared to US state-level reference data, spatial patterns were better, while country totals were not always better. For calculating the cropping periods, 30-year climate means are needed, the choice of which was found to be relevant. Four chosen periods before 1981-2010 all resulted in considerable, pertaining changes of ICU spatial pattern, and various percent changes in country totals. This might be because of already present climate change.

The new GIM code provides much more flexibility for studies at runtime. Even if the historical AEI development is best represented via HID, still uncertainty exist about the sensitivity on, e.g. the choice of different AEI products for current and future conditions.

Possible topics for future studies with the new GIM version might include quantification of the sensitivity of ICU ACT, e.g.

(1) For a current reference year to the choice of AEI, e.g. HID HYDE vs. HID Earthstat, GMIA4, or GMIA5, to evaluate implications for calculations of present-day conditions,
(2) For its historical development to the choice of AEI, e.g. HID-AEI_HYDE_FINAL_IR (year 2005) and HID-AEI_EARTHSTAT_IR (2005) or the whole range of HID products,
(3) For its historical development to different climate forcing, perhaps also the sensitivity of the shares of all water uses or of renewable water resources as calculated by Müller Schmied et al. (2016a),
(4) Using selected climate projections to the choice of AEI, like (1), to evaluate implications for projections to the future.

Future data or code development may include:

(1) Generation of year-specific time series of harvest area of irrigated rice (AHI Rice) from census statistics, replacing the country-specific scaling of AHI Rice from MIRCA2000,
(2) Introduction of optional grid-cell-specific deficit irrigation factor,
(3) Introduction of permanent crops as a new cropping pattern, with kc-value parametrization and/or grid-cell specific presence supported by grid-cell specific majority class of permanent crops in MIRCA2000,
(4) Introduction of additional temperature sums for the ranking of growing periods.

Keywords: GIS, Global Irrigation Model (GIM), Historical Irrigation Data set (HID), Irrigation, Water use, Irrigation consumptive use, Net irrigation water requirement, Irrigation efficiency, WaterGAP (Water – Global Analysis and Prognosis), Global Map of Irrigation Areas (GMIA), MIRCA2000

Zusammenfassung

Das globale Bewässerungsmodell GIM (“Global Irrigation Model”) (Döll and Siebert, 2002) wird im Rahmen des globalen hydrologischen Modells WaterGAP (Müller Schmied et al., 2014) genutzt, um monatliche Werte des Bewässerungsbedarfs zu berechnen. Ergebnisse auf einem 0,5 Grad Gitter sind konsumtiver Bedarf (ICU) und, über die Division mit Bewässerungseffizienzen, gegebenenfalls auch Entnahmebedarf (IWU). GIM unterscheidet bis zu zwei Anbauperioden von Reis- und Nicht-Reis Kulturen von je 150 Tagen Dauer pro Jahr, unter Nutzung der für die Bewässerung ausgerüsteten Fläche (AEI), die als Gitter vorliegt. Die historische Entwicklung der AEI und der tatsächlich bewässerten Fläche (AAI) wurde bislang über eine Skalierung der zellspezifischen Ergebnisse mit länderspezifischen Faktoren berücksichtigt. In der vorliegenden Arbeit wurde GIM erweitert zur Anwendung des neuen Historical Irrigation Data set (HID), der zellspezifische AEI für 14 Zeitscheiben zwischen 1900 und 2005 angibt. Durch eine Interpolation für die Jahre dazwischen können nun Zeitreihen von 1901-2014 berechnet werden. Optional kann ein Gitter des AAI-Anteils berücksichtig werden (Läufe „HID-ACT“). Hierdurch können die neu hinzugekommenen oder aufgelassenen Bewässerungsinfrastrukturen in weiteren Gitterzellen räumlich explizit berücksichtigt werden. Für die ausgewerteten Jahre 1910, 1960, 1995 und 2005 war das räumliche Muster des ICU von HID-ACT besser als jenes mit länderspezifischer Skalierung (Lauf „HID-ACTHIST“). Das galt auch für den Vergleich mit Summen der Bundesstaaten der USA, wobei die Ländersumme nicht immer besser war. Für die Berechnung der Anbauperioden werden Klimamittelwerte benötigt, bei welcher die Wahl des 30-Jahres-Zeitraumes einen wichtigen Einfluss ausübt. Für vier ausgewählte Perioden vor 1981-2010 ergab sich ein deutliches und wiederkehrendes Muster der räumlichen Abweichungen, bei unterschiedlichen prozentualen Abweichungen in den Ländersummen. Eine mögliche Ursache könnte eine schon vorhandene Klimaänderung sein.

Der neue GIM Code ermöglicht deutlich größere Flexibilität bei Programmausführung. Auch wenn HID die historische AEI-Entwicklung am besten darstellt, gibt es Unsicherheit darüber, wie sensitiv die Simulations-Ergebnisse etwa auf die Wahl eines AEI-Produktes für heutige und zukünftige Zeitperioden reagieren.

Mit der neuen GIM-Version könnte in weiteren Studien beispielsweise die Sensitivität von ICU ACT untersucht werden in Abhängigkeit von z.B.

(1) Für ein Referenzjahr: von der AEI-Wahl, z.B. HID HYDE im Vergleich zu HID Earthstat, GMIA4 oder GMIA5, um die Auswirkungen auf Berechnungen für die Bedingungen eines aktuellen Zeitraumes zu untersuchen,
(2) Für die historische Entwicklung: von der AEI-Wahl, z.B. HID HYDE im Vergleich zu HID Earthstat, oder die ganze Breite der HID-Produkte,
(3) Für die historische Entwicklung: von der Wahl der Klimazeitreihen, eventuell auch die Unterschiede in relativen Anteilen an der Wassernutzung oder den erneuerbaren Wasserressourcen gemäß Müller Schmied et al. (2016a),
(4) Mit ausgewählten Klimaprojektionen von der Wahl der AEI wie in (1), um die Auswirkungen auf Berechnungen zukünftiger Zeiträume zu untersuchen.

Weitere Entwicklungen zu Daten oder Code könnten umfassen:

(1) Erstellen der Zeitreihe der Erntefläche von bewässerten Reis (AHI Reis) aus Agrarstatistiken statt der länderspezifischen Skalierung von MIRCA2000-Summen,
(2) Einführung eines optionalen zellspezifischen Faktors für Defizit-Bewässerung,
(3) Einführung von Dauerkulturen als neues Anbaumuster, Parametrisierung der kc-Werte oder zellspezifischen Präsenz in Abhängigkeit der Majorität von MIRCA2000-Dauerkulturklassen,
(4) Einführung von zusätzlichen Temperatursummen bei der Rangbildung der Anbauperioden.

Schlagwörter: GIS, Global Irrigation Model (GIM), Historical Irrigation Data set (HID), Bewässerung, Globales Bewässerungsmodell, Wassernutzung, Konsumtiver Bewässerungsbedarf, WaterGAP (Water – Global Analysis and Prognosis), Global Map of Irrigation Areas (GMIA), MIRCA2000

Table of contents

List of figures

List of tables

1. Introduction

1.1 Role of irrigation and of modeling context

Irrigation has an important role in the domains of meteorology, hydrology, and agriculture. From the meteorological point of view of Global Climate Models (or General Circulation Models, GCMs), irrigation modifies the behavior of the land surface which, in turn, significantly influences the surface energy balance and water cycle, and thus, the climate (Cook et al., 2015; Cook et al., 2011; Mahmood et al., 2014). In GCMs, irrigation was found to have nearly no effect on global top of the atmosphere mean radiative balance, but on a reduction of global surface air temperature over land, while regional warming trends are reduced (Cook et al., 2015; Cook et al., 2011). There are contradicting trends on net longwave radiation: An increase through irrigation-induced cooling of the surface which reduces the upward longwave radiation, and an increase though irrigation-induced increase in cloud cover which enhances shortwave reflection. The former is dominating in northern India, the latter in Central Asia and China (Cook et al., 2015). In an atmosphere-ocean interaction GCM experiment with varying vs. constant Sea-Surface Temperature (SST), local climate effects were found to remain similar, whereas non-local effects tended to be larger, especially over oceans (Krakauer et al., 2016). Local effects on coastal ocean may exist, e.g. as irrigation in California's Central Valley, through a decrease in land surface temperature, land-sea heat contrast, sea breezes, subsidence, lower tropospheric stability over the near coastal region and, hence, also in coastal stratocumulus cloud cover (Lo et al., 2013). Current knowledge about the effects of irrigation and land cover change on climate is summarized in the review of Mahmood et al. (2014). These authors state that there is still a lack of comprehensive understanding of irrigation effects at the regional scale on atmosphere and climate, e.g. via precipitation recycling. Nonetheless, irrigation should be considered as an important anthropogenic climate forcing in next generation of historical climate simulations and multi-model assessments (Cook et al., 2015).

In Global Hydrological Models (GHMs), water abstracted for irrigation is also considered to be important (Döll and Siebert, 2002; Wisser et al., 2008; Wisser et al., 2010; Wada et al., 2013; Wada et al., 2012). Irrigation water use accounts for about 60-70% of water withdrawals and 80-90% of water consumption (Döll et al., 2014; Döll et al., 2012). This is mostly "blue" water, i.e. freshwater from surface water bodies (lakes, rivers) or aquifers (about 30% and 40% groundwater share for withdrawals and consumption, respectively Döll et al., 2012). Blue water accounted for about 56% of crop evapotranspiration of irrigated crops and 18% of total crop evapotranspiration (period 1998-2002) (Siebert and Döll, 2010).

Also from the point of view of food security, agriculture and employment, irrigation is important: Irrigation of agricultural crops secures globally the food supply for humanity. In case of no irrigation considerable global production losses would occur for rice (38%), date palms (60%), cotton (38%), citrus (32%), and sugar cane (31%) (Siebert and Döll, 2010). Benefits are highest in arid and semi-arid areas, which often are located in developing countries. There irrigated agriculture provides income to a large number of persons, especially in rural areas where alternative sources of income are scarce (Siebert and Döll, 2010).

Thus, it is clear that to calculate correctly the water balance of a catchment, river basin, or a country, possibly assisted through hydrological modeling, it is important to know the crop water consumption (and ideally also their abstraction), in the past and in the future.

From all the crops, rice is an important water consumer in agriculture, e.g. in precipitation-limited Pakistan it accounts for the highest share in water consumption (Brauman et al., 2013). According to the global land use data set MIRCA2000 (Portmann et al., 2010), around the year 2000, rice accounted for around 40% of irrigated and 16% of rainfed harvested area in Asia. Globally, rice has by far the largest absolute irrigated harvested area of ca. 1.032 Mha (million hectares), contributing to about 63% irrigated share of harvested area. In contrast, wheat globally has only 667,000 ha irrigated harvested area and 31% irrigated share of harvested area, and in Asia 25% of irrigated and 12% of rainfed harvested area (Portmann et al., 2010). Therefore, the correct representation or modeling of irrigated rice contributes to a better estimation of the global agricultural water use, in GHMs (Döll and Siebert, 2002; Wisser et al., 2008; Wisser et al., 2010) and GCMs, possibly indirectly via GHM-based estimation (Krakauer et al., 2016).

For representing the historical development of water demand of agricultural irrigation (water abstraction for irrigation or water consumption from irrigated plants), there is often no reliable direct statistical data from agricultural census, whereas data on harvested areas of selected crops or area of agricultural land mostly exist. For the determination of the total or irrigation crop water requirement, especially for scenario calculations, e.g. under conditions of climate change or changed harvested or cropped areas, generally numerical models are used. An example is the Global Irrigation Model (GIM) (Döll and Siebert, 2002; Siebert, 2002) as the most important water use model of the global hydrological model WaterGAP2 (Water – Global Analysis and Prognosis) (Müller Schmied et al., 2014), based on a digital global map of areas equipped for irrigation (AEI), i.e. land area with infrastructure to provide water to crops or potentially irrigable areas, with an original spatial resolution of 5 arc-minutes, which was aggregated to 0.5 degrees (30 arc-min) used by the WaterGAP2 model. In previous studies, the spatial basic pattern always referred to a temporally constant reference dataset for a reference period, the Global Map of Irrigation Areas (GMIA) (Siebert et al., 2013a, 2013b), while country-specific (national spatial units) scaling factors (Freydank and Siebert, 2008) were used to derive the historical development based on the constant pattern of spatial units. The same approach for a temporal reconstruction, but with older version GMIA 2.2, was performed with the WBMplus model (Wisser et al., 2010), which was used in a number of GCM studies (Cook et al., 2011; Puma and Cook, 2010), even with a linear extrapolation from 1901 back to 1850 (Cook et al., 2015). Both GHMs WaterGAP GIM and WBMplus, use a similar approach to calculate irrigation water demand from reference potential evapotranspiration and multiplication with crop-specific coefficients (Döll and Siebert, 2002; Wisser et al., 2008).

In contrast to GMIA, which is to a large extend based on administrative-level agricultural census statistics, the International Water Management Institute (IWMI) produced the Global Irrigation Area Map (GIAM) based on optical remote sensing of 1 km spatial resolution with an aggregation to 10 km (International Water Management Institute (IWMI), 2017; Thenkabail, 2010; Thenkabail et al., 2008; Thenkabail et al., 2006; Thenkabail et al., 2009; Thenkabail et al., 2010). Their areas are about 40% larger than GMIA 2.2, with largest differences in India (plus 36%) and China (plus 56%) (Wisser et al., 2008). Both GMIA and GIAM only represent conditions of the years 1999 (GIAM, Thenkabail et al., 2006), 2000 (GMIA 4.0.1, Siebert et al., 2007; Siebert et al., 2006), and 2005 (GMIA5, Siebert et al., 2013a, 2013b).

In contrast to GMIA and GIAM, the newly established Historical Irrigation Data set (HID) (Siebert et al., 2015) presents cell-specific AEI with an original spatial resolution of 5 arc-minutes for 14 time slices every 10-5 years between 1900 and 2005, promising better accuracy with improved data for both spatial and temporal domain.

In addition to that, the Area Actually Irrigated (AAI) may differ from AEI because of several reasons (see Chapter 2), but has to be used to compare the water use results with observed validation data. GMIA5 provides estimates of AAI for the year 2005 (Siebert et al., 2013b).

1.2 Scientific aim

The scientific task of this master thesis is to examine the hypothesis that the use of HID improves the estimation of the historical temporal development and spatial pattern of the irrigation water demand (possibly estimated water abstraction) against the previously used country-specific AEI scaling approach which scales the AEI grid of a reference year with a factor representing country-specific historical development on national level, relative to the reference year. It is also suspected that an improvement is also visible at the national level of country totals. For this purpose, results of an extended GIM version using HID with either spatially-explicit representation or country-specific scaling of the historical development of AEI are compared.

1.3 Structure of document

This document is structured as follows: After the introduction in this Chapter, the Global Irrigation Model (GIM) is introduced in Chapter 2. In the following Chapter 3, the data and methods for the analysis and recoding are presented, while Chapter 4 is dedicated to the specific GIM results and Chapter 5 to the validation of the results. The discussion in Chapter 6 concludes the main text before Chapter 7 with the references. In Appendix A, supplementary tables are presented. Appendix B includes comments about software engineering aspects and an overview of GIM code changes. Appendix C is dedicated to scripts used for starting GIM and data preprocessing, while Appendix D lists scripts and tools used for data postprocessing. Appendix E includes the poster, while the electronic Appendix F presents a homepage (HTML website) about the topic.

2. Description of the Global Irrigation Model (GIM)

2.1 Current model

WaterGAP (Water – Global Analysis and Prediction) consists of the WaterGAP Global Hydrology Model (WGHM) and water use models for five sectors (irrigation, domestic/household, livestock, manufacturing, and cooling water for thermal power plants) (Müller Schmied et al., 2014). The state-of-the-art global model has been used for the assessment of global water resources, including groundwater depletion, and impacts of climate change (Döll and Siebert, 2002; Döll et al., 2012; Döll et al., 2015; Portmann et al., 2013; Schewe et al., 2014; Siebert et al., 2013b). The Global Irrigation Model (GIM) (Döll and Siebert, 2002; Siebert, 2002) is designed to calculate net irrigation water requirement, also called irrigation water consumption or Irrigation Consumptive Use (ICU), i.e. the water that is lost due to crop evapotranspiration. Based on ICU, the water that has to be withdrawn to supply ICU at the field, the so called gross irrigation water requirement or Irrigation Withdrawal Use (IWU) can be directly calculated. Concerning shares of global water use, it is globally the most important water use model of WaterGAP, accounting for the aforementioned 60-70% of water withdrawals and 80-90% of water consumption (Döll et al., 2014; Döll et al., 2012). GIM has been developed to calculate ICU for the past (since the year 1901), but also for scenarios of future climate, i.e. climate change projections. Its ICU values, are used in a subsequent module of WaterGAP version 2.2, the GWSWUSE (GroundWaterSurfaceWaterUSE) together with water use from the other sectors and further information to derive monthly net abstractions from surface water and groundwater compartments, which are used in further modeling of WGHM (Figure 2.1).

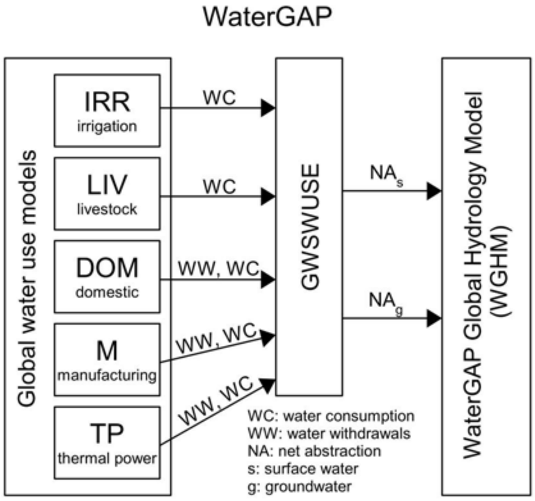


Figure 2.1: The relationship of the WaterGAP2.2 models for water use, groundwater and surface water shares, and hydrology (Müller Schmied et al., 2014)

In the following text of this subchapter, the most important technical details of the current GIM are described. More technical details are documented in Döll and Siebert (2002), whereas a sensitivity analysis has been performed in Siebert (2002).

The current GIM calculates ICU and IWU in a two-stage process:

(1) It first determines potential cropping periods (i.e. sequence of crops plus specific growing seasons) for two different crop types (rice and non-rice), considering potentially suited areas (areas equipped for irrigation AEI, areas topographically suited for rice growing), climate means, country-specific totals of harvested area of irrigated rice (AHI Rice), and overall cropping intensities. For this, monthly climate averages of shortwave radiation (RADIATION), temperature (T), precipitation (P) and number of rain days (NRD) together with distinction of arid and humid grid cells (ARID HUMID) for potential evapotranspiration (Epot, with Priestley-Taylor alpha factor explained at the end of this subchapter). Suited grid cells and possible extent is defined via grids of AEI and grid cells topographically suited for rice growing (TOPO RICE AREA). Country-specific harvested area of irrigated rice (AHI Rice) is distributed to the grid cells according to a prescribed country grid corresponding to a prescribed grid of regions of cropping intensities (REG_CI) for the listed cropping intensities (CI) used for the calculation of cropping periods (Figure 2.2).

(2) In a second step, GIM simulates potential evapotranspiration from monthly or daily weather data (“climate”) and the previously determined cropping periods are applied on climate input only for the desired time period to calculate irrigation water use, first net irrigation water requirement (Inet, ICU), then gross irrigation water requirement (Igross, IWU). Through scaling factors depending on spatial (country, i.e. national) units, the historical development of AEI, and possibly indirectly also AAI, can be superimposed, if desired (Figure 2.3). In addition to that, irrigation water use efficiencies are defined for spatial units (currently regions) which correspond to the ratio of Inet / Igross, i.e. ICU / IWU. Dividing Inet (ICU) by the efficiencies result in the gross irrigation water requirements Igross (IWU) which can be multiplied like Inet with historical development scaling factors (e.g. from Table A.6). The regions of cropping intensities are modified to obtain the regions of irrigation efficiency (REG_IE) for the listed irrigation efficiencies (IE) (Figure 2.3). The definition of Inet (ICU) is given in the next paragraph.

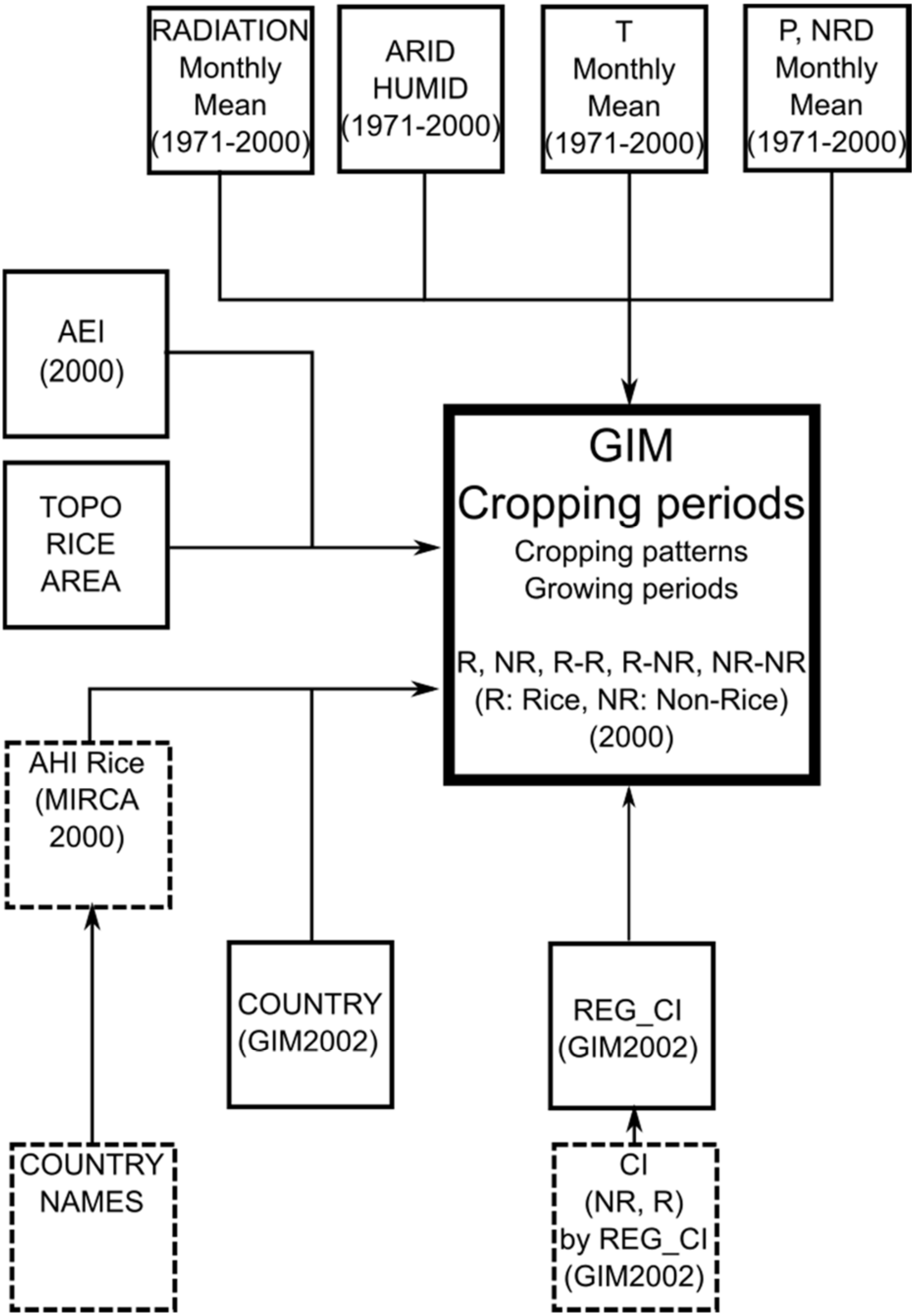


**Figure 2.2: Current GIM calculation step 1 (cropping periods)
and the related data flow of input and output data
(solid boxes mark grids, dashed boxes mark tables, bold box marks procedure and output)**

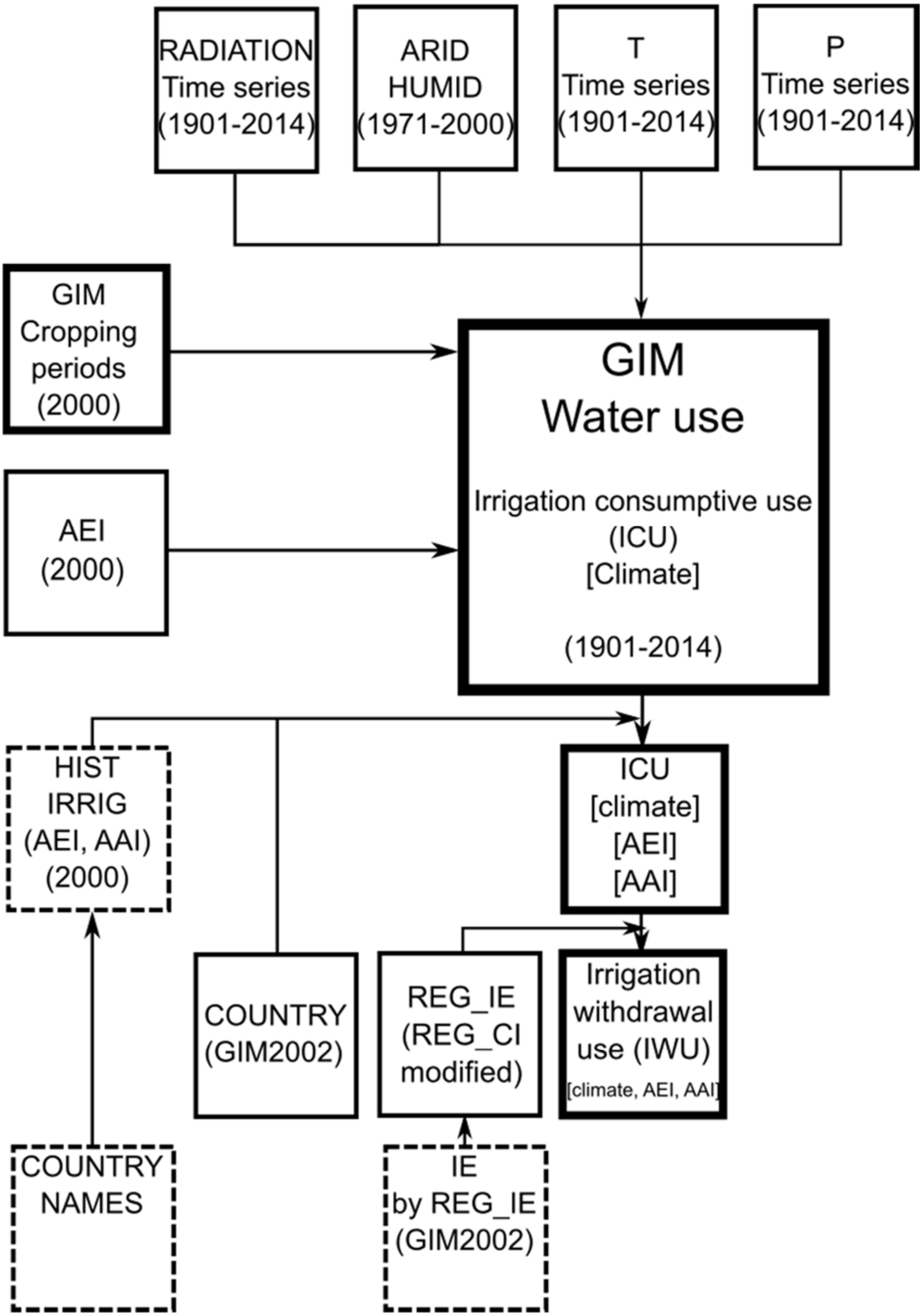


Figure 2.3: Current GIM calculation step 2 (water use) and the related data flow of input and output data (solid boxes mark grids, dashed boxes mark tables, bold boxes mark procedure, cropping periods input, and output)

GIM is based on the Food and Agriculture Organization of the United Nations (FAO) CROPWAT approach of Smith (1992) which computes for growing seasons (sometimes called cropping periods, too, e.g. in the MIRCA2000 land use data set Portmann et al., 2010) the net irrigation requirement per unit irrigated area (Inet or Irrigation Consumptive Use, all units as mm d^{-1}) as difference of crop-specific potential evapotranspiration ($Epot_c$) minus effective precipitation Peff, in case that $Epot_c$ is larger than Peff (Eq. 1, top). When $Epot_c$ does not surpass Peff, i.e. when enough precipitation is available to fulfill the evaporative demand of the plants, no irrigation requirement is assumed (Inet = 0) (Eq. 1, bottom). $Epot_c$ is derived as the product of potential evapotranspiration Epot times the dimensionless crop coefficient kc which depends on the crop development stage (Döll and Siebert, 2002).

$$Inet = \begin{cases} Epot_c - Peff = kc * Epot - Peff, \ Epot_c < Peff \\ 0, \ Epot_c \leq Peff \end{cases} \qquad \text{(Eq. 1)}$$

where

Inet: net irrigation requirement (Irrigation Consumptive Use) per unit area [mm d^{-1}]

$Epot_c$: crop-specific potential evapotranspiration [mm d^{-1}]

Peff: effective precipitation [mm d^{-1}]

Epot: potential evapotranspiration [mm d^{-1}].

Epot may be calculated from two different approaches within GIM, the Priestley-Taylor approach which uses a scaling “alpha” factor depending on climate to relate radiation to Epot, or the Penman-Monteith algorithm which uses, inert alia, also wind speed and saturation deficit. In the first approach each grid cell is attributed either as arid (alpha factor of 1.76) and humid climate conditions (1.26) (Shuttleworth, 1993). In this study, the first approach was used with the attribution being the result of multi-stage calculation for 1971-2000 with the same climate forcing was used as in other WaterGAP studies (Müller Schmied et al., 2014). This enabled the comparability in Epot and, thus ICU estimates across studies.

The effective precipitation Peff within the context of crop water balance modeling is the fraction of the total precipitation Ptot (including rainfall and snowmelt) which is available to plants (and thus agricultural crops) through infiltration, but which is not transformed to canopy evaporation, deep percolation or runoff. Several methods exist for the estimation of effective precipitation, e.g. (1) site-specific information on land cover, land use, soils, (2) simple assumptions, e.g. a fixed fraction of 70-90%, (3) stochastic or empirical relationships, e.g. based on precipitation exceedance (Smith, 1992). GIM uses the empirical relationship of the Unites States Department of Agriculture (USDA) Soil Conservation Service (SCS) Method, originally derived for monthly precipitation and used in the CROPWAT model (Eq. 2) (Smith, 1992):

$$Peff = \begin{cases} Ptot * \frac{(4.17 - 0.2 * Ptot)}{4.17}, \ Ptot < 8.3 \, mm \, d^{-1} \\ 4.17 + 0.1 * Ptot, \ Ptot \geq 8.3 \, mm \, d^{-1} \end{cases} \qquad \text{(Eq. 2)}$$

GIM and CROPWAT differ in terms of calculation time steps, which has to be considered when applying this formula (Döll and Siebert, 2002). While GIM uses daily time steps, CROPWAT uses three calculation time steps of 10 days within a month (differing only in crop coefficients kc) and monthly climatic data (including monthly precipitation sums). According to Döll and Siebert (2002), modeling with a daily time step while interpolating daily precipitation and evapotranspiration from monthly values (as one option in GIM) roughly corresponds to the CROPWAT approach. When applying Eq. 2 directly to daily precipitation sums, i.e. with wet days (precipitation) and dry days (no precipitation), Inet would be overestimated considerably, because the relatively high precipitation sums at wet days exceeding the daily $Epot_c$ would be lost from the soil water balance, whereas temporal averaging of precipitation effectively mimics the capacity of the soil to store the precipitation between wet days. To accordingly consider the storage capacity of the soil and remain consistent with related CROPWAT approaches, the daily precipitation sums are averaged over 10 days, irrespective of whether derived from interpolation, number of rain days per month, or direct daily data. A special 3-days period used only for rice in Asia results in a higher irrigation requirement and mimics the management and special conditions of paddy rice fields in Asia, where only small amounts of precipitation can be stored because of long-term field inundation and subsequent water-saturated soils (Döll and Siebert, 2002)

The crop coefficients kc are specific to crops and for typical stages of crop development (Allen et al., 1998; Doorenbos and Kassam, 1986; Steduto et al., 2012). GIM only represents two crop types, rice (R) and non-rice (NR), with up to two growing periods per year, each of 150 days length, with five possible combinations of sequences (cropping patterns), with one or two crops per year: R, NR, R-R, R-NR, NR-NR. The cell-specific sequence and installation depends on climatic conditions, e.g. minimum temperature and precipitation requirements, with the selection and ranking criteria as described in detail in Döll and Siebert (2002). The temporal sequence for a standard growing period is shown in Figure 2.4:

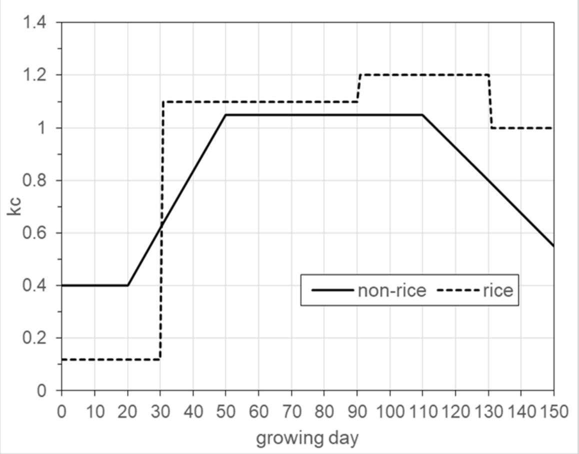


Figure 2.4: Crop coefficients kc for rice and non-rice agricultural crops, for individual 150-day cropping periods (redrawn for Frankfurt Hydrology Paper 18 following Döll and Siebert, 2002).

For rice, the crop coefficient kc representing optimal evapotranspiration is only 0.15 during the first 30 days, mimicking that only about 10% of the area is planted at the nursery stage, whereas during later stages much larger kc values occur, once the paddy rice seedlings are planted in the fields with continuous water coverage. Kc values larger than 1 occur because they are based on a reference evapotranspiration of grass. For non-rice crops, kc is only 0.4 during the initial stage with small plants, steadily increasing with plant growth and soil coverage up to a maximum of 1, and finally gradually decreasing after full ripening before harvest.

In GIM, for a given 0.5 degree (30 arc-min) grid cell with cropping periods, the daily net irrigation requirement Inet (ICU) during plant growth is the sum of Inet of both rice and non-rice, while the annual sum of Inet includes all selected cropping periods.

AHI of rice crop is distributed according to sums of the spatial units for a certain reference period, ideally consistent to the AEI. Through cropping intensities for 19 world regions, the respective total irrigated harvested area of rice and of non-rice crops is derived (see following subchapter and Table 3.1).

GIM limits the location of the irrigated crops to prescribed areas equipped for irrigation (AEI) at a 0.5 degree grid, potentially shifting crops from one grid cell to another to accommodate for a complete coverage of the harvested area (not shown in the Figures).

In a second step, the water use simulation, GIM computes potential evapotranspiration from monthly or daily weather data ("climate") and subsequent irrigation water use through the application of the cropping periods defined in the first step (Figure 2.3, Figure 2.5).

This approach with the currently applied kc values represents irrigation management with "full irrigation", i.e. without any limitation of water, whereas it is known that at least in some regions worldwide, "deficit irrigation" is applied, especially as often not enough water for full irrigation is available (Steduto et al., 2012). In a subsequent module of WaterGAP, the GWSWUSE (GroundWaterSurfaceWaterUSE), grid cells with suspected deficit irrigation are used to limit Inet_deficit to 70% of the full-irrigation Inet_full calculated by GIM. Furthermore, groundwater use fractions of irrigation, household and manufacturing sectors and return flows to groundwater and surface water from irrigation are considered as well as country-specific irrigation water use efficiencies, resulting eventually in net abstractions from surface water and groundwater storage compartments used in the WaterGAP Global Hydrology Model (Müller Schmied et al., 2014).

The sensitivity analysis of GIM of Siebert (2002) found three possible improvements of GIM, which are not part of this study:

(1) Use of calibrated alpha factor in the applied Priestley-Taylor equation for potential evapotranspiration (Epot).
The uncertainty of Epot as a key to ICU calculation should be kept in mind. The Priestley-Taylor approach (Priestley and Taylor, 1972) relies on one hand, easily available radiation and temperature data (McAneney and Itier, 1996), on the other hand, on the best guess of grid-cell specific differentiation for arid and humid climate conditions.

(2) Reduced runtime through deactivation of snow module when extensive simulation runs are performed.
This was not needed for the current simple simulations on a dedicated Linux system.

(3) Differentiation of non-rice crops for an improved definition of kc-values, with proposed introduction of permanent crops, and the substitution or refinement of temperature criterion in the ranking procedure of crop patterns and growing periods by the temperature sum concept.
This remains a highly attractive option for future development, in order to maintain the simulation capability for different situations in a changed climate.

2.2 Foreseen modifications of the model

GIM has to be adapted to be able to work in three different conceptual modes:

(1) The traditional mode where for one set of cropping periods using one reference year for AEI and AHI Rice (and a 30-year average climate), water use is calculated for several years, and potentially unit-specific (country-specific or national) scaling of AEI is applied for representing the historical AEI development.

(2) The new HID mode where (2.1) cropping periods for every year with an individual combination of year-specific AEI, year-specific AHI Rice, and respective climate average, e.g. for 30 years, are generated, and (2.2) water use is calculated only for the same year.

(3) In the original version of GIM, multi-annual statistics of ICU (minimum, medium, maximum, and quantiles of 75% and 10% for dry and wet years) are always calculated. As in HID mode (2.2), typically only one year is calculated, an explicit third separate conceptual mode for calculating these statistics on demand was introduced.

GIM code and files will be restructured to first calculate cropping periods for any individual combination of year-specific AEI, year-specific AHI Rice, and selectable 30-year average climate (Figure 2.5). To get regions for the calculated cropping periods, the year-specific country grid and a region attribute in the list of countries is used to generate appropriate year-specific regions of cropping intensities (REG_CI) for the listed cropping intensities (CI) (Figure 2.5). These basic data can be used in a second step either to calculate results only for the same reference year or for a number of freely selectable years. In addition to that, country-specific (national level) scaling can be applied to represent any future development of AEI or special conditions, e.g. scaling with ratios of Area Actually Irrigated (AAI) as grid-cell specific ratio. As in the current version, the regions of cropping intensities are modified to obtain the regions of irrigation efficiency (REG_IE) for the listed irrigation efficiencies (IE) (Figure 2.6).

AHI Rice for countries was taken from the MIRCA2000 data set, representative for the year 2000, and scaled according to AEI country totals for the years under consideration. This procedure was considered to result in AHI Rice with the highest consistency to AEI within the limited time and personal resources. In a future step, AHI Rice may be provided from a mixture of historical statistics on total (irrigated and rainfed) area harvested (AH) of rice and an estimated AHI Rice / AH Rice share, potentially assisted with the scarcely available time series or estimations of AHI Rice.

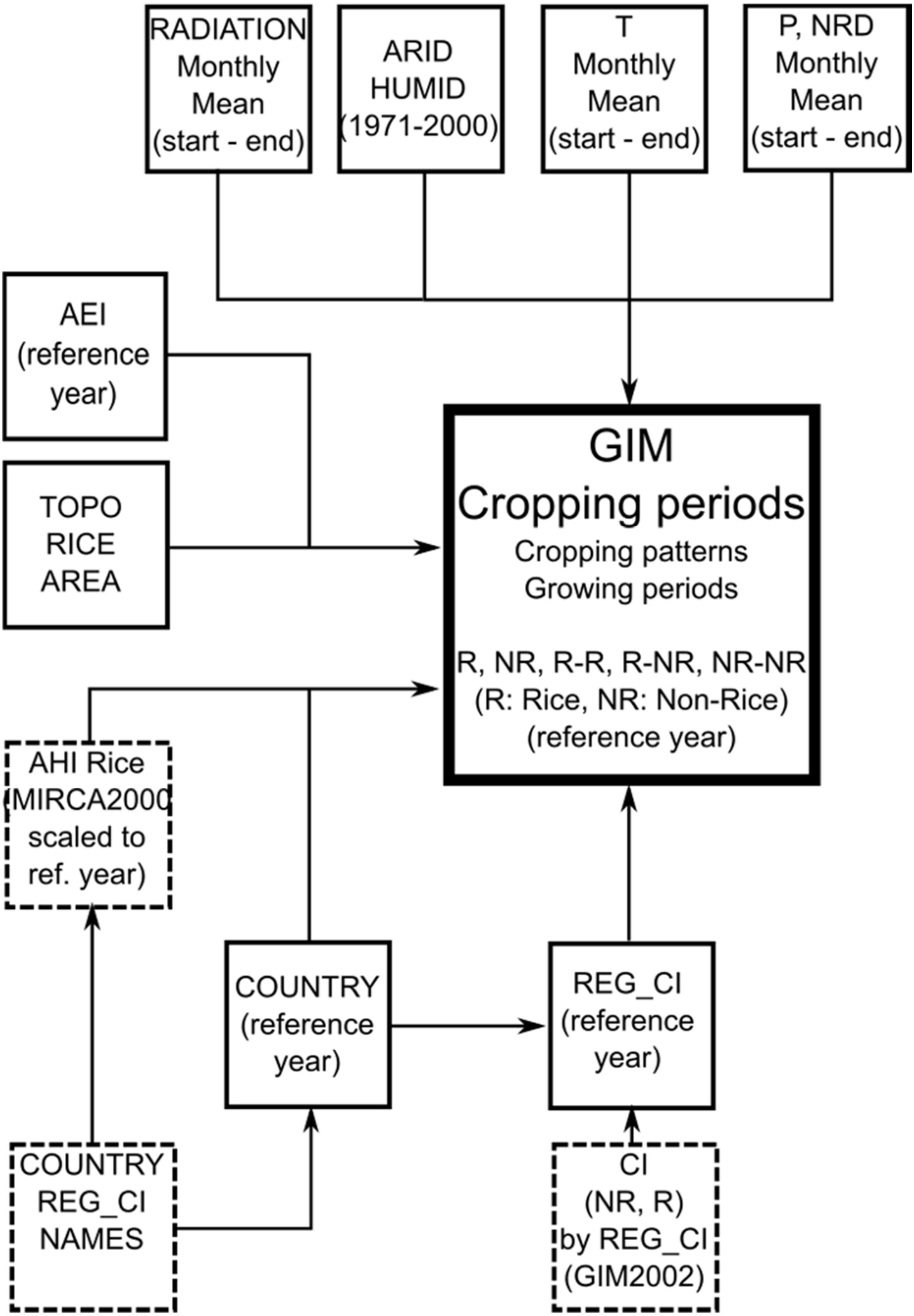


Figure 2.5: Refined GIM calculation step 1 (cropping periods) and the related data flow of input and output data (solid boxes mark grids, dashed boxes mark tables, bold box marks procedure and output)

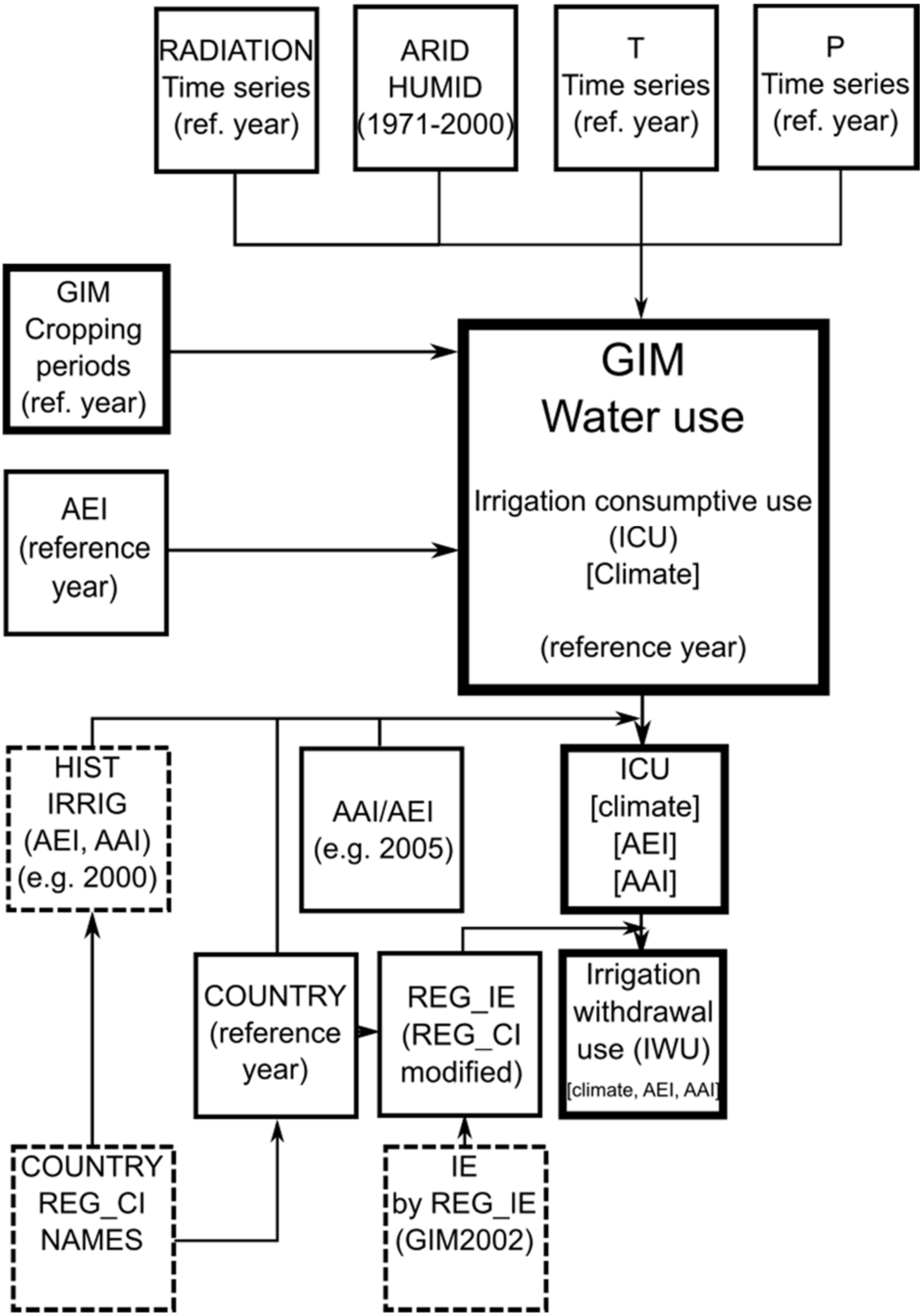


Figure 2.6: Refined GIM calculation step 2 (water use) and the related data flow of input and output data (solid boxes mark grids, dashed boxes mark tables, bold boxes marks procedure, cropping periods input, and output)

3. Data and Methods

3.1 Country list and mask

The GIM model needs a list of countries and a mask (grid) with country codes according to the United Nations (UN) M49 numerical codes with a maximum of 3 digits (United Nations Statistical Division, 2016). This has to be considered when merging data from sources which do not use UN M49 codes like the "Historical Irrigation Data set" (HID) (Siebert et al., 2015).

As reference source of the list of countries (with the associated country names used hereafter) and the related country mask, the HID delivered subnational units for 14 time slices every 10-5 years between 1900 and 2005. A full list of national-level country units representing all possible units within the time slices was derived as a standard reference for any spatial reference. The national-level character codes ISO-3166 ALPHA 2, and ALPHA 3 used in HID were recoded to corresponding UN M49 3-digits code (United Nations Statistical Division, 2016; Nations Online Project, 2016). For 3 units not present in the UN list, additional codes outside the current domain of numbers (901, 902, and 903) were introduced, see Table A.1 and Table A.2The names in HID were maintained in order to indicate the data source, although they differ somewhat from the official UN ones (United Nations Statistical Division, 2016). Likewise, the author declares that used names and borders do not represent any acceptance or denial of their true legal status, which is sometimes also controversial and a source of conflict between states, e.g. between Pakistan and India (Wikipedia, 2017h). The 14 subnational units grids were aggregated from 5 arc-min to 30 arc-min with a majority rule, and data holes from equally present classes filled with the smaller subnational number code. In a further step, the grids were recoded to UN M49 country 3 digit numerical codes.

As the administrative borders not only within countries but also between countries changed over time, a decision had to be taken how to fill the temporal gaps between the 14 HID time slices of 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1985, 1990, 1995, 2000, and 2005. With the aim to provide good spatial resolution of AEI estimates, in HID in some cases subnational and national administrative boundaries were maintained for historical time periods even before the dissolution of countries, e.g. for the Former USSR and Former Yugoslavia, with associated steps to estimate values for these units from higher-level, e.g. national, administrative data (Stefan Siebert, 2016). As a result, changes in country borders in the final 30 arc-min country mask grid between the 14 time slices are mostly minor ones, mainly attributable to differences in the original spatial setup of data sources and obvious uncertainties in the aggregation from 5 arc-min to 30 arc-min, where e.g. grid cells in the country mask switch in country code between neighboring countries (e.g. Figure 3.3 and Figure 3.4). The major change in HID country mask grid occurs from 1940 to 1950, after World War II, when the "German Empire" became the smaller "Germany" (surrender of German armed forces in May 1945, establishment of Federal Republic of Germany and German Democratic Republic in 1949) (Wikipedia, 2017b), and when the "Indian Empire" under the dominance of the United Kingdom (UK) was split in 1947/1948 into India (independence in 1947) (Wikipedia, 2017e), Pakistan (independence in 1947) (Wikipedia, 2017h), Bangladesh (independence from UK in 1947, independence from the rest of Pakistan in 1971) (Wikipedia, 2017a), and Myanmar (independence from UK in 1948) (Wikipedia, 2017f). It was decided to use the 1950 country set up of HID already starting in 1945, because statistics on rice harvested area are available already in 1945 for Pakistan (including then also Bangladesh) and Myanmar, and since 1961 separately for Pakistan and Bangladesh (Mitchell, 2007; International Rice Research Institute

(IRRI), 2016). Respective changes from 1910 to 1960 are shown in Figure 3.2. For the rest of time slices, it was generally assumed that the country grid code setup was valid until the next HID country setup, i.e. 1900 until 1909, 1910 until 1920, etc. The only exception is the mentioned time slice between 1940 and 1950, where the country mask of 1940 is valid until 1944, and the mask of 1950 since 1945. Figure 3.1 to Figure 3.4 show the global country mask for 1910, 1960, 1995, and 2005, respectively. To ease the addressing of these data layers in the figure or table captions, as well as in the presentation of the results and in the analysis, the data layer acronym starts with the name of the data set reference (here HID), followed by an identifier of the specific data type, and terminated by the year for which it is valid, e.g. HID-COUNTRY-1910, with HID for the Historical Irrigation Data set, COUNTRY for country mask, and 1910 for the year under discussion. As the resulting data layers are generally at a 30 arc-min spatial resolution, this is not mentioned separately.

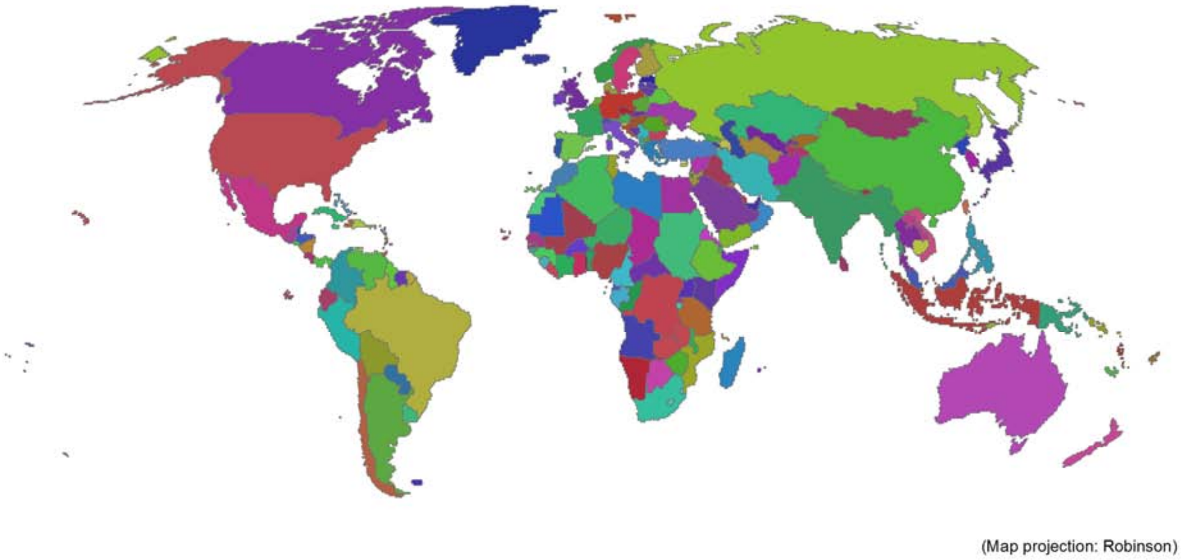


Figure 3.1: HID-COUNTRY-1910

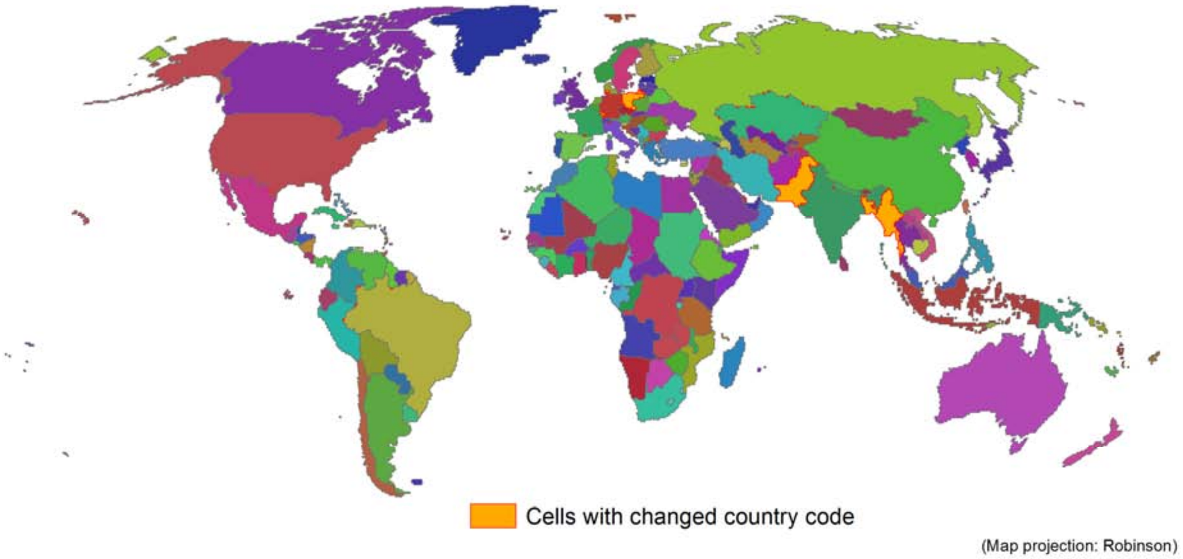


Figure 3.2: HID-COUNTRY-1960, with 760 cells with changed country code from 1910 to 1960 (mainly old German Empire, new Pakistan, Bangladesh, Myanmar)

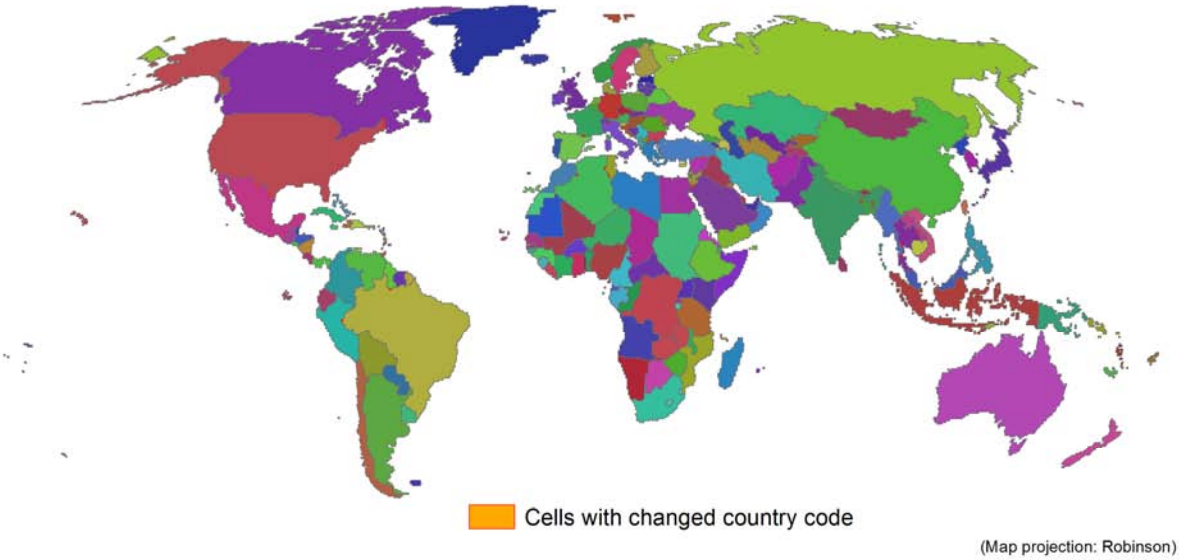


Figure 3.3: HID-COUNTRY-1995, with 21cells with changed country code from 1960 to 1995.

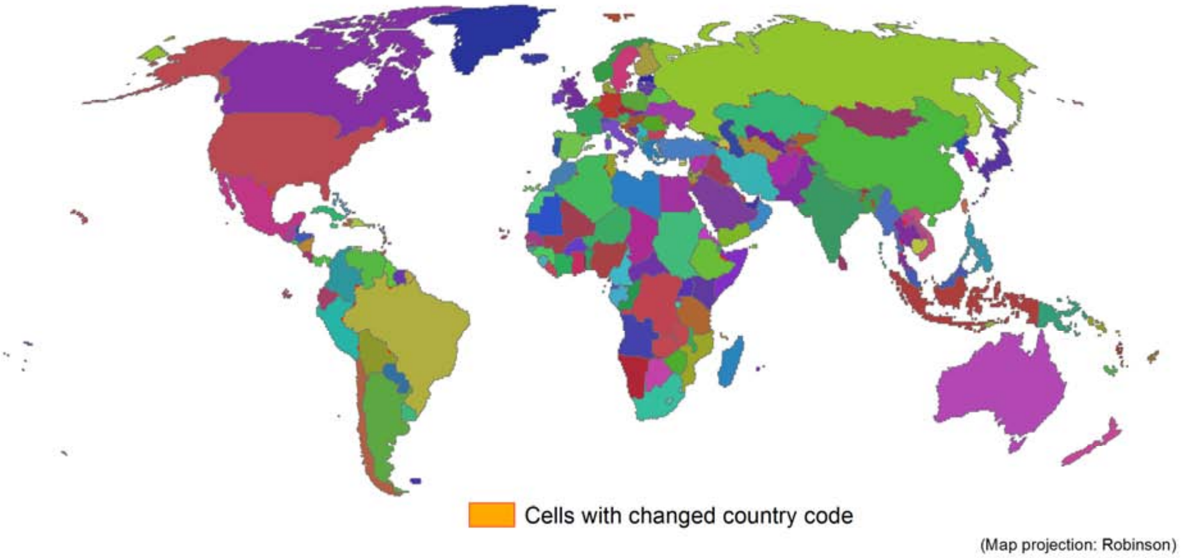


Figure 3.4: HID-COUNTRY-2005, with 53 cells with changed country code from 1995 to 2005.

3.2 Historical development of Area Equipped for Irrigation (AEI)

The main sources for the historical development of AEI and its validation were the "Historical Irrigation Data set" (HID) (Siebert et al., 2015) which provided AEI for 14 time slices between 1900 and 2005, including the Global Map of Irrigation Areas version 5 (reference year 2005) (Siebert et al., 2013b, 2013a), and both specifying AEI in physical unit of hectare [ha] per grid cell. The AEI of HID contains area equipped for full or partial control irrigation, equipped lowland areas, and areas equipped for spate irrigation (Food and Agriculture Organization of the United Nations (FAO), 2017a). Areas of rainwater harvesting are not included. The data sources of AEI (or related areas of irrigated crops) behind HID are national census data and international data bases, e.g. FAOSTAT (Food and Agriculture Organization of the United Nations (FAO), 2017b), AQUASTAT of FAO (Food and Agriculture Organization of the United Nations (FAO), 2017a), or EUROSTAT (Statistical office of the European Union (EUROSTAT), 2016).

The HID AEI product (Siebert et al., 2015) is delivered as a set of 5 arc-min resolution products with two basic versions derived from different land use data sets: (1) History Database of the Global Environment (HYDE), version 3.1 for about 12000 years from 10000 BC until AD 2005 (http://themasites.pbl.nl/tridion/en/themasites/hyde/index.html), and (2) Earthstat global cropland and pasture data set for 1700 until 2007 developed by the Land Use and Global Environment Research Group (LUGE) at the University of British Columbia, Vancouver, Canada (http://www.earthstat.org/). The differences between these primordial versions are larger than the differences between the product sub-lines which maximize consistency either with subnational irrigation statistics (suffix IR) or with historical cropland and pasture (suffix CP) of the same spatial resolution. For the present evaluation focusing on irrigation, the product AEI_HYDE_FINAL_IR was selected, which maximized consistency with subnational irrigation statistics and which was most often used in the reference publication of Siebert et al. (2015), thus enabling a better comparison with GIM results. Furthermore, consistency with HYDE long-term historical coverage before 1700 may be of interest when linking with climate studies on historical and Holocene climate development before that year.

The HID AEI_HYDE_FINAL_IR grid cell sums for the years 1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1985, 1990, 1995, 2000, and 2005 were aggregated from 5 arc-min to 30 arc-min grids and, for each grid cell, linearly interpolated in time between the subsequent time slices. To derive the appropriate country-level AEI totals from the interpolated AEI grid for a specific year, the predefined country mask of the appropriate year was used as a reference for the specific country setup, with two possible constellations. First, for the calculation of cropping periods for each year separately, the MIRCA2000 AHI Rice of the year 2000 had to be scaled with the “true” AEI, for which the specific years of AEI were used to be in line with the changing AEI per country setup. Second, for national AEI scaling factors with one reference year, the country mask of the reference year was used, in order to be consistent with the constant spatial AEI grid of the reference year. Figure 3.5 to Figure 3.8 show the resulting global distribution of AEI from HID for 1910, 1960, 1995, and 2005, respectively. These data layers, as for the country mask, are addressed with a data layer name starting with the name of the data set reference (here HID), followed by an identifier of the specific data type, and the year for which it is valid, e.g. HID-AEI-1910, with HID for the Historical Irrigation Data set, AEI for Area Equipped for Irrigation, and 1910 for the year under discussion. Again, as the resulting data layers are generally at a 30 arc-min spatial resolution, this is not mentioned separately. In addition to that, the HID product name of AEI_HYDE_FINAL_IR is only explicitly mentioned in this section, and is implicitly included when referring to HID-AEI, unless stated otherwise.

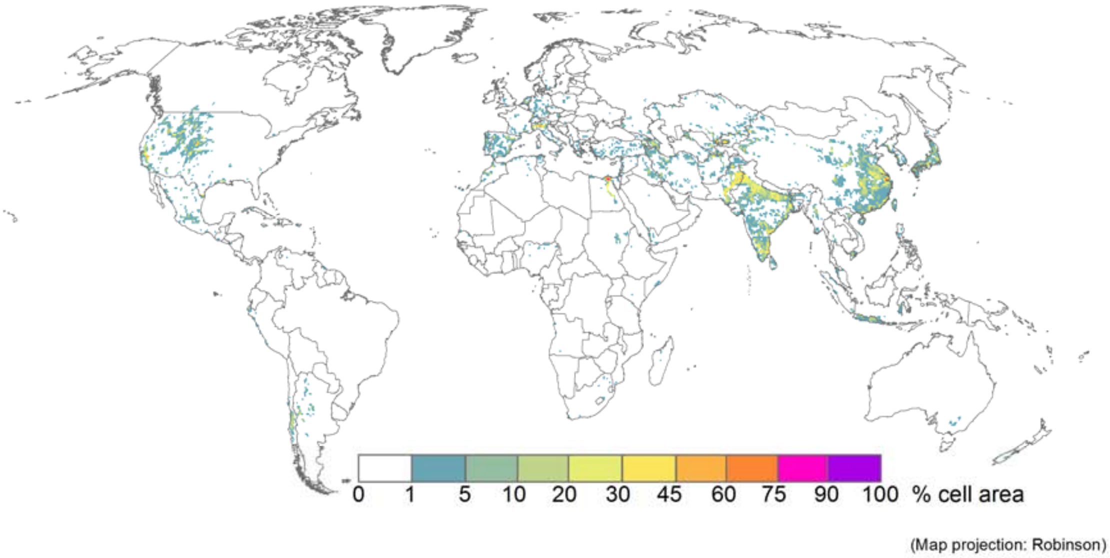


Figure 3.5: HID-AEI-1910 (AEI_HYDE_FINAL_IR) [% of cell area]

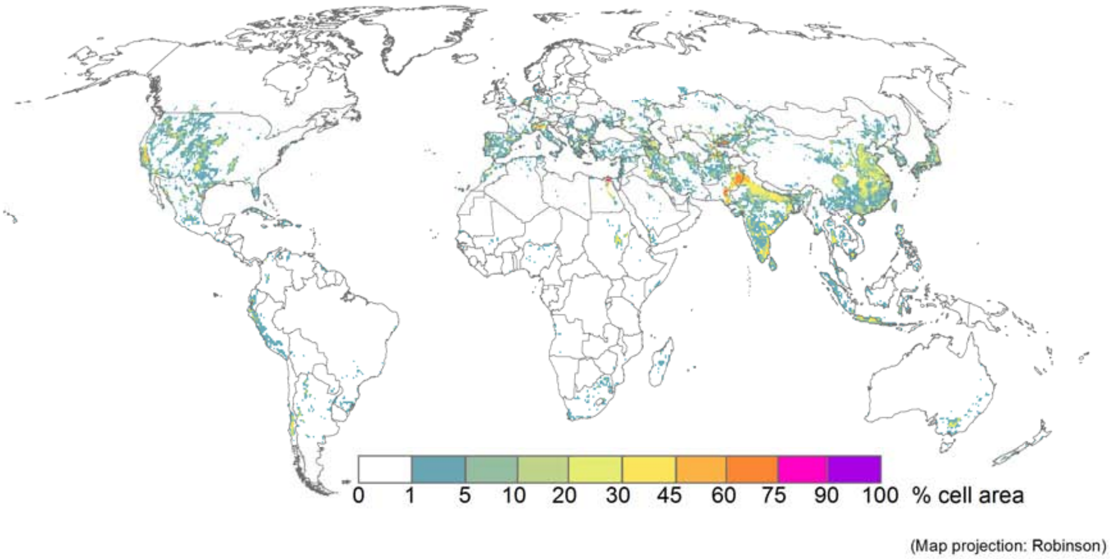
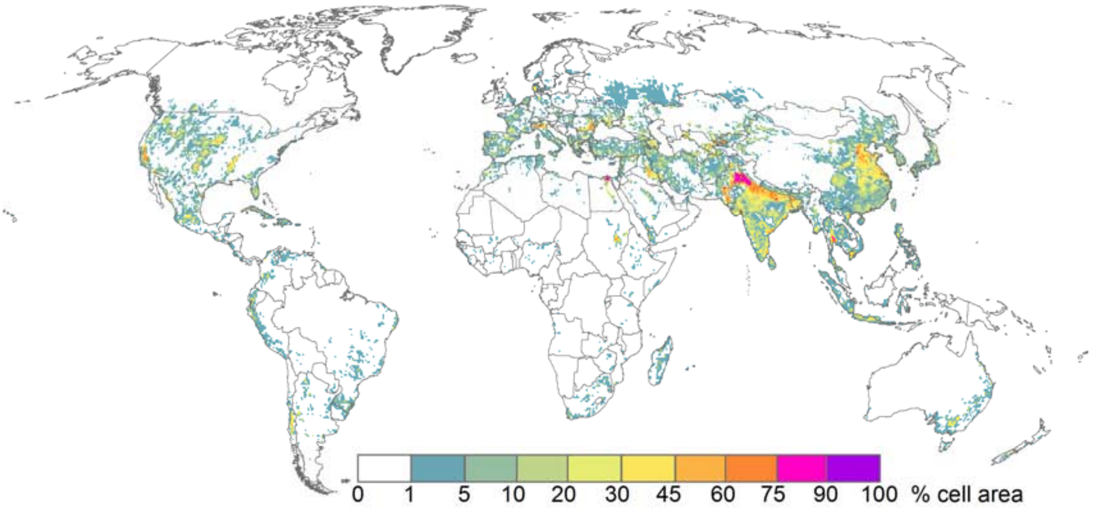
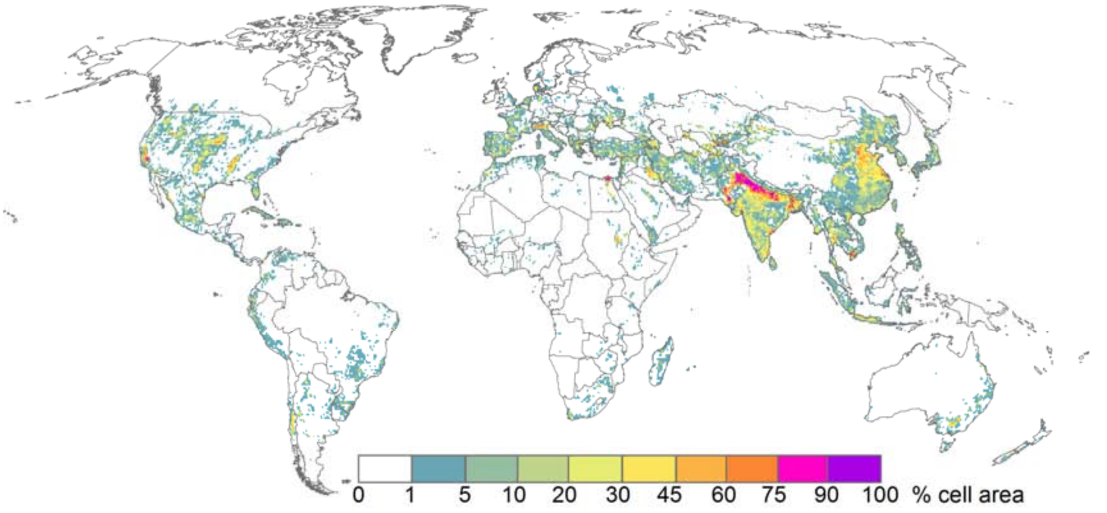


Figure 3.6: HID-AEI-1960 (AEI_HYDE_FINAL_IR) [% of cell area]



(Map projection: Robinson)

Figure 3.7: HID-AEI-1995 (AEI_HYDE_FINAL_IR) [% of cell area]



(Map projection: Robinson)

Figure 3.8: HID-AEI-2005 (AEI_HYDE_FINAL_IR) [% of cell area]

3.3 Area Actually Irrigated (AAI)

The area actually irrigated, i.e. actually used for irrigation (AAI) can be significantly smaller than the area equipped for irrigation (AEI), e.g. due to weather conditions (supplementary irrigation only when needed), crop rotation, short-term failure of irrigation infrastructure, short-term changes in market conditions (e.g. subsidies, change in governmental policies), water shortages (Siebert et al., 2013b; Siebert et al., 2015). Only in areas with very intensive agricultural land use, AEI is nearly always used.

The AAI in percent of AEI from the Global Map of Irrigation Areas version 5 for reference year 2005 (Siebert et al., 2013b, 2013a) was used for all years. When calculating average percentage ratios from AAI sum divided by AEI sum, if both sums are aggregated from 5 arc-min to 30 arc-min, then some grid cells are not filled with data (Figure 3.9). This would imply that for any further grid cells not included within the pattern of 2005, no water consumption based on an AAI value could have been derived. In order to have a complete global coverage, the 5 arc-min grid-based percentages were interpolated to a global grid using ESRI ArcGIS 10.4 Inverse Distance Weighting (IDW) with 5 points in up to 150 degrees distance, and a distance exponent of 2. This resulted in a spatial distribution where the values of remote single locations were distributed more to its surrounding than with exponent 1. The resulting ratios on 5 arc-min grid were then aggregated (averaged) to 30 arc-min means. Figure 3.10 shows the resulting global distribution of AAI in percent of AEI for 2005. These data layers, as for the country mask, are addressed with a data layer name starting with the name of the data set reference (here GMIA5), followed by an identifier of the specific data type, and the year for which it is valid, e.g. GMIA5-PCTAAIAEI-2005, with GMIA5 for the Global Map of Irrigation Areas version 5, PCTAAIAEI for Percentage ratio of Area Actually Irrigated over Area Equipped for Irrigation, and 2005 for the year under discussion. In addition to that, a suffix characterized whether original (_ORI) or interpolated (_IDW) are meant. Again, as the resulting data layers are generally at a 30 arc-min spatial resolution, this is not mentioned separately.

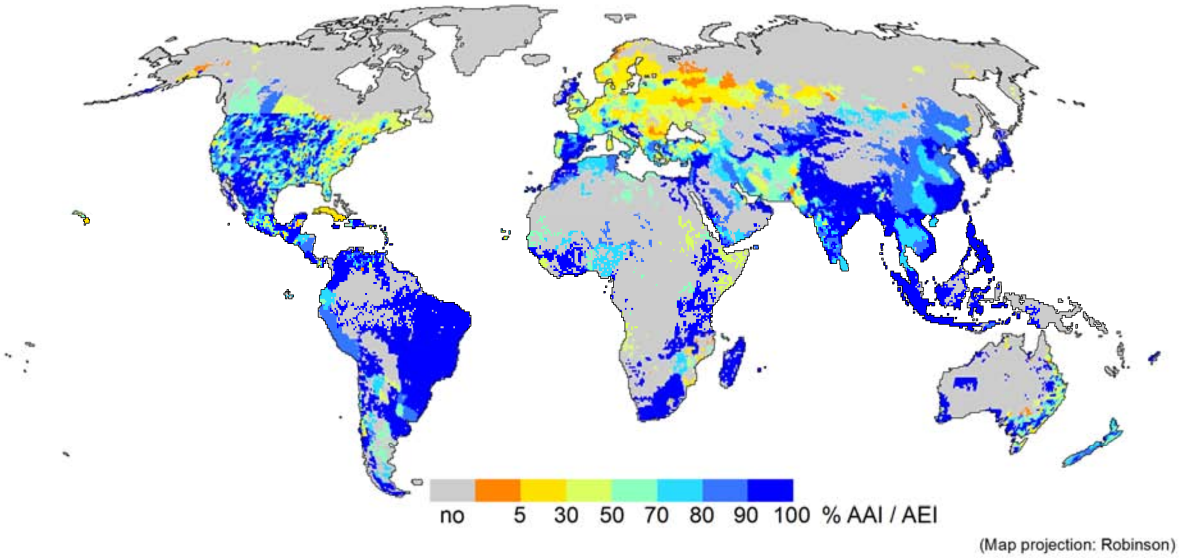


Figure 3.9: GMIA5-PCTAAIAEI-2005_ORI, aggregated from 5 arc-min to 30arc-min, original without interpolation, but with areas where ratio AAI/AEI is not defined

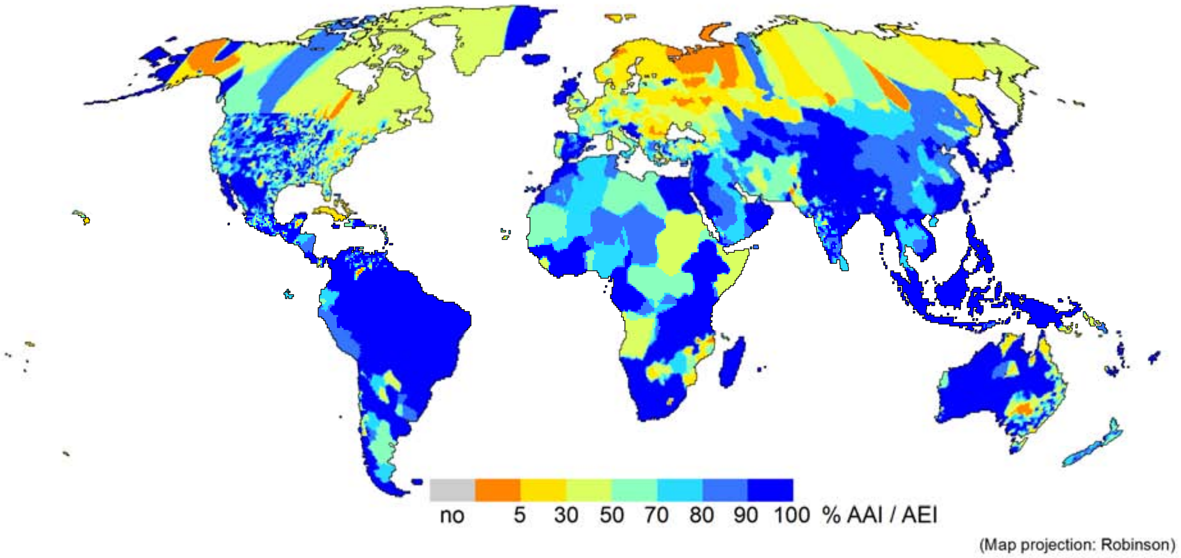


Figure 3.10: GMIA5-PCTAAIAEI-2005_IDW, values from inverse distance weighting (IDW) interpolation, aggregated from 5 arc-min to 30arc-min, showing no areas with undefined ratio AAI/AEI

3.3 Harvested area of irrigated rice (AHI Rice)

As mentioned in the foreseen changes of the model, for simplicity purposes, harvested area of irrigated rice (AHI Rice) for countries was taken from the MIRCA2000 data set, representative for the year 2000 (Table A.5), and scaled according to AEI country totals for the years under consideration. This procedure was considered to result in AHI Rice with the highest consistency to AEI within the limited time and personal resources.

For a future step, AHI Rice may be provided from a mixture of historical statistics on total (irrigated and rainfed) AH of rice and an estimated AHI Rice / AH Rice share, potentially assisted with the scarcely available time series or estimations of AHI Rice, as described in the next paragraphs.

Sources of rice harvested area are different according to considered periods in time. For years 1961-2014, rice harvested area per country is available from the International Rice Research Institute (IRRI) World Rice Statistics (WRS) (International Rice Research Institute (IRRI), 2016) which cites data of FAO and of the United States Department of Agriculture (USDA). In order to be consistent with FAO statistics of AHI Rice, FAO data should be used, which in principle also includes data of EUROSTAT for European countries, for which generally irrigation of all rice was assumed, following Döll and Siebert (2002). EUROSTAT data is available for years 1955-2016 (Statistical office of the European Union (EUROSTAT), 2016) and may be used as primary data source for European countries. For years 1900-1960, data from International Historical Statistics could be used (Mitchell, 1998a, 1998b, 2007).

In case of missing years, data can be linearly interpolated between available neighboring years. In case that no rice area is available for the start of the series, its area may be estimated from the ratio of harvested area of rice to AEI from HID for the specific spatial unit for the first available year, multiplied with the AEI of the year of the estimate. This ensures the consistency to the historical development of AEI.

To derive irrigated harvested area, the harvested area of rice may be multiplied with the fraction of irrigated rice drawn for the respective spatial unit of the MIRCA2000 land use data set (Portmann et al., 2010), or perhaps via using FAO statistics AHI Rice for available years.

3.4 Cropping intensity (CI)

Cropping intensity (CI) is calculated traditionally as the average number of harvests (or of cropping periods, i.e. of crops grown consecutively) per physical area (e.g. field, grid cell, country, region) during a year, and as such it is used in crop modeling. An example drawn from Döll and Siebert (2002) may help to understand the concept of cropping intensity: Assuming that on one half of the irrigated area of the selected physical spatial unit (e.g. region), crops are grown once a year, and on the other half, two crops are grown, one after another, the resulting average cropping intensity is (1 + 2) / 2 = 1.5. CI in general is higher in irrigated agriculture than in rainfed agriculture (Portmann et al., 2010). On the other hand, when considering only harvested area statistics, several crops with one or more cropping periods, and both irrigated and rainfed crops, it may be differently defined either as the ratio of harvested area over cropland extent including fallow (minimum CI) or ratio over area actually cultivated (maximum CI) (Siebert et al., 2010). Regional efforts to estimate CI based on remote sensing in the Aral Sea Basin support these general rules, e.g. with CI averages ranging from 0.53 in the Karakum

Canal, 0.78 in the Amu Darya Delta, to 1.23 in the Upper Amu Darya, where up to two cropping periods are observed in Afghanistan (Conrad et al., 2016). The time series in this mostly irrigation-based agricultural system, CI in general correlated positively with the available total water inflow from upstream, whereas percent of fallow land was negatively correlated to water inflow. The authors found double cropping of winter wheat and a summer crop, and single cropping of rice, which in the lower Syr Darya also occurred between years without any cropping. Rice was difficult to distinguish from wetland in the classification process of (temporal) Crop Vegetation Patterns based on Normalized Difference Vegetation Index (NDVI) (Conrad et al., 2016).

Following Döll and Siebert (2002), countries are attributed to one of 18 regions (excluding Antarctica) for uniform cropping intensities (regions referenced as GIM2002-REG_CI, cropping intensities as GIM2002-CI). Two regions are further subdivided during model execution for different irrigation efficiencies, namely the Organization for Economic Cooperation Development (OECD) region Europe to northern and southern parts, and the Commonwealth of Independent States (CIS, most states of the former USSR) to Baltic States and Belarus, on one hand, and the rest of the former USSR, on the other. In contrast to the current and former GIM versions, Ireland was also included in the neighboring (northern) OECD region with associated CI values, whereas before the higher CI of Canada was used. Eventually 19 effective regions result, which are referenced as GIM2002-REG_IE hereafter. Through the aggregation of the HID-COUNTRY from original 5 arc-min to 30 arc-min spatial resolution, minor spatial units are generalized, and, as a result, only 204 out of the 245 original national spatial units are really used. A detailed list of the 245 countries present in HID and their attribution to a region is documented in Table A.1 (sorted by UN M49 country number) and Table A.2 (sorted by country name).

A homogeneous situation within these regions is assumed. The cropping intensities together with the irrigation water use efficiencies are listed in Table 3.1 (Döll and Siebert, 2002). The regions of cropping intensity (GIM2002-REG_CI) and irrigation efficiency (IE) (GIM2002-REG_IE) are shown in Figure 3.11, and the associated regional cropping intensities (GIM2002-CI) in Figure 3.12, with the borders in this example following the regions derived from the newest country mask HID-COUNTRY-2005.

Table 3.1: Estimated cropping intensity for irrigated agriculture (GIM2002-CI) and irrigation efficiency (GIM2002-IE) in 19 world regions (Döll and Siebert, 2002), with main region codes and names of GIM2002

Region code CI	Region code IE	Region name CI	Region name IE	CI	IE_NR (Non-rice)	IE_R (Rice) (IE_NR-0.1)
1	1	Canada	Canada	1.0	0.7	0.6
2	2	USA	USA	1.0	0.6	0.5
3	3	Central America	Central America	1.0	0.45	0.35
4	4	South America	South America	1.0	0.45	0.35
5	5	North Africa (“Northern Africa”)	North Africa (“Northern Africa”)	1.5	0.7	0.6
6	6	West Africa (“Western Africa”)	West Africa (“Western Africa”)	1.0	0.45	0.35
7	7	East Africa (“Eastern Africa”)	East Africa (“Eastern Africa”)	1.0	0.55	0.45
8	8	South Africa (“Southern Africa”)	South Africa (“Southern Africa”)	1.0	0.55	0.45
9	9	OECD-Europe (Organization for Economic Cooperative Development)	OECD Europe 1: Northern OECD-Europe	1.0	0.5	0.4
	18		OECD Europe 2: Southern OECD-Europe	1.0	0.6	0.5
10	10	Eastern Europe	Eastern Europe	1.0	0.5	0.4
11	11	CIS (Commonwealth of Independent States)	CIS 1: Baltic Republics + Belarus	0.8	0.5	0.4
	19		CIS 2: Rest of former USSR (Soviet Union)	0.8	0.6	0.5
12	12	Near East Countries	Near East Countries	1.0	0.6	0.5
13	13	India + South Asia (“South Asia”)	India + South Asia (“South Asia”)	1.3	0.35	0.25
14	14	China + CPC (“East Asia”)	China + CPC (“East Asia”)	1.5	0.35	0.25
15	15	East Asia (“South East Asia”)	East Asia (“South East Asia”)	1.2	0.4	0.3
16	16	Oceania	Oceania	1.5	0.7	0.6
17	17	Japan	Japan	1.5	0.35	0.25
18		Greenland	(not used, no irrigation)	1.0	(not used)	(not used)
19		*Antarctica (not present in grid)*	-	-	-	-

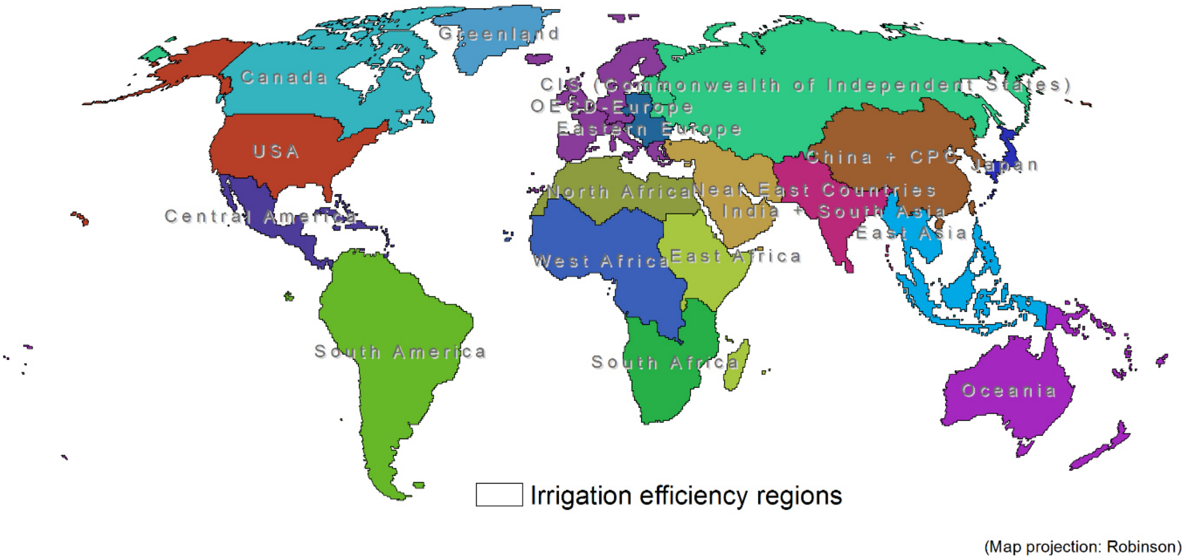


Figure 3.11: Regions of uniform cropping intensity (GIM2002-REG_CI) and irrigation efficiency (GIM2002-REG_IE), example with borders of regions derived from newest HID-COUNTRY-2005

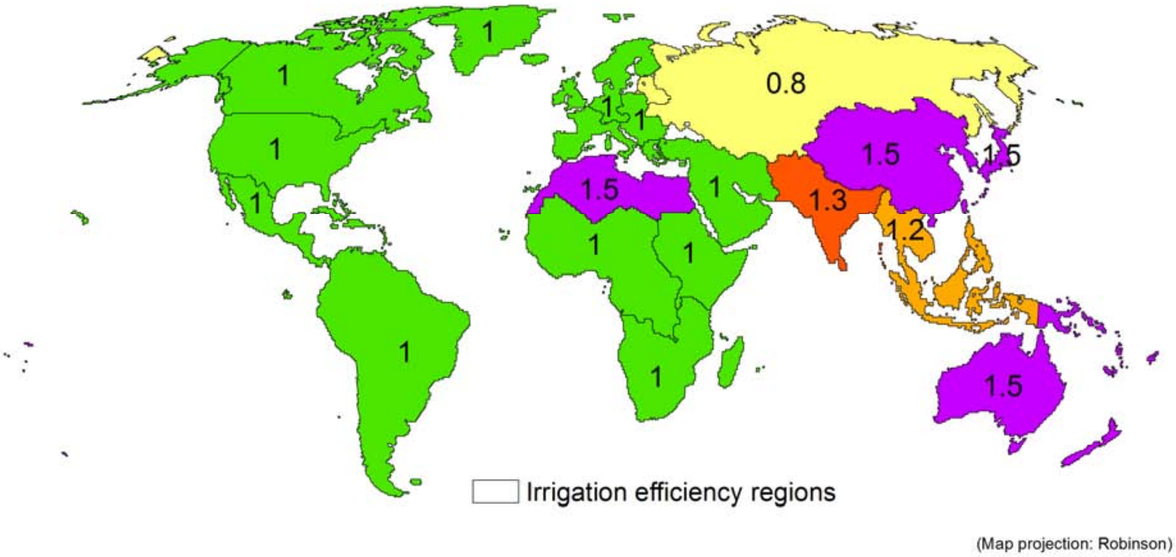


Figure 3.12: Cropping intensities (GIM2002-CI) for the 19 effective regions (GIM2002-REG_IE), example with borders of regions derived from newest HID-COUNTRY-2005

3.5 Irrigation efficiency (IE)

The irrigation efficiency (IE) is the ratio of the water consumption at the site of use (ICU) and the water withdrawn (or abstracted, or delivered, IWU). The GIM cropping patterns and growing periods consider effective regional irrigation efficiencies of non-rice crops, which partly are different from the prescribed regional project irrigation efficiencies of GIM2002-IE listed in Table 3.1 (mostly higher). Second, the regional irrigation efficiencies of rice crops are assumed to be 0.1 lower. The cell-specific irrigation efficiency is a weighted average of these two different categories, with weights being the cell-specific crop fractions of the rice and non-rice cropping patterns. An example for year 1995 is given for all regions in Table A.3. Within GIM, the ICU is the primarily calculated value. The division of grid-cell specific ICU by the cell-specific IE results in IWU. Unit-specific totals are derived from the grid-cell ICU and IWU. This methodology is different from the current procedure in WaterGAP2.2, where through the intermediate GWSWUSE module, grid-cell specific monthly ICU as provided by GIM is transformed to IWU via country-specific (national-level) IE, possibly different for surface water and groundwater sources (Figure 2.1, Müller Schmied et al., 2014)

3.6 Climate forcing data

The used climate data forcing at an interpolated 30 arc-min spatial resolution was a combination of bias-corrected WATCH Forcing Data (WFD) (1901 until 2001, but used only until 1978) (Weedon et al., 2010; Weedon et al., 2011) and WATCH Forcing Data ERA Interim reanalysis (WFDEI) (since 1979, with extensions to 2014) (Weedon et al., 2014). The WFD has been generated differently depending on available data: For 1958-2001 it is based on ERA-40, the 40-year European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis, while for 1901-1957 it is based on reordered reanalysis data (Weedon et al., 2011). The "WATCH Forcing Data methodology applied to ERA-Interim data" (WFDEI) uses the basically same methodology as WFD but with small differences in basis data, processing, and formatting (Weedon et al., 2014). Finally, to get homogeneous time series, the WFD was homogenized (WFD_hom) to meet WFDEI radiation and temperature levels because of an offset especially in shortwave downwelling radiation between WFD and WFDEI, using the overlapping period of 1979 to 2001 (Müller Schmied et al., 2016b).

The daily data of air temperature, precipitation, shortwave downwelling radiation, and number of rain days were averaged to monthly climate means of 30 years from 1901-1930 until 1985-2014, with number of rain days calculated from the original daily precipitation values with a minimum sill value of 1 mm of precipitation for indicating a rain day.

3.7 Data processing and start of the model

The data pre-processing to get eventually e.g. grid data files in GIM proprietary binary format or text format was successfully performed using a suite of Python scripts for ESRI ArcGIS geoprocessing, Linux shell scripts, C^{++} programs to calculate climate means, and R scripts (R Core Team, 2006). The associated scripts are contained in Appendix C.

Post-processing included e.g. R scripts and an ArcGIS Add-on to read proprietary binary files developed by the Working Group Hydrology of the Institute of Physical Geography (IPG) of the Goethe University Frankfurt am Main. The associated scripts are contained in Appendix D.

GIM itself is started via a core shell script that, depending on the used arguments, generates appropriate copies of control files. In a higher-level script framing the core shell script, the arguments for the runs for individual years are generated. The associated scripts are contained in Appendix C. As a result, the refinement of GIM provides an updated and corrected code version with much more freedom to choose, during runtime, for the first step (calculation of cropping periods), the source of AEI (and related country masks), AEI reference year, and the start and end years of climate periods. Also the next step (calculation of water use) has been improved by selecting arbitrary cropping periods for any AEI reference year, the optional application of AAI/AEI ratio of a selected, possibly different, reference year and optional application of AEI scaling factors with values of start year or end year used when the time series to calculate starts earlier or ends later. The calculation of multi-annual statistics is now a separately controlled option. Through a specific combination of arguments and option files with control parameters, the three conceptual modes described in subchapter 2.2 are executable.

4. Results

To compare the results with already published reference values of AEI, AAI, water use (ICU and IWU), and IE, the years 1910, 1960, 1995, and 2005 were selected for evaluation. Year 1910 is the first HID reference year with climate forcing data, years 1960 and 1995 have validation data for the United States of America, and finally year 2005 shows the most current situation.

In addition to that, to check whether the selection of the 30-year climate period for the computation of the cropping periods is also important, the sensitivity of ICU for the year 1995 was tested with HID-AEI of 1995, using alternative climate means, two of them representing the climate means of other selected reference years, while the other two are a multiple of 30-year periods before the regularly chosen period 1981-2010, in order to check whether decadal climate variability had an influence on the results:

- 1901-1930, same climatic conditions as for HID-AEI reference year 1910,
- 1921-1950, two averaging periods before regular period 1981-2010,
- 1946-1975, same climatic conditions as for HID-AEI reference 1960,
- 1951-1980, one averaging period before regular period 1981-2010.

Two different versions of results were evaluated:

(1) GIM runs with year-specific HID-AEI (and respective cropping periods), with AAI/AEI ratios applied, for years 1901-2005. For the years 2006-2014, results were calculated based on HID-AEI and cropping periods for the reference year 2005 (and mean climate 1985-2014), with no country-specific (national-level) scaling applied. These runs are referenced together as HID-ACT hereafter. For reasons of clarity, the following unique hierarchical naming is introduced (Table 4.1), with the results of a specific run, e.g. HID-ACT-1910_refclim referring to the AEI data source (HID), where the following "ACT" refers to the application of the ratio AAI/AEI that scales the water use from the value using AEI as maximum area, i.e. potentially used area ("POT", used later in this study to characterize country specific scaling done on AEI), to a value representing conditions of AAI as the actually used area (ACT). The final suffix "refclim" indicates the use of the standard reference period normally chosen in the current study, i.e. between -14 years and +15 years around the AEI reference year for determining the cropping periods that are also tabulated in Table 4.1. If the reference year was within the first 14 years of the time series, i.e. 1901 to 1914, then the period of 1901-1930 was always chosen, in order to avoid any bias from artificially enlarging the time series by, e.g. mirroring data years. A suffix "clim" followed by a year, e.g. "clim1901", refers to the tabulated start year of the 30-year mean period for cropping periods which does not correspond to the standard reference period for the chosen AEI reference year (e.g. 1901 for reference year 1981).

(2) A GIM run based on cropping periods for the HID-AEI reference year 2000 (and mean climate 1985-2014), with country-specific AEI scaling applied with scaling factors mentioned in Table A.6, with additionally AAI/AEI ratios applied. An additional "HIST" refers to the application of country-specific (national-level) scaling factors to mimic historical development of AEI with respect to the HID-AEI grid of a chosen

reference year. This run is referenced as HID-ACTHIST, to enhance clarity, dropping the year 2000 in the name, because it is the only run with country-specific scaling in this study.

Table 4.1: Naming of the selected years of GIM runs based on HID, with description of specific applicable conditions

GIM run selection	Year of result (e.g. ICU)	AEI HIST scaling factors	HID-AEI reference year	Cropping period mean climate start and end
HID-ACT-1910_refclim	1910	No	1910	1901 - 1930
HID-ACT-1960_refclim	1960	No	1960	1946 - 1975
HID-ACT-1995_refclim	1995	No	1995	1981 - 2010
HID-ACT-1995_clim1901	1995	No	1995	1901 - 1930
HID-ACT-1995_clim1921	1995	No	1995	1921 - 1950
HID-ACT-1995_clim1946	1995	No	1995	1946 - 1975
HID-ACT-1995_clim1951	1995	No	1995	1951 - 1980
HID-ACT-2005_refclim	2005	No	2005	1985 - 2014
HID-ACTHIST-1910_clim1985	1910	Yes	2000	1985 - 2014
HID-ACTHIST-1960_clim1985	1960	Yes	2000	1985 - 2014
HID-ACTHIST-1995_clim1985	1995	Yes	2000	1985 - 2014
HID-ACTHIST-2005_clim1985	2005	Yes	2000	1985 - 2014
Remarks: All runs have AAI/AEI ratios applied and HID as basis for AEI, therefore, run name starts with “HID-ACT”. “HIST” refers to AEI from year 2000, and in this study is always linked to the climate means period for the calculation of cropping periods around the year 2000, i.e. 1985-2014. Any difference from the reference mean climate period (suffix “refclim”, with standard 30-year period around the calculated year) is indicated with the suffix “clim” and the start year of the actually 30-year period.				

4.1 Comparison of irrigation consumptive use (ICU) from HID-ACT with ICU from HID-ACTHIST using country-specifically scaled HID-AEI of 2000

ICU for the years 1910, 1960, 1995, and 2005 from run HID-ACT, with standard reference 30-year climate periods around the current AEI year, was compared to ICU from run HID-ACTHIST with 30-year climate periods around their AEI reference year 2000. To ease the comparison, for each selected year, the ICU values of run HID-ACT are opposed to the ICU difference HID-ACTHIST minus HID-ACT in order to show the deviation of the results obtained with country-specific (national-level) scaling from the reference values. The resulting global patterns are shown in the following Figure 4.1 to Figure 4.4.

The spatial pattern of HID-AEI grid cell coverage for the selected years Figure 3.5 to Figure 3.8) is clearly visible constraining the borders of irrigated area, and thus grid cells with ICU from HID-ACT of all years (Figure 4.1(a) to Figure 4.4(a)). In addition to that, the highest AEI grid cell coverage class (in percent of grid cell area) that is present in California, the River Nile delta, Pakistan, northern India and northern China also produces very high ICU (larger than 300 mm a^{-1} or even 600 mm a^{-1}, respectively) (mainly Egypt, Figure 4.1(a) to Figure 4.4(a)). On the other hand, also smaller AEI grid cell coverage like in southwestern India (HID-AEI-1995, Figure 3.7) may produce high ICU (larger than 150 mm a^{-1}) (Figure 4.3(a)).

Concerning the differences HID-ACTHIST minus HID-ACT (Figure 4.1(b) to Figure 4.4(b)), the strongest absolute difference occurs in year 1910 for the difference HID-ACTHIST-1910_clim1985 minus HID-ACT-1910_refclim (Figure 4.1(b)), where strongly reduced HID-AEI-1910 vs. HID-AEI-2005 areas occur in central USA for the High Plains Aquifer (mainly states of Texas, Kansas, and Nebraska), where the HID-ACTHIST run has much larger ICU (positive difference larger than 130 mm a^{-1} per grid cell). Similar positive absolute differences values occur in the North China Plain (around Bejing, northern China). The tendency is not generally present in the other mentioned areas with high HID-AEI grid cell coverage: In some parts of India, HID-ACTHIST has much less ICU (difference < -130 mm a^{-1}), in others much larger ICU (difference > 130 mm a^{-1}), whereas in Pakistan these areas mostly show less ICU (difference < -130 mm a^{-1}) in HID-ACTHIST, as in the River Nile delta.

This contrast of differences between HID-ACTHIST and HID-ACT is smaller, but still visible in 1960 (Figure 4.2(b)), whereas the differences in 1995 (Figure 4.3(b)) are much smaller (less than 45 mm a^{-1}) compared to those in 1910 and 1960. In the last year 2005, the pattern of differences resembles that of the years 1910 and 1960, but much fainter, e.g. in Russia less grid cells with ICU are present (Figure 4.4(b)).

The national ICU totals and ICU differences for China, Egypt, India, Bangladesh, Myanmar, Pakistan, and the USA are given in Table 4.2, and for all countries in Table A.7.

Table 4.2: Irrigation consumptive use national totals [km^3 a^{-1}], rounded, for 1910, 1960, 1995, and 2005, from HID-ACT, HID-ACTHIST, and their difference HID-ACTHIST minus HID-ACT, with standard reference climate for cropping periods, for selected countries, with UN M49 country code

	Year	**1910**	1910	1910	1910	**1960**	1960	1960	1960	**1995**	1995	1995	1995	**2005**	2005	2005	2005
	Run	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT
Ctry cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]
156	China	63.0	64.1	1.1	1.8	108.4	106.7	-1.7	-1.6	183.8	184.7	0.9	0.5	213.5	212.5	-1.1	-0.5
818	Egypt	33.1	33.6	0.5	1.5	39.6	39.7	0.1	0.3	47.4	47.6	0.3	0.6	50.5	50.6	0.1	0.2
356	India & Indian Empire	119.9	78.4	-41.6	-34.7	137.0	125.6	-11.4	-8.3	228.9	227.7	-1.2	-0.5	264.3	266.3	2.1	0.8
50	Bangladesh	0.000	1.3	1.3	0.0	3.6	3.7	0.1	2.7	14.7	15.8	1.2	7.9	18.6	18.7	0.02	0.1
104	Myanmar	0.000	1.1	1.1	0.0	1.5	1.7	0.2	12.3	4.0	4.0	0.02	0.6	5.2	5.2	0.08	1.5
586	Pakistan	0.000	23.5	23.5	0.0	58.1	47.8	-10.4	-17.8	69.9	64.5	-5.4	-7.7	63.4	65.1	1.8	2.6
	India as sum of UN 356 & 50 & 104 & 586	119.9	104.3	-15.6	-13.0												
840	United States	45.6	37.2	-8.354	-18.3	84.0	71.7	-12.3	-14.6	107.5	104.9	-2.6	-2.4	116.6	117.8	1.2	1.1

Interestingly, the higher grid-cell ICU values in central USA (High Plains Aquifer) for HID-ACTHIST-1910_clim1981 are not reflected in the national total which is 8 km^3 (or 18%) smaller than ICU from HID-ACT-1910, probably because of smaller grid-cell ICU values in western USA. In contrast, the national ICU total for India in 1910, represented by current India, Bangladesh, Myanmar, and Pakistan in HID-ACTHIST-1910_clim1981, with 13% smaller ICU values than HID-ACT-1910_refclim, reflects the considerably smaller grid-cell ICU values present also in 1960, with HID-ACTHIST-1960_clim1985 versus HID_ACT-1960_refclim about 11% less total ICU in India and 10% less total ICU in Pakistan. In Egypt, where the grid-cell ICU values in the River Nile delta in HID-ACTHIST_clim1981 results for 1910, 1960 and 1995 are smaller than those of the corresponding HID-ACT run, these grid-cell differences are not reflected in the difference of the national total ICU which even is slightly larger for all of these years, by 0.3% (1960) to 1.5% (1910).

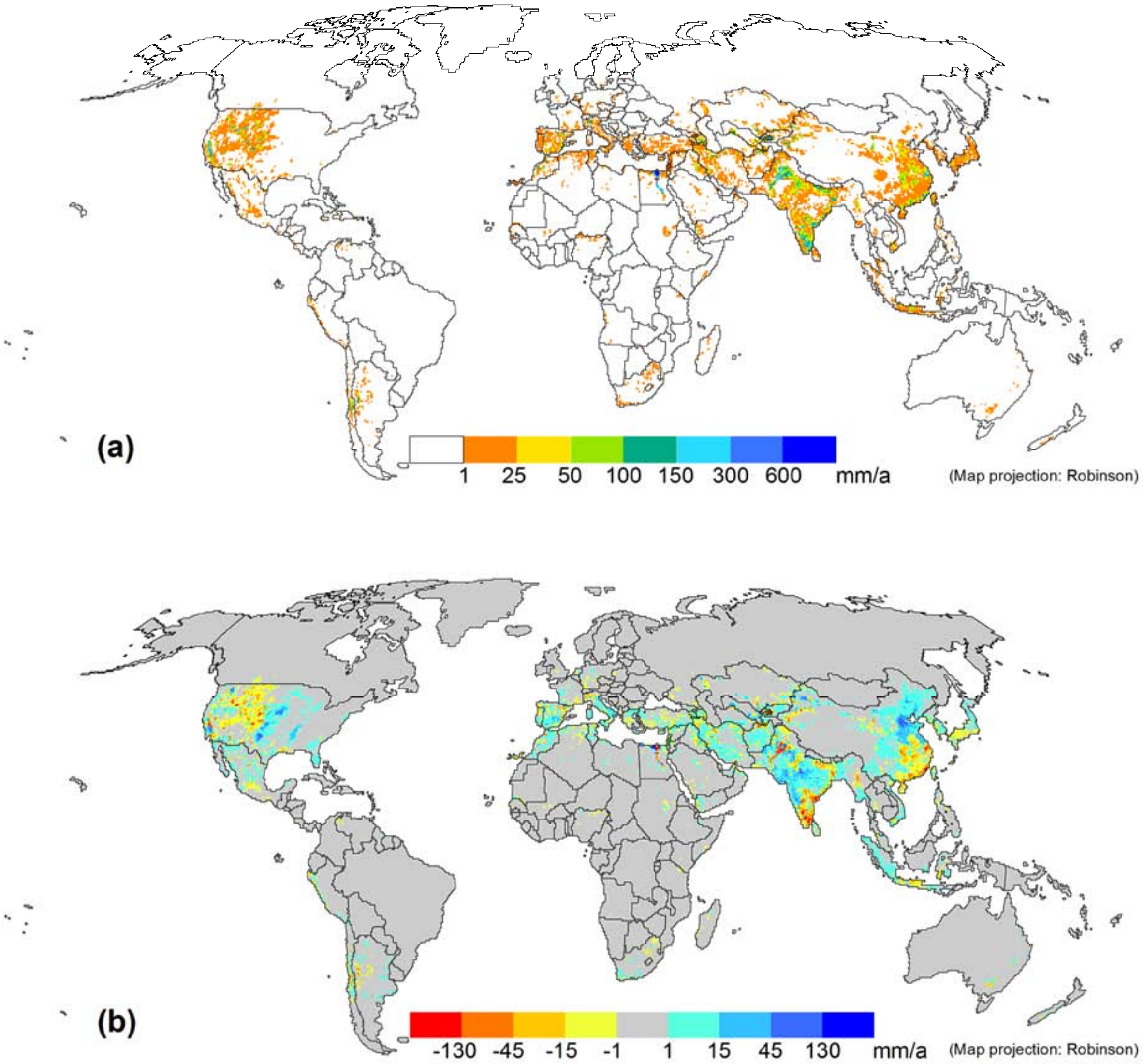


**Figure 4.1: Irrigation consumptive use [mm a^{-1}] for 1910,
(a) HID-ACT-1910_refclim
(using HID-AEI-1910 and cropping periods for climate 1901-1930),
(b) Difference HID-ACTHIST-1910_clim1985
(using country-specifically scaled HID-AEI-2000 and cropping periods for climate 1985-2014)
minus HID-ACT-1910_refclim**

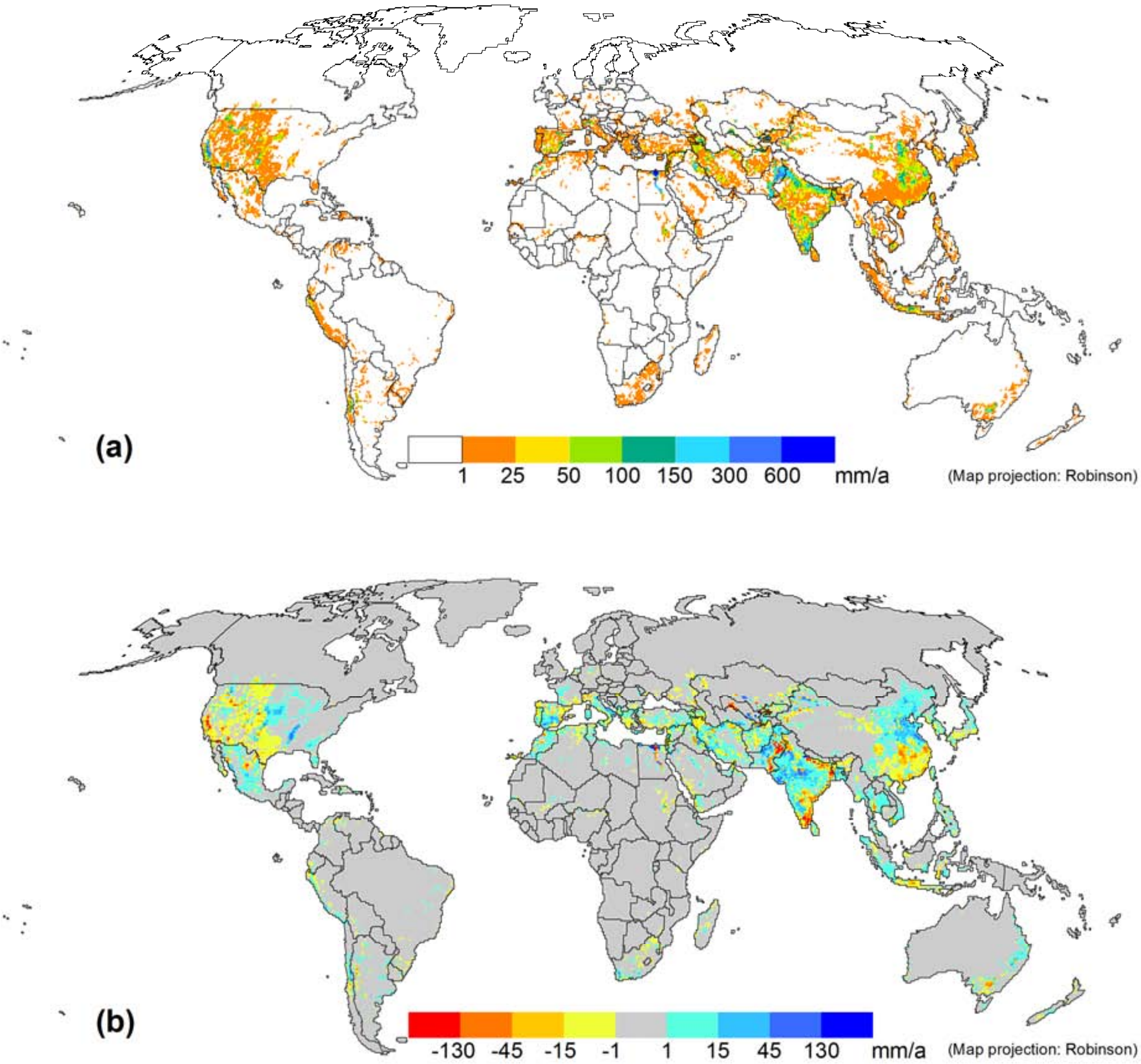


Figure 4.2: Irrigation consumptive use [mm a^{-1}] for 1960,
(a) HID-ACT-1960_refclim
(using HID-AEI-1960 and cropping periods for climate 1946-1975),
(b) Difference HID-ACTHIST-1960_clim1985
(using country-specifically scaled HID-AEI-2000 and cropping periods for climate 1985-2014) minus HID-ACT-1960_refclim

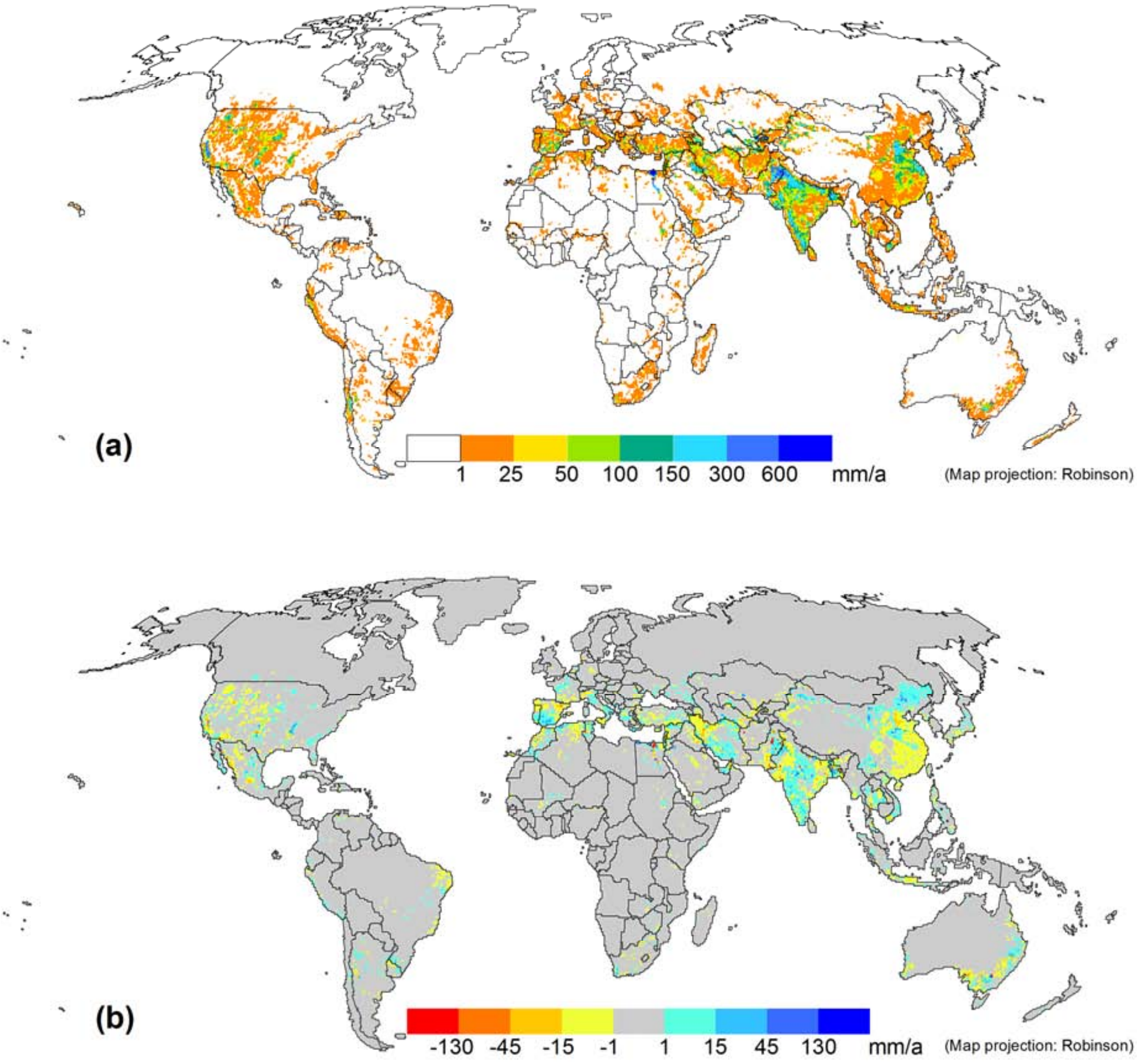


Figure 4.3: Irrigation consumptive use [mm a^{-1}] for 1995,
(a) HID-ACT-1995_refclim
(using HID-AEI-1995 and cropping periods for climate 1981-2010),
(b) Difference HID-ACTHIST-1995_clim1985
(using country-specifically scaled HID-AEI-2000 and cropping periods for climate 1985-2014)
minus HID-ACT-1995_refclim

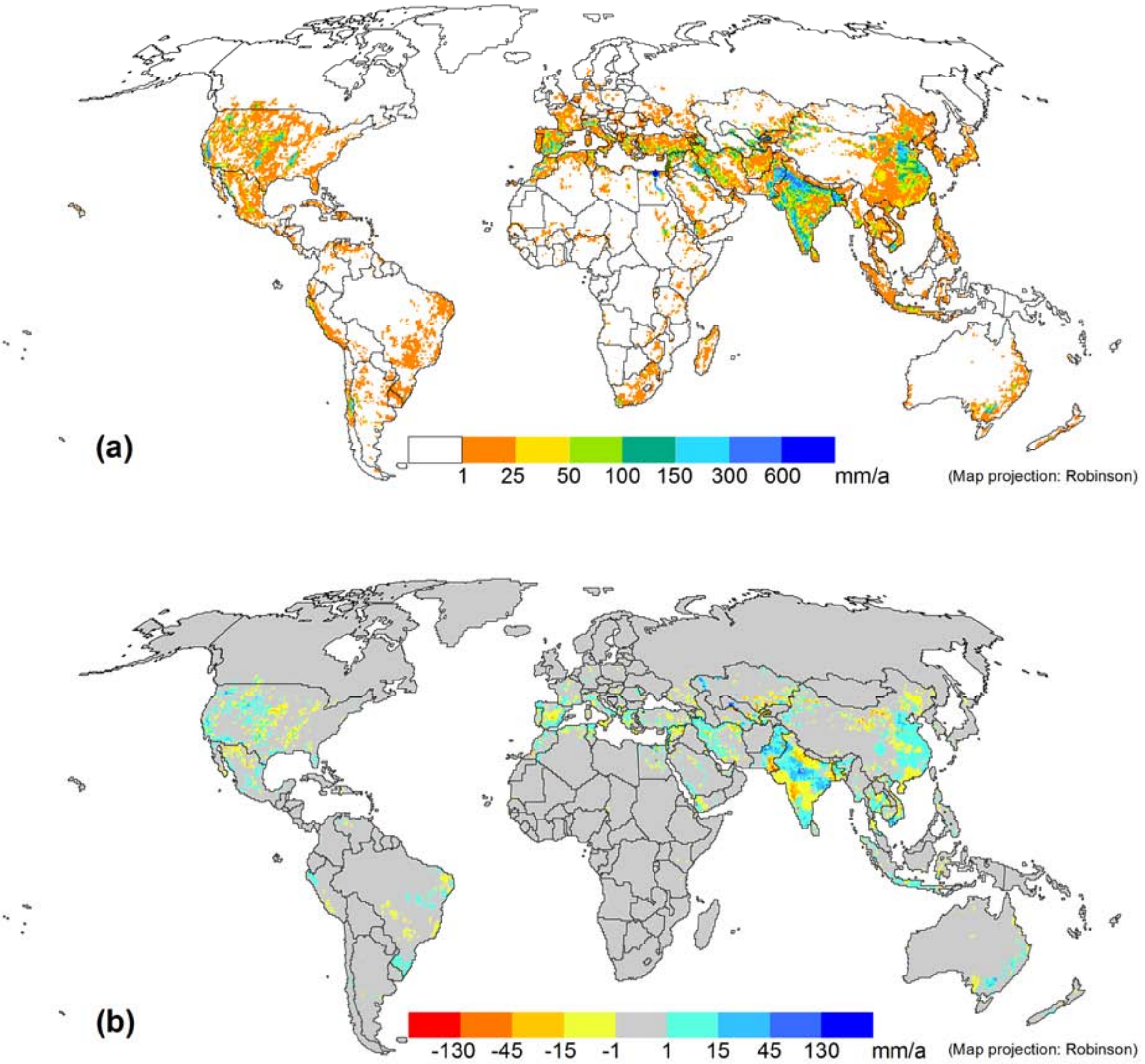


**Figure 4.4: Irrigation consumptive use [mm a^{-1}] for 2005,
(a) HID-ACT-2005_refclim
(using HID-AEI-2005 and cropping periods for climate 1985-2014),
(b) Difference HID-ACTHIST-2005_clim1985
(using country-specifically scaled HID-AEI-2000 and cropping periods for climate 1985-2014) minus HID-ACT-2005_refclim.**

4.2 Sensitivity of irrigation consumptive use of HID-ACT for 1995 depending on cropping periods from different climate periods

The specific cropping periods depend not only on AEI, but also on the climate means which might determine, for each grid cell, different climatically suitable rice-growing areas, different cropping patterns in terms of relative shares of R, NR, R-R, R-NR, or NR-NR, and subsequent different start and end days of the specific growing seasons. As a result, spatial patterns and values of ICU may differ. In order to evaluate the sensitivity of ICU depending on the selected climate period for the computation of the cropping periods, the ICU for the year 1995 with HID-AEI 1995 with standard climate means for 1981-2010 was used as a reference, because for that year, validation data was available for the United States of America (see next Chapter). The absolute and relative percent ICU differences against HID-ACT-1995_refclim were calculated for four alternative climate means:

- 1901-1930 (clim1901, period as HID-ACT-1910_refclim)
- 1921-1950 (clim1921, second 30-year period before HID-ACT-1995_refclim)
- 1946-1975 (clim1946, period as HID-ACT-1960_refclim)
- 1951-1980 (clim1951, first 30-year period before HID-ACT-1995_refclim)

The special case where ICU values larger than zero are present in "new" grid cells which have no irrigation in the reference is also indicated (Figure 4.5 to Figure 4.8). The country-specific (national) ICU totals and ICU differences for China, Egypt, India, Bangladesh, Myanmar, Pakistan, and the USA are given in Table 4.3, and for all countries in Table A.8.

Table 4.3: Irrigation consumptive use (ICU) [km^3 a^{-1}], rounded, for year 1995, for runs HID-ACT-1995_refclim, clim1901, clim1921, clim1946, clim1951 and their difference to standard reference climate period refclim (1981-2010) [km^3 a^{-1} and % of HID-ACT-1995_refclim], for selected countries, with UN M49 country code

	Climate period	**Refclim (1981-2010)**	**Clim 1901**	Clim 1901 – Refclim	Clim 1901 – Refclim	**Clim 1921**	Clim 1921 – Refclim	Clim 1921 – Refclim	**Clim 1946**	Clim 1946 – Refclim	Clim 1946 – Refclim	**Clim 1951**	Clim 1951 – Refclim	Clim 1951 – Refclim
	Run	ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT
Cty cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT 1981]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]
156	China	183.8	183.9	0.1	0.1	183.6	-0.2	-0.1	183.9	0.1	0.1	184.3	0.5	0.3
818	Egypt	47.7	50.1	2.8	5.8	49.8	2.4	5.1	49.7	2.3	4.9	49.8	2.5	5.2
356	India & Indian Empire	228.9	236.0	7.1	3.1	241.3	12.4	**5.4**	237.0	8.1	3.6	236.0	7.1	3.1
50	Bangladesh	14.7	13.5	-1.2	-8.1	13.7	-1.0	-6.7	14.6	-0.01	**-0.1**	14.0	-0.7	-4.6
104	Myanmar	4.0	3.5	-0.4	-10.8	3.6	-0.4	-9.0	3.6	-0.3	-8.5	3.7	-0.2	-5.9
586	Pakistan	69.9	83.3	13.5	19.3	85.7	15.8	22.6	81.3	11.4	16.4	80.8	10.9	15.6
840	United States	107.5	108.8	1.3	1.2	108.8	1.2	1.2	108.2	0.7	0.7	108.5	1.0	0.9

Most interestingly, the spatial patterns of absolute and percent difference for all compared climate periods are similar, with positive or negative absolute differences larger than 130 mm a^{-1} in Pakistan, India, and Bangladesh, whereas such negative absolute differences occur in Pakistan and India, while in Bangladesh only smaller decreases occur. Positive percent differences of more than 200% occur in eastern Argentina and Uruguay, where absolute differences are small. Negative percent differences between -50% and -95% occur e.g. in central and southeastern USA, Colombia, Ivory Coast, Nigeria, eastern states of India, and Myanmar. The maximal ICU decrease between -95% and -100% is present in 157 out of 66896 cells (HID-ACT-1995_clim1901), typically in mountainous or cold regions like eastern India, Nepal, Mongolia, western Russia, Finland, and Sweden, with difference mean -0.94 mm a^{-1} (minimum -51 mm a^{-1}), while 155 new cells with ICU, i.e. increase from zero are typically found in cold regions like Mongolia, eastern Russia, Finland, Sweden, and Norway, with difference mean 0.96 mm a^{-1} (maximum 25 mm a^{-1}).

The country-specific totals in Table 4.3 reflect this pattern in the case of China where, with increasing temporal distance to refclim, percent changes are nearly the same (0.3% (clim1951), 0.1% (clim1946), -0.1% (clim1921), and 0.1% (clim1901)). In other sample cases with increasing temporal distance to refclim, percent changes are also in general increasing in the case of Bangladesh (except clim1921: -0.1%, marked in bold, from -4.6% to -8.1%), Myanmar (from -5.9% to -10.8%), Pakistan (from 15.6% to 19.3%), and USA (from 0.9% to 1.2%). In Egypt, only oldest period clim1901 has stronger percent difference (5.8%) than the other periods (4.9% - 5.2%), while in India the period clim1921 has stronger percent difference (5.4%, marked in bold) than the other periods (3.1% - 3.6%).

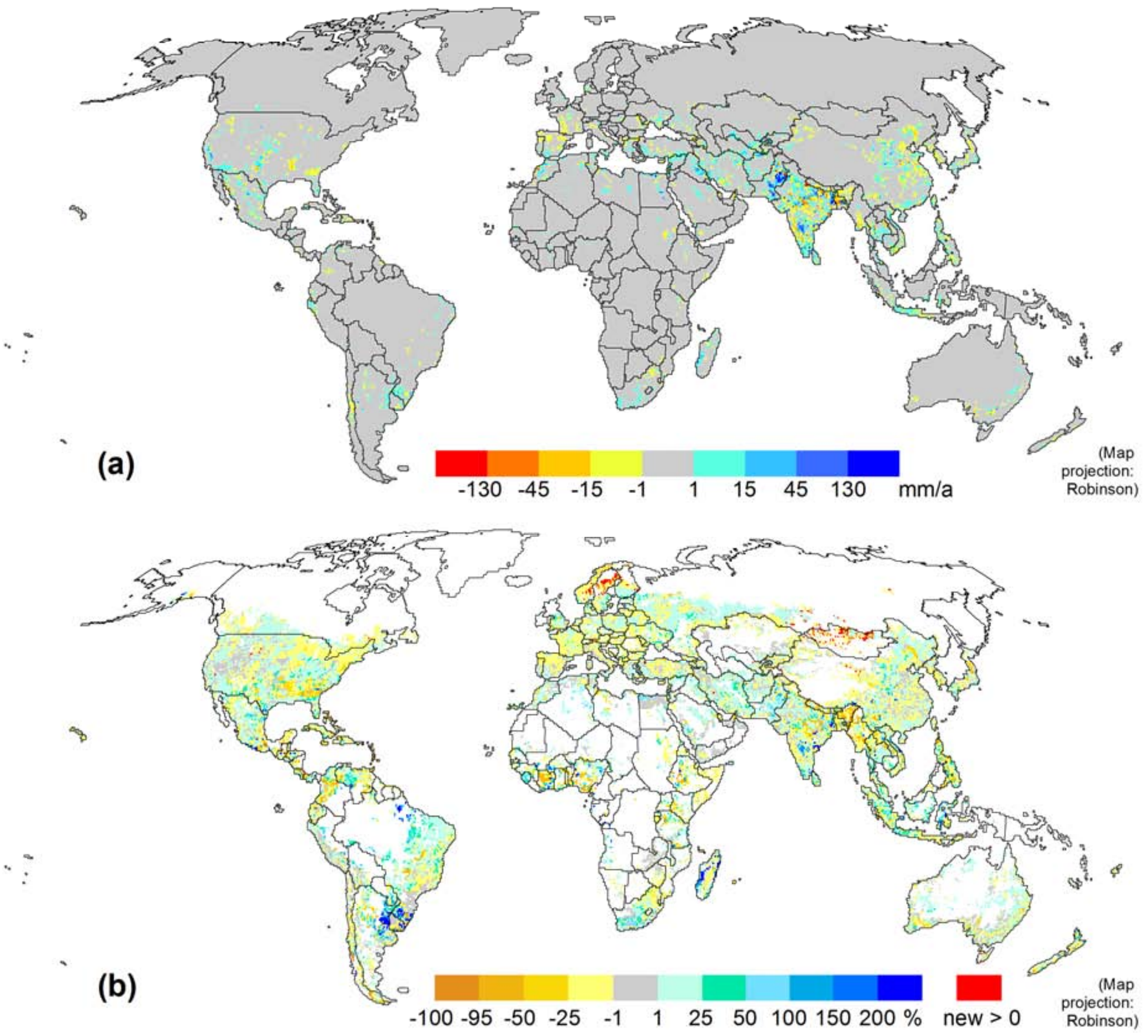


Figure 4.5: Differences in irrigation consumptive use [mm a^{-1}] for 1995, HID-ACT-1995 using HID-AEI-1995 and cropping period from climate period 1901-1930 vs. standard period 1981-2010, (a) Absolute difference HID-ACT-1995_clim1901 minus HID-ACT-1995_refclim, (b) Percent difference (HID-ACT-1995_clim1901 - HID-ACT-1995_refclim) / HID-ACT-1995_refclim

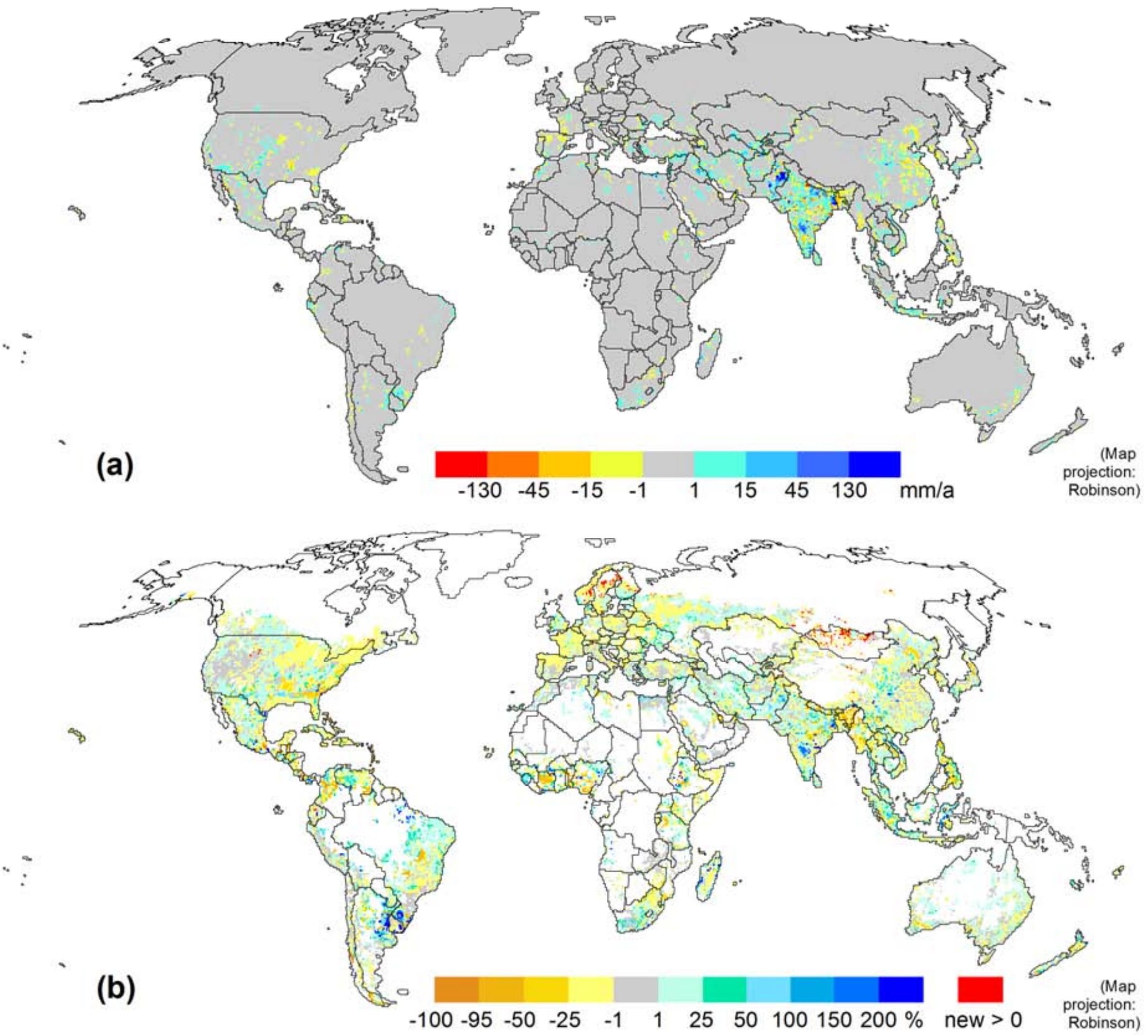


Figure 4.6: Differences in irrigation consumptive use [mm a^{-1}] for 1995, HID-ACT-1995 using HID-AEI-1995 and cropping period from climate period 1921-1950 vs. standard period 1981-2010, (a) Absolute difference HID-ACT-1995_clim1921 minus HID-ACT-1995_refclim, (b) Percent difference (HID-ACT-1995_clim1921 - HID-ACT-1995_refclim) / HID-ACT-1995_refclim

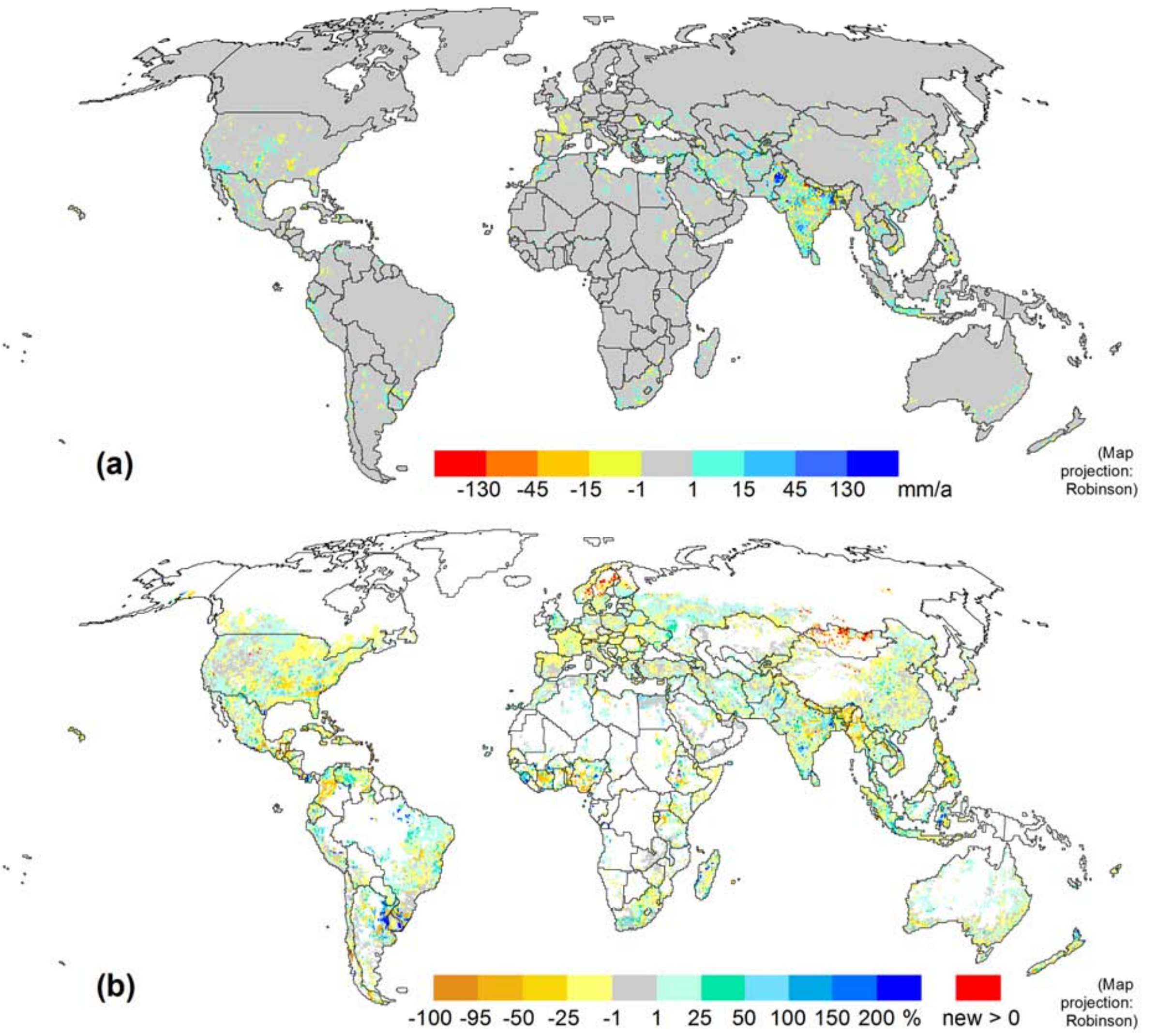


Figure 4.7: Differences in irrigation consumptive use [mm a^{-1}] for 1995, HID-ACT-1995 using HID-AEI-1995 and cropping period from climate period 1946-1975 vs. standard period 1981-2010, (a) Absolute difference HID-ACT-1995_clim1946 minus HID-ACT-1995_refclim, (b) Percent difference (HID-ACT-1995_clim1946 - HID-ACT-1995_refclim) / HID-ACT-1995_refclim

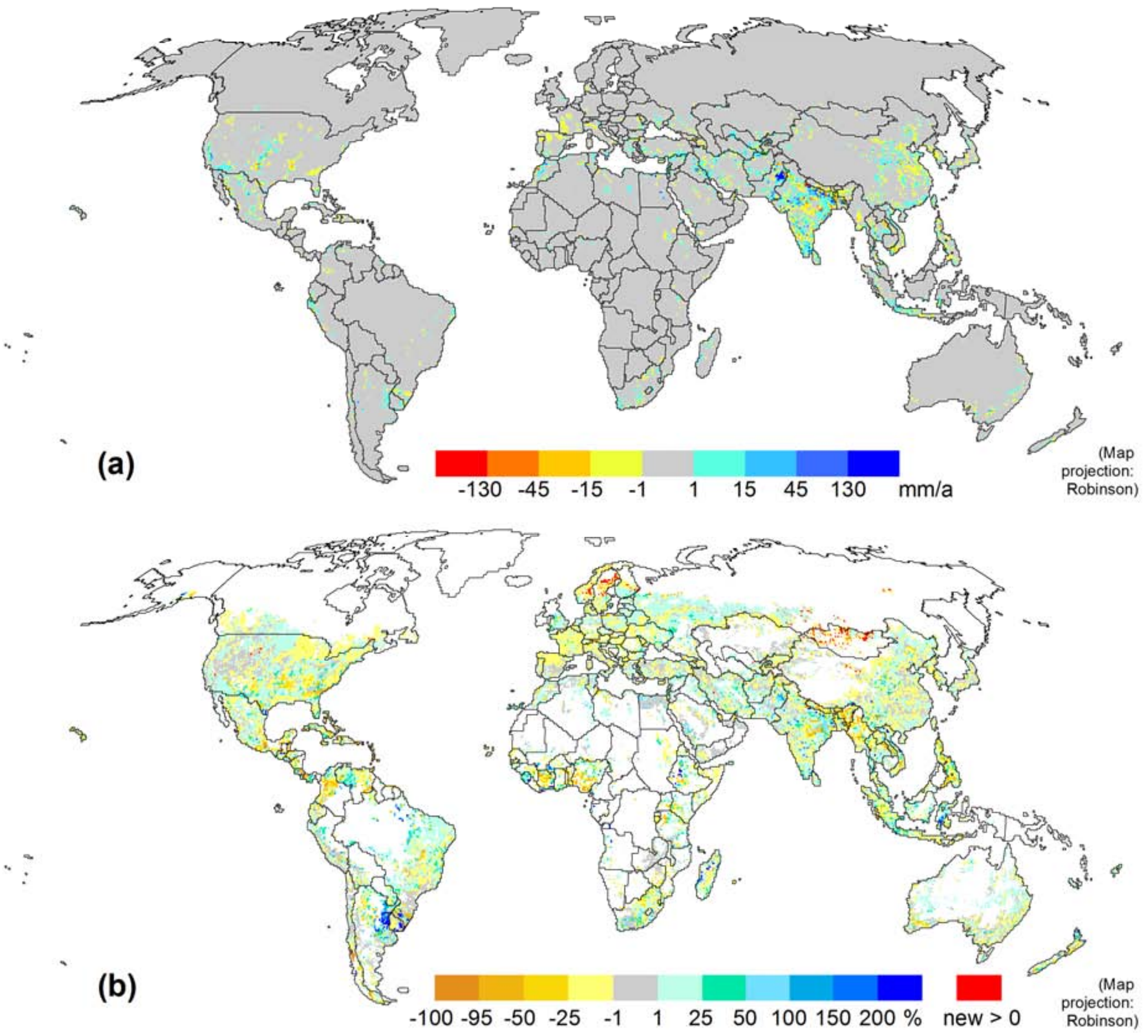


Figure 4.8: Differences in irrigation consumptive use [mm a^{-1}] for 1995, HID-ACT-1995 using HID-AEI-1995 and cropping period from climate period 1951-1980 vs. standard period 1981-2010, (a) Absolute difference HID-ACT-1995_clim1951 minus HID-ACT-1995_refclim, (b) Percent difference (HID-ACT-1995_clim1951 - HID-ACT-1995_refclim) / HID-ACT-1995_refclim

5. Validation

For validation, the United States of America (USA) have been selected because of the structure, quality and availability of reference data. Since the reporting year 1950 to the year 2010, every 5 years water use data on state level, sometimes also on county level, are freely available from the United States Geological Survey (USGS) National Water Use Information Program (NWUIP) (e.g. United States Geological Survey, 2017; MacKichan, 1951, 1957; MacKichan and Kammerer, 1961; Solley et al., 1987; Solley et al., 1983; Solley et al., 1988; Solley et al., 1998; Kenny et al., 2008; Maupin et al., 2014). Water withdrawals by sector are available for all reporting years, while irrigation consumptive use (ICU) on state level is only available between 1960 and 1995. These two years were used as a reference to validate the volume, and most of all the spatial pattern year-specific GIM ICU (run HID-ACT and HID-ACTHIST) versus state-level USGS ICU, named USGS-ICU-1960 and USGS-1995 following the conversions mentioned in Table 5.1. To estimate the possible uncertainty in irrigation withdrawal use (IWU), the effective IE of GIM (as ratio ICU / IWU) was compared to the respectively computed USGS IE and spatial patterns (USGS-IE-1960 and USGS-IE-1995). The results for 51 USA states and comparison data from runs HID-ACT-1960/1995 and HID-ACTHIST-1960/1995 with standard climate are given in Table 5.2 (extended data in electronic Appendix). For the map display, the GIM polygon grids of results were clipped to the boundaries of 49 USA states (without Alaska and Hawaii) (ESRI, 2004) plus a 50 km buffer, in order to be able to view whether grid cell values at the USA national boundaries were from neighboring countries or not.

Table 5.1: Used USGS state-level water use reference data for irrigation consumptive use, irrigation withdrawal use, and irrigation efficiency and explanation of applied data unit conversions and calculations

Acronym of reference data	**Water use element**	**ICU**	**IWU**	**IE**	**Source**
	Year	[km^3 a^{-1}] [mm a^{-1}]	[km^3 a^{-1}] [mm a^{-1}]	[%]	
USGS-ICU/IE-1960	1960	Conversion [mgal d^{-1}] to [km^3 a^{-1}], then to [mm a^{-1}] via state area given in (ESRI, 2004)	Conversion [mgal d^{-1}] to [km^3 a^{-1}], then to [mm a^{-1}] via state area given in (ESRI, 2004)	ICU*100/IWU	(MacKichan and Kammerer, 1961)
USGS-ICU/IE-1995	1995	Conversion [mgal d^{-1}] to [km^3 a^{-1}], then to [mm a^{-1}] via state area given in (ESRI, 2004)	Conversion [mgal d^{-1}] to [km^3 a^{-1}], then to [mm a^{-1}] via state area given in (ESRI, 2004)	ICU*100/IWU	(Solley et al., 1998)

Table 5.2: USGS state-level irrigation consumptive use and irrigation withdrawal use ([km^3 a^{-1}], [mm a^{-1}]), and irrigation efficiency [%] for years 1960 and 1995, for 51 USA states, with the respective state code, name, and area (ESRI, 2004), and data from runs HID-ACT-1960/1995 and HID-ACTHIST-1960/1995 with their respective mean climate period

Cde	State name	State area [km^2]	IWU1960 [km^3 a^{-1}]	ICU1960 [km^3 a^{-1}]	**IE1960 [%]**	IWU1995 [km^3 a^{-1}]	ICU1995 [km^3 a^{-1}]	**IE1995 [%]**	**ICU1960 [mm a^{-1}]**	IWU1960 [mm a^{-1}]	**ICU1995 [mm a^{-1}]**	IWU1995 [mm a^{-1}]
AL	Alabama	134454.80	0.0166	0.0166	100.0	0.1914	0.1914	100.0	0.12	0.12	1.42	1.42
AK	Alaska	1499362.00	0.0001	0.0001	62.5	0.0008	0.0004	50.9	0.00	0.00	0.00	0.00
AZ	Arizona	294304.41	6.4931	4.0064	61.7	7.8356	4.3916	56.0	13.61	22.06	14.92	26.62
AR	Arkansas	137529.69	1.2710	0.8842	69.6	8.2007	6.0685	74.0	6.43	9.24	44.13	59.63
CA	California	407350.72	24.8670	19.3410	77.8	39.9167	32.4953	81.4	47.48	61.05	79.77	97.99
CO	Colorado	269959.13	12.4335	6.6312	53.3	17.5934	6.7898	38.6	24.56	46.06	25.15	65.17
CT	Connecticut	12820.91	0.0014	0.0014	100.0	0.0381	0.0381	100.0	0.11	0.11	2.97	2.97
DE	Delaware	5067.32	0.0033	0.0033	100.0	0.0668	0.0668	100.0	0.65	0.65	13.18	13.18
DC	District of Columbia	159.77	0.0000	0.0000	0.0	0.0000	0.0000	0.0	0.00	0.00	0.00	0.00
FL	Florida	146202.92	0.9118	0.9118	100.0	4.7922	2.9923	62.4	6.24	6.24	20.47	32.78
GA	Georgia	152474.55	0.0511	0.0511	100.0	0.9979	0.9978	100.0	0.34	0.34	6.54	6.54
HI	Hawaii	16772.41	1.2710	0.5112	40.2	0.9004	0.5727	63.6	30.48	75.78	34.15	53.68
ID	Idaho	215998.86	15.1965	6.2168	40.9	18.0259	5.9570	33.0	28.78	70.35	27.58	83.45
IL	Illinois	150006.95	0.0033	0.0033	100.0	0.2487	0.2487	100.0	0.02	0.02	1.66	1.66
IN	Indiana	94663.95	0.0099	0.0099	100.0	0.1600	0.1440	90.0	0.10	0.10	1.52	1.69
IA	Iowa	145053.00	0.0843	0.0843	100.0	0.0533	0.0533	100.0	0.58	0.58	0.37	0.37
KS	Kansas	211835.16	2.4867	2.2104	88.9	4.6742	4.4551	95.3	10.43	11.74	21.03	22.07
KY	Kentucky	104090.63	0.0035	0.0035	100.0	0.0159	0.0151	95.1	0.03	0.03	0.15	0.15
LA	Louisiana	119039.89	1.1190	0.7875	70.4	1.0626	0.8240	77.5	6.62	9.40	6.92	8.93
ME	Maine	83792.27	0.0012	0.0012	100.0	0.0370	0.0333	90.0	0.01	0.01	0.40	0.44
MD	Maryland	25550.12	0.0073	0.0073	100.0	0.0857	0.0857	100.0	0.29	0.29	3.35	3.35
MA	Massachusetts	21032.23	0.0104	0.0046	44.0	0.1127	0.1121	99.5	0.22	0.49	5.33	5.36
MI	Michigan	250211.72	0.0304	0.0304	100.0	0.3139	0.2978	94.9	0.12	0.12	1.19	1.25
MN	Minnesota	224400.80	0.0098	0.0098	100.0	0.2165	0.1931	89.2	0.04	0.04	0.86	0.96
MS	Mississippi	124003.93	0.7046	0.5664	80.4	2.4059	1.5331	63.7	4.57	5.68	12.36	19.40
MO	Missouri	180287.83	0.0387	0.0387	100.0	0.7837	0.5822	74.3	0.21	0.21	3.23	4.35
MT	Montana	379981.53	7.0457	3.3156	47.1	11.8068	2.5115	21.3	8.73	18.54	6.61	31.07
NE	Nebraska	199851.77	3.0393	1.5197	50.0	10.4300	9.3152	89.3	7.60	15.21	46.61	52.19
NV	Nevada	286356.25	2.3486	1.3262	56.5	2.2715	1.4625	64.4	4.63	8.20	5.11	7.93
NH	New Hampshire	24148.85	0.0019	0.0018	92.9	0.0088	0.0079	90.1	0.07	0.08	0.33	0.36
NJ	New Jersey	19691.96	0.0484	0.0484	100.0	0.1724	0.0642	37.3	2.46	2.46	3.26	8.75
NM	New Mexico	315161.25	2.4867	1.7960	72.2	4.1355	2.3180	56.1	5.70	7.89	7.35	13.12
NY	New York	136684.75	0.0387	0.0387	100.0	0.0408	0.0366	89.7	0.28	0.28	0.27	0.30
NC	North Carolina	127852.28	0.0373	0.0373	100.0	0.3296	0.3296	100.0	0.29	0.29	2.58	2.58
ND	North Dakota	182050.78	0.1160	0.0774	66.7	0.1610	0.1450	90.0	0.43	0.64	0.80	0.88
OH	Ohio	116288.46	0.0117	0.0106	90.6	0.0377	0.0356	94.5	0.09	0.10	0.31	0.32
OK	Oklahoma	181125.67	0.3730	0.2625	70.4	1.1941	0.5533	46.3	1.45	2.06	3.05	6.59
OR	Oregon	250821.56	6.6312	3.8682	58.3	8.5206	4.2440	49.8	15.42	26.44	16.92	33.97
PA	Pennsylvania	119194.94	0.0041	0.0041	100.0	0.0220	0.0220	100.0	0.03	0.03	0.18	0.18
RI	Rhode Island	2731.78	0.0003	0.0003	100.0	0.0032	0.0032	100.0	0.11	0.11	1.17	1.17
SC	South Carolina	80529.14	0.0635	0.0635	100.0	0.0719	0.0719	100.0	0.79	0.79	0.89	0.89
SD	South Dakota	198303.77	0.2072	0.1520	73.3	0.3710	0.2421	65.3	0.77	1.04	1.22	1.87
TN	Tennessee	108956.13	0.0152	0.0152	100.0	0.0338	0.0338	100.0	0.14	0.14	0.31	0.31
TX	Texas	685501.13	12.2954	8.5653	69.7	13.0563	11.2512	86.2	12.49	17.94	16.41	19.05
UT	Utah	219676.61	4.5590	3.0393	66.7	4.8808	2.6645	54.6	13.84	20.75	12.13	22.22
VT	Vermont	24662.45	0.0010	0.0010	94.7	0.0053	0.0048	89.9	0.04	0.04	0.19	0.21
VA	Virginia	103768.91	0.0497	0.0484	97.2	0.0410	0.0252	61.3	0.47	0.48	0.24	0.40
WA	Washington	173756.91	5.1116	1.7960	35.1	8.9368	3.8636	43.2	10.34	29.42	22.24	51.43
WV	West Virginia	62456.36	0.0017	0.0017	100.0	0.0000	0.0000	0.0	0.03	0.03	0.00	0.00
WI	Wisconsin	169366.98	0.0221	0.0221	100.0	0.2331	0.2089	89.6	0.13	0.13	1.23	1.38
WY	Wyoming	253935.11	4.2827	2.6249	61.3	9.1106	3.6740	40.3	10.34	16.87	14.47	35.88
USA	USA_51	9449281.30	115.8175	70.9686	61.3	184.6046	112.2278	60.8	7.51	12.26	11.88	19.54
	HID-ACT		139.3739	83.9833	60.3	178.4413	107.5281	60.3				
	HID_ACTHIST		118.9985	71.7075	60.3	174.1670	104.9109	60.2				

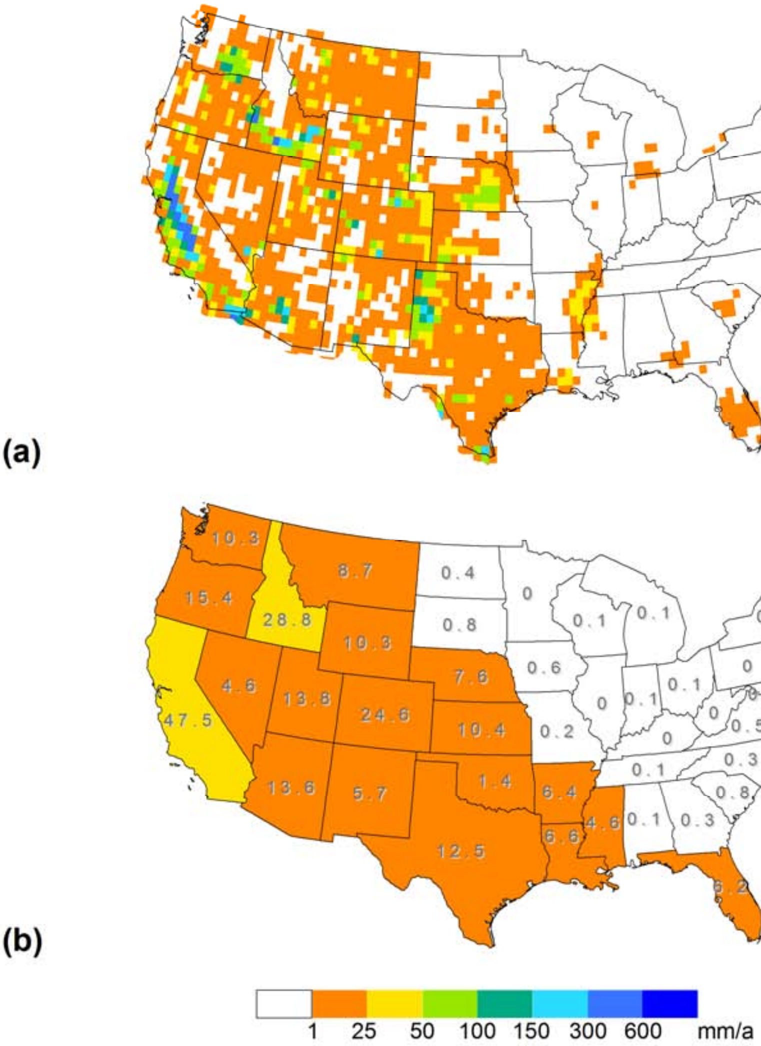
5.1 *Comparison of irrigation consumptive use (ICU) of 1960 and 1995 for states of the USA*

In 1960, most irrigation was concentrated in the westerns states of California and Idaho, with mean USGS-ICU of 47.2 mm a^{-1} and 28.8 mm a^{-1}, respectively, with the grid cells of highest ICU HID-ACT clearly located there. The central and eastern USA observed nearly no irrigation, besides the states of Florida and New Jersey (Figure 5.1).

In 1995, in addition to California and Idaho, the High Plains Aquifer (Texas, Kansas, Nebraska) has high ICU, visible in the state averages of 46.6 mm a^{-1} USGS-ICU for Nebraska, whereas for Nebraska only 21 mm a^{-1} and for Texas only 16.4 mm a^{-1} are reported. Probably this is an effect of spatial averaging. Also Arkansas (USGS-ICU 44.1 mm a^{-1}) is similarly visible in HID-ACT. On the other hand, the high value of Colorado (USGS-ICU 25.2 mm a^{-1}) probably is not visible as a hot spot in HID-ACT because of much broader distribution of irrigation within this state (Figure 5.2).

In contrast, the spatial pattern in the country-specific scaled HID-ACTHIST run result for 1960 is still strongly influenced by the pattern of 2000 (assumed to be similar to that of 1995, see Figure 4.3). The values for 1960 in the High Plains Aquifer and the state of Arkansas appear to be overestimated (Figure 5.3).

Regarding the country-specific (national) totals as tabulated in Table 5.2, in 1995, HID-ACT-1995_refclim fits better to both ICU and IWU of reference USGS-1995 than the scaled result HID-ACTHIST-1995_refclim. In 1960, in contrast to the worse spatial pattern in HID-ACTHIST-1960_refclim, the country-specific totals of both IWC and IWU are smaller than that of HID-ACT-1960_refclim and fit better to the USGS-1960 reference values. Nevertheless, the calculated IE of both HID-ACT and HID-ACTHIST is about 60.3%, which compares well to the country-specific totals of 61.3% (USGS-IE-1960) and 60.8% (USGS-IE-1995), with differences being discussed in the next subchapter.



(Map projection: EPSG 6350
NAD 1983 (2011)
Albers Equal Area Conic)

Figure 5.1: Irrigation consumptive use [mm a^{-1}] for 1960,
(a) ICU HID-ACT-1960_refclim
(using HID-AEI-1960 and cropping periods for climate 1946-1975),
(b) USGS-ICU-1960 (MacKichan and Kammerer, 1961)

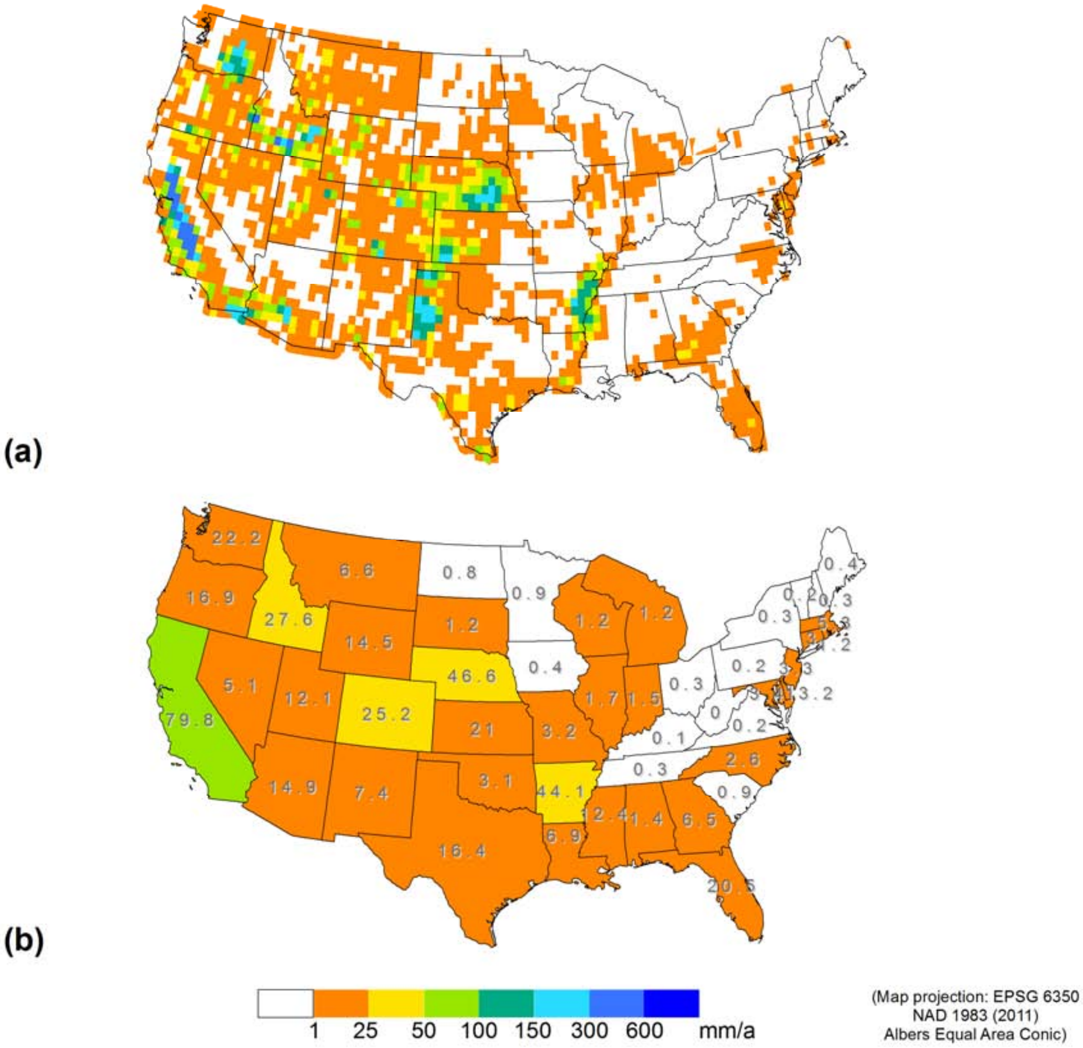


Figure 5.2: Irrigation consumptive use [mm a^{-1}] for 1995,
(a) ICU HID-ACT-1995_refclim
(using HID-AEI-1995 and cropping periods for climate 1981-2010),
(b) USGS-ICU-1995 (Solley et al., 1998)

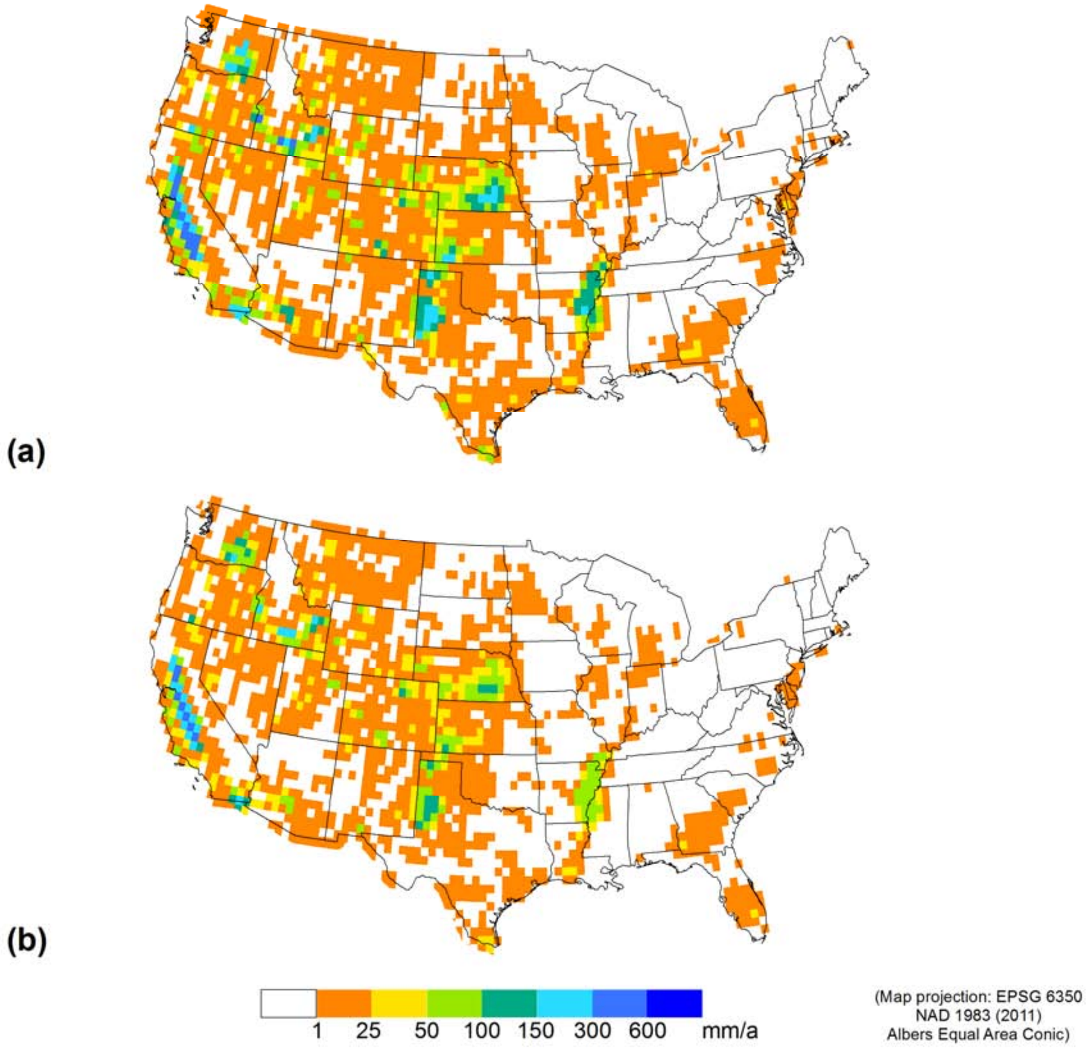


Figure 5.3: Irrigation consumptive use [mm a^{-1}] with country-specific scaling, using country-specifically scaled HID-AEI-2000 and cropping periods for climate 1985-2014,
(a) HID-ACTHIST-1995_clim1985
(b) HID-ACTHIST-1960_clim1985

5.2 *Comparison of irrigation efficiency (IE) of 1960 and 1995 for states of the USA*

In order to assess the uncertainty from regional and country-specific IE, for the USA, for 1960 and 1995, the country-specific IE and the pattern of grid-cell specific IE of HID-ACT are compared to reference values of state-level USGS-IE. As mentioned in the previous subchapter, the country-specific national average IE from ratio ICU/IWU of HID-ACT and also of HID-ACTHIST of ca. 60% quite well corresponds to the national USGS average of the USA of ca. 61% (Table 5.2). Within GIM, for each region, from the prescribed regional IE (60% for non-rice crops for USA), effective regional IE for rice and non-rice crops are calculated, with an example for 1995 given in Table A.3, with these values being used to transform ICU to IWU also on grid-cell level, applied to the grid-cell specific shares of cropping patterns.
Concerning the IE spatial pattern of HID-ACT, it its clearly visible, that irrigation is much broader distributed in 1995 (Figure 5.5(a)) than in 1960 (Figure 5.4(a)), where the central USA was less covered (zero IE, 1960: 51% of grid cells covering the USA including Alaska and Hawaii, 1995: 31%). In southern USA towards the Gulf of Mexico, mainly Texas, Louisiana and Florida, the IE with ca. 50% is 10% less than IE for the rest of the irrigated areas, indicating that GIM cropping periods locate rice-growing areas there, probably due to the applied climatic limits and, possibly, flat topography. The similar class values in the bordering cells of Mexico are valid for non-rice crops in the region of Central America, such as the value of ca. 70% in the bordering cells of Canada (Table 3.1, Table A.3). In addition to that, the spatial pattern reveals high regional variability. As a consequence, IWU were not compared, because the difference would have been mainly caused by the difference in IE, rather than in ICU.

Concerning the IE spatial pattern of USGS-IE, state-level IE values of nearly 100% (> 95%) are probably an artifact of small ICU and IWU values in census statistics, as they occur only with relatively small totals of withdrawal and consumption, e.g. in 1960 mostly less than USGS-ICU-1960 0.1 $km^3 a^{-1}$ or 0.3 $mm a^{-1}$ (except Kansas with 2.2 $km^3 a^{-1}$ or 10.4 $mm a^{-1}$), and in 1995 mostly less than USGS-ICU-1995 0.33 $km^3 a^{-1}$ or 5 $mm a^{-1}$ (except Kansas with 4.4 $km^3 a^{-1}$ or 21.0 $mm a^{-1}$, Georgia with 1.0 $km^3 a^{-1}$ or 6.5 $mm a^{-1}$, Delaware with 0.07 $km^3 a^{-1}$ or 13.2 $mm a^{-1}$) (Figure 5.4(b) and Figure 5.5(b)). Except for California and Nevada, in all western states IE surprisingly often decreased from 1960 to 1995, while in most other states ICU and IWU totals increased. In the High Plains Aquifer, IE increased in Texas and Kansas, while it decreased in Oklahoma. IE decrease is also visible in Mississippi and Florida, together with an increase in ICU, while in Virginia IE decrease is associated with decreased ICU.

Thus, the obvious different spatial pattern of IE from GIM run HID and in USGS reference data shows different aspects: In GIM, it mainly depends on the partitioning of rice and non-rice crops, because only one IE value is used for each category. The USGS census statistics clearly show that IE higher than 95% should be questioned, and that IE is not constant over time, possibly an effect of newly introduced agricultural practices, e.g. implementation of irrigation projects supplied by surface water or with long-distance water transfers and associated conveyance losses, or just different methods to estimate losses, and thus, the IWU (Dickens et al., 2011).

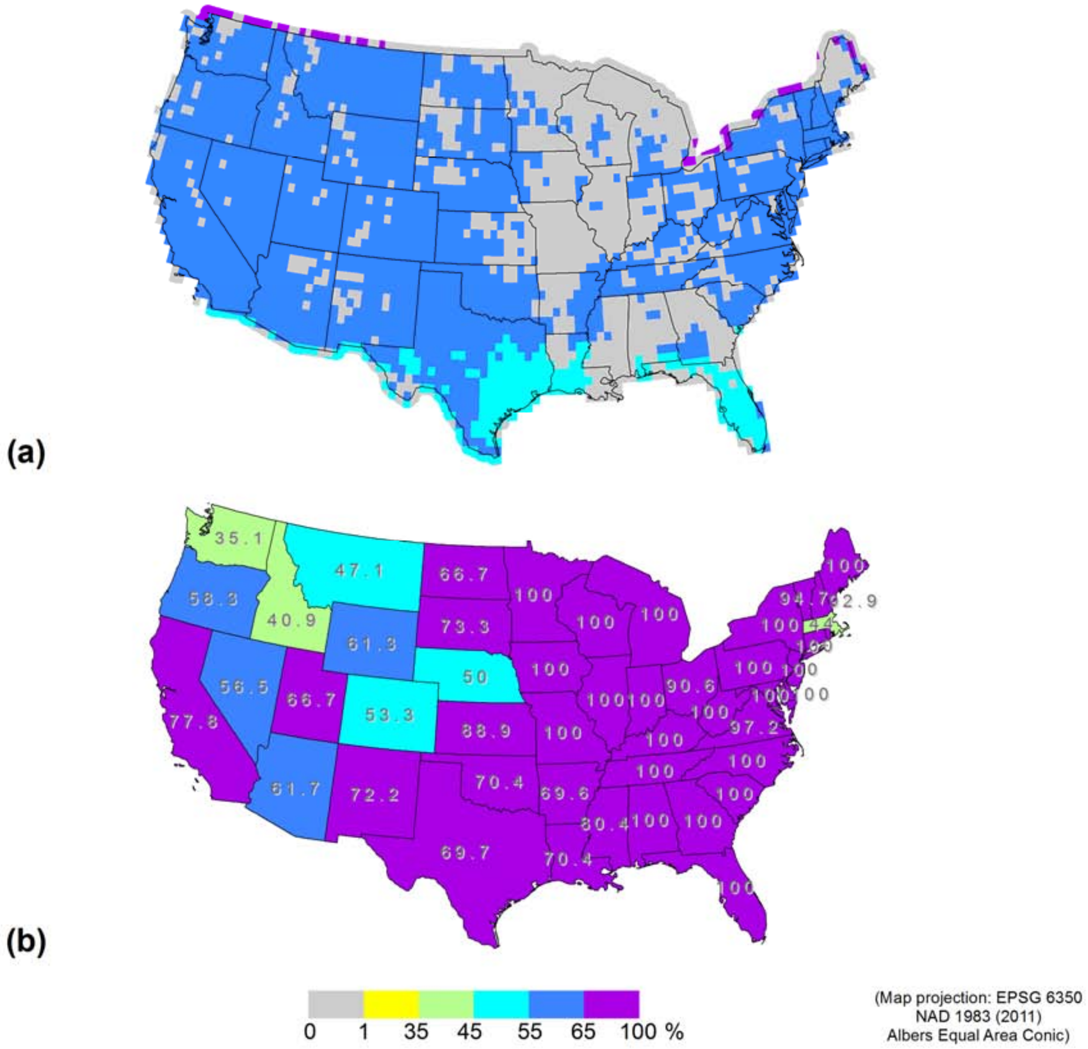
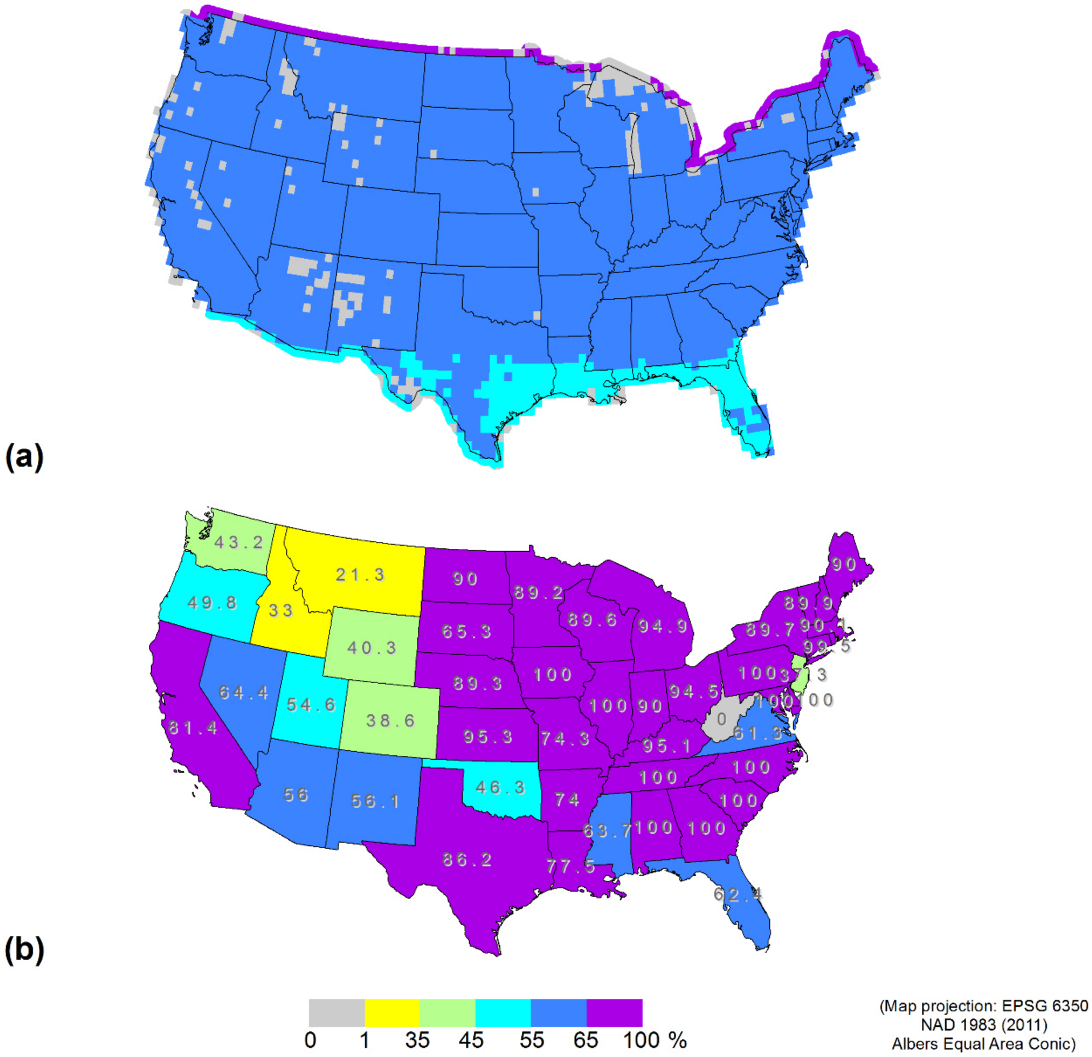


**Figure 5.4: Irrigation efficiency [%] for 1960,
(a) IE HID-ACT-1960_refclim
(using HID-AEI-1960 and cropping periods for climate 1946-1975),
(b) USGS-IE-1960 (MacKichan and Kammerer, 1961)**



(Map projection: EPSG 6350
NAD 1983 (2011)
Albers Equal Area Conic)

Figure 5.5: Irrigation efficiency [%] for 1995,
(a) IE HID-ACT-1995_refclim
(using HID-AEI-1995 and cropping periods for climate 1981-2010),
(b) USGS-IE-1995 (Solley et al., 1998)

6. Discussion and outlook

The extent of irrigated area is a key variable in modeling ICU from agricultural crops (Döll and Siebert, 2002; Wisser et al., 2008) which is used in GHMs like WaterGAP (Müller Schmied et al., 2014) and WBMplus (Wisser et al., 2010). Because there are different methods to characterize and derive irrigated area, e.g. from Area Equipped for Irrigation (AEI) for administrative units or geospatial information on irrigation projects like in the Global Map of Irrigation Areas (GMIA) (Siebert et al., 2013a, 2013b), or from multisensor remote sensing from classification of land use and land cover pattern like in the Global Irrigation Area Map (GIAM) (Thenkabail et al., 2008), the resulting absolute areas or percent coverage per grid cell are different between the products. The new Historical Irrigation Data set (HID) combines historical data on land use and AEI from various sources, and tries to maximize consistency between them which results in different products depending on the desired focus. The "average" product AEI_HYDE_FINAL_IR was chosen which uses the History Database of the Global Environment (HYDE) with the longest historical record and which maximizes consistency with AEI, the point of focus of this study.

The Global Irrigation Model (GIM) is used within the state-of-the-art WaterGAP model for calculating ICU. The scientific aim was to test the hypothesis that the use of HID with GIM improves the estimation of the historical development and spatial pattern of ICU (and possibly IWU) against the country-specific national scaling approach in GIM, at the grid-cell and national level. ICU and IWU of GIM were multiplied with the fraction of AAI/AEI to obtain "actual" ICU and IWU using AAI (Area Actually Irrigated, and not "potential", using the full AEI), and to enable a comparison to validation statistics for the USA.

The country-specific (national-level) AEI scaling always preserves the spatial pattern of AEI of the reference year, irrespective of the source of AEI, e.g. GMIA or HID, as can be clearly seen when comparing the ICU spatial patterns of HID-ACT and deviations of HID-ACTHIST for the reference years 1910, 1960, 1995, and 2005 (Figure 4.1 to Figure 4.4). Thus, any change in spatial coverage, especially more grid cells with irrigation, cannot be represented with such an approach. Also, any change in grid cell-specific AEI represented by country-specific scaling factors is only uniformly applied to all grid cells of a country. This means, that the complete abandonment of AEI in a subset of these grid cells cannot be represented with this type of scaling. The evaluation of the grid cell-specific differences is based on the assumption that the grid-cell specific values of HID-AEI represent a best guess of the history of spatial pattern in terms of extent (covered grid cells) and intensity (area per grid cell or fraction of grid cell). This should hold true at least for the 14 reference years, but also for intermediate years for which the AEI grid was linearly interpolated. Any ICU derived from this baseline in run HID-ACT is considered as the reference spatial pattern or optimal spatial guess. Then, the differences HID-ACTHIST minus HID-ACT show the deviations from the optimal spatial guess. These differences increase with temporal distance to the scaling reference year 2000 (Figure 4.1(b) to Figure 4.4(b)): The strongest absolute difference occurs in the year 1910 for the difference HID-ACTHIST-1910_clim1985 minus HID-ACT-1910_refclim (Figure 4.1(b)), followed by smaller differences in 1960, and even smaller differences in the years 1995 and 2005. Also, the percent relative difference of national ICU totals in general increase from 2005 backward to 1910, as e.g. in the example of the USA (Table 4.2). This supports the conclusion that country-specific AEI scaling as in run HID-ACTHIST results generally in spatial patterns that are worse than the reference HID-ACT which uses year-specific AEI. This means that we can accept the research hypothesis that HID-ACT better represents the historical development and the related spatial pattern. Therefore, it should preferably be used when looking at historical time periods.

A source of uncertainty might be the chosen climate period for the calculation of the cropping patterns. To test this, ICU for the year 1995 was calculated using cropping patterns with the same AEI, but different climate periods starting as early as 1901, and the results were compared to reference climate (refclim, 1981-2010). The resulting patterns show a persistent absolute and percentage difference for historical periods before refclim (e.g. Figure 4.5(b)). This pattern might stem from an already present climate change trend in temperature. This indicates that the selected climate period matters for the definition of cropping patterns, and thus, the ICU calculation. On the other hand, interruptions in this temporal trend as in Bangladesh and India might be due to the quality of the climate forcing data. For a more detailed analysis, the trends of specific climate elements (e.g. temperature) in the climate forcing data and related changes in calculated cropping patterns and growing periods could be compared.

The ICU and IE were validated using USA state-level data from USGS for 1960 and 1995. The spatial pattern of HID-ACT agrees much better with USGS-ICU reference data than HID-ACTHIST for both years, supported by a better fit of the national total for 1995. But surprisingly, the national total for 1960 of HID-ACTHIST fits better to the USGS-ICU reference. Several reasons might be responsible for this difference, first of all perhaps a different method to estimate USGS-ICU in 1995 than in 1960. Unfortunately, only a documentation and evaluation of the USGS methodology for the years 2000 and 2005 is available (Dickens et al., 2011). Another possible source of discrepancy may be the uncertainty related to climate forcing (Müller Schmied et al., 2016a). The IE is a key to transform ICU to IWU in global models, with currently regional or country-specific (national-level) IE averages. This method is used, e.g. in GIM (regional IE for rice and non-rice crops, averaged to grid cell via weighting of cropping patterns), GWSWUSE (country-specific IE) (Döll et al., 2012; Müller Schmied et al., 2014) as well as in WBMplus (country-specific IE) (Wisser et al., 2010). The IE patterns of GIM are dominated by the spatial differentiation of non-rice and rice crops, whereas the reference USGS-IE shows considerable spatial variation on state level (Figure 5.4 and Figure 5.5). Nevertheless, national average IE of GIM and USGS are nearly the same with 60% and 61%, respectively, in both 1960 and 1995. This indicates that IWU derived from ICU via IE should have a large uncertainty if subnational spatial heterogeneity of IE is large as in the case of the USA. Perhaps maps with subnational project-specific IE including conveyance losses etc. like that from GMIA version 5 for the ratio AAI/AEI could help in obtaining a better spatial estimate. For comparison purposes, ICU should be preferred to IWU, as done in this study. Concerning country totals, the better fit of ICU from HID-ACTHIST-1960 than HID-ACT-1960 does not support the hypothesis of an improvement at the national level of country totals. But as mentioned before, various factors are responsible for the discrepancy, and for 1995, HID-ACT is superior also at country totals. But, for the most common application case of catchment-based analyses, the correct representation of the spatial pattern is more important than a possibly arbitrary fit to rarely available country totals.

As ICU is derived from Epot, the choice of the Epot calculation algorithm is important. For this study, the Priestley-Taylor approach was selected, because for the alternative Penman-Monteith algorithm, time series of wind speed and saturation deficit would have been necessary, and as these data are rarely available globally in high quality with daily temporal resolution, the preferred time step. For the water use calculation direct daily precipitation data was preferred to the estimation of daily precipitation from a combination of monthly data of precipitation sum and number of rain days, which introduces more uncertainty for this important climate element. In the case of monthly precipitation data, the spatial pattern resulting from the temporal disaggregation of monthly to daily values using the method described in Döll et al. (2003) is not coherent. The uncertainty of the Priestley-Taylor alpha factor was considered to be acceptable versus the uncertainty of the other meteorological elements.

Overall, the newly developed GIM code enables much more flexibility for studies at runtime than the previous code. Even if the historical development is best represented via HID, still uncertainty exist about the sensitivity on, e.g. the choice of HID products, and possible difference when using another AEI source, for current and future conditions.

Possible topics for future studies with the new GIM version might include quantification of the sensitivity of ICU ACT, e.g.

(1) For a current reference year to the choice of AEI, e.g. HID HYDE vs. HID Earthstat, GMIA4, or GMIA5, to evaluate implications for calculations of present-day conditions,
(2) For its historical development to the choice of AEI, e.g. HID-AEI_HYDE_FINAL_IR (year 2005) and HID-AEI_EARTHSTAT_IR (2005) or the whole range of HID products,
(3) For its historical development to different climate forcing, perhaps also the sensitivity of the shares of all water uses or of renewable water resources as calculated by Müller Schmied et al. (2016a),
(4) Using selected climate projections to the choice of AEI, like (1), to evaluate implications for projections to the future.

Future data or code development may include:

(1) Generation of year-specific AHI Rice time series from census statistics, replacing the country-specific scaling of AHI Rice from MIRCA2000,
(2) Introduction of optional grid-cell-specific deficit irrigation factor,
(3) Introduction of permanent crops as a new cropping pattern, with kc-value parametrization and/or grid-cell specific presence supported by grid-cell specific majority class of permanent crops in MIRCA2000,
(4) Introduction of additional temperature sums for the ranking of growing periods.

7. References

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Appendix A: Supplementary tables

In this Appendix, tables and other information extending the main part of the document are given. All tables together with additional material, e.g. data columns, sorting, and selected input data, are also available in the electronic Appendix as Microsoft © Excel files (xls-format 97-2003).

A.1 Lists of countries with grid presence and attribution to region

In the following tables, a full list of the 245 countries (national spatial units) present in HID is given, together with an indication whether the country is present in the 30 arc-min country mask of year 2000 (used for the country-specific AEI scaling). There are 41 units or 17% missing, which includes small countries like Andorra or Liechtenstein, state-cities like Monaco, and mostly islands). Country numerical 3 digit code is of UN M49 list. Spatial units that had no original UN country code, were given a numerical code larger than 900 (i.e. 901, 902, and 903). The regions are specified according to the numerical code used for cropping intensity (GIM2002-REG_CI) and for irrigation efficiency (GIM2002-REG_IE). In order to be consistent to HID, the country names are primarily given as specified in HID documentation of unit-specific AEI sums (Supplement S3 of Siebert et al. (2015)). The used naming and attribution to regions does not imply any legal correctness in terms of official or controversial naming or attribution. Table A.1 presents the list sorted by UN numerical country code as used in other tables, too, while Table A.2 presents the same list sorted by HID country name.

Table A.1: List of HID countries (sorted by country code) with country code (UN M49), presence in 30 arc-min country mask HID-COUNTRY-2000, attribution to regions of cropping intensity (GIM2002-REG_CI) and irrigation efficiency (GIM2002-REG_IE), and country name

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
4	1	13	13	Afghanistan
8	1	10	10	Albania
10	0	19	19	Antarctica
12	1	5	5	Algeria
16	1	16	16	American Samoa
20	0	9	18	Andorra
24	1	8	8	Angola
28	1	3	3	Antigua and Barbuda
31	1	11	19	Azerbaijan
32	1	4	4	Argentina
36	1	16	16	Australia
40	1	9	9	Austria
44	1	3	3	Bahamas
48	1	12	12	Bahrain
50	1	13	13	Bangladesh
51	1	11	19	Armenia
52	1	3	3	Barbados
56	1	9	9	Belgium
60	0	2	2	Bermuda

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
64	1	13	13	Bhutan
68	1	4	4	Bolivia
70	1	10	10	Bosnia and Herzegovina
72	1	8	8	Botswana
74	0	19	19	Bouvet Island
76	1	4	4	Brazil
84	1	3	3	Belize
86	0	13	13	British Indian Ocean Territory
90	1	16	16	Solomon Islands
92	1	3	3	British Virgin Islands
96	1	15	15	Brunei
100	1	10	10	Bulgaria
104	1	15	15	Myanmar
108	1	7	7	Burundi
112	1	11	11	Belarus
116	1	15	15	Cambodia
120	1	6	6	Cameroon
124	1	1	1	Canada
132	1	6	6	Cape Verde
136	0	3	3	Cayman Islands
140	1	6	6	Central African Republic
144	1	13	13	Sri Lanka
148	1	6	6	Chad
152	1	4	4	Chile
156	1	14	14	China
158	1	14	14	Taiwan
162	0	15	15	Christmas Island
166	0	15	15	Cocos Islands
170	1	4	4	Colombia
174	1	7	7	Comoros
175	1	7	7	Mayotte
178	1	6	6	Republic of Congo
180	1	6	6	Democratic Republic of the Congo
184	0	16	16	Cook Islands
188	1	3	3	Costa Rica
191	1	10	10	Croatia
192	1	3	3	Cuba
196	1	12	12	Cyprus
203	1	10	10	Czech Republic
204	1	6	6	Benin
208	1	9	9	Denmark
212	1	3	3	Dominica
214	1	3	3	Dominican Republic
218	1	4	4	Ecuador
222	1	3	3	El Salvador
226	1	6	6	Equatorial Guinea
231	1	7	7	Ethiopia
232	1	7	7	Eritrea

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
233	1	11	11	Estonia
234	1	9	9	Faroe Islands
238	1	4	4	Falkland Islands
239	0	19	19	South Georgia and the South Sandwich Islands
242	1	16	16	Fiji
246	1	9	9	Finland
250	1	9	18	France
254	1	4	4	French Guiana
258	0	16	16	French Polynesia
260	0	19	19	French Southern Territories
262	1	7	7	Djibouti
266	1	6	6	Gabon
268	1	11	19	Georgia
270	1	6	6	Gambia
275	1	12	12	Palestine (West Bank & Gaza Strip)
276	1	9	9	Germany & German Empire
288	1	6	6	Ghana
292	0	9	18	Gibraltar
296	0	16	16	Kiribati
300	1	9	18	Greece
304	1	18	18	Greenland
308	1	3	3	Grenada
312	1	3	3	Guadeloupe
316	0	16	16	Guam
320	1	3	3	Guatemala
324	1	6	6	Guinea
328	1	4	4	Guyana
332	1	3	3	Haiti
334	0	19	19	Heard Island and McDonald Islands
336	0	9	18	Vatican City
340	1	3	3	Honduras
344	1	14	14	Hong Kong
348	1	10	10	Hungary
352	1	9	9	Iceland
356	1	13	13	India & Indian Empire
360	1	15	15	Indonesia
364	1	12	12	Iran
368	1	12	12	Iraq
372	1	9	9	Ireland
376	1	12	12	Israel
380	1	9	18	Italy
384	1	6	6	Côte d'Ivoire
388	1	3	3	Jamaica
392	1	17	17	Japan
398	1	11	19	Kazakhstan
400	1	12	12	Jordan
404	1	7	7	Kenya
408	1	14	14	North Korea

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
410	1	14	14	South Korea
414	1	12	12	Kuwait
417	1	11	19	Kyrgyzstan
418	1	15	15	Laos
422	1	12	12	Lebanon
426	1	8	8	Lesotho
428	1	11	11	Latvia
430	1	6	6	Liberia
434	1	5	5	Libya
438	0	9	9	Liechtenstein
440	1	11	11	Lithuania
442	1	9	9	Luxembourg
446	0	14	14	Macao
450	1	7	7	Madagascar
454	1	8	8	Malawi
458	1	15	15	Malaysia
462	0	13	13	Maldives
466	1	6	6	Mali
470	1	9	18	Malta
474	1	3	3	Martinique
478	1	6	6	Mauritania
480	1	7	7	Mauritius
484	1	3	3	Mexico
492	0	9	18	Monaco
496	1	14	14	Mongolia
498	1	11	19	Moldova
500	1	3	3	Montserrat
504	1	5	5	Morocco
508	1	8	8	Mozambique
512	1	12	12	Oman
516	1	8	8	Namibia
520	0	16	16	Nauru
524	1	13	13	Nepal
528	1	9	9	Netherlands
530	1	3	3	Netherlands Antilles
533	0	3	3	Aruba
540	1	16	16	New Caledonia
548	1	16	16	Vanuatu
554	1	16	16	New Zealand
558	1	3	3	Nicaragua
562	1	6	6	Niger
566	1	6	6	Nigeria
570	0	16	16	Niue
574	0	16	16	Norfolk Island
578	1	9	9	Norway
580	0	16	16	Northern Mariana Islands
581	0	16	16	United States Minor Outlying Islands
583	0	16	16	Micronesia

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
584	0	16	16	Marshall Islands
585	0	16	16	Palau
586	1	13	13	Pakistan
591	1	3	3	Panama
598	1	16	16	Papua New Guinea
600	1	4	4	Paraguay
604	1	4	4	Peru
608	1	15	15	Philippines
612	0	16	16	Pitcairn Islands
616	1	10	10	Poland
620	1	9	18	Portugal
624	1	6	6	Guinea-Bissau
626	1	15	15	East Timor
630	1	3	3	Puerto Rico
634	1	12	12	Qatar
638	1	7	7	Reunion
642	1	10	10	Romania
643	1	11	19	Russia
646	1	7	7	Rwanda
654	0	8	8	Saint Helena
659	1	3	3	Saint Kitts and Nevis
660	0	3	3	Anguilla
662	1	3	3	Saint Lucia
666	1	2	2	Saint Pierre and Miquelon
670	1	3	3	Saint Vincent and the Grenadines
674	0	9	18	San Marino
678	1	6	6	Sao Tome and Principe
682	1	12	12	Saudi Arabia
686	1	6	6	Senegal
690	0	7	7	Seychelles
694	1	6	6	Sierra Leone
702	1	15	15	Singapore
703	1	10	10	Slovakia
704	1	15	15	Vietnam
705	1	10	10	Slovenia
706	1	7	7	Somalia
710	1	8	8	South Africa
716	1	8	8	Zimbabwe
724	1	9	18	Spain
732	1	5	5	Western Sahara
736	1	7	7	Sudan
740	1	4	4	Suriname
744	1	9	9	Svalbard and Jan Mayen
748	1	8	8	Swaziland
752	1	9	9	Sweden
756	1	9	9	Switzerland
760	1	12	12	Syria
762	1	11	19	Tajikistan

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
764	1	15	15	Thailand
768	1	6	6	Togo
772	0	16	16	Tokelau
776	1	16	16	Tonga
780	1	3	3	Trinidad and Tobago
784	1	12	12	United Arab Emirates
788	1	5	5	Tunisia
792	1	12	12	Turkey
795	1	11	19	Turkmenistan
796	1	3	3	Turks and Caicos Islands
798	0	16	16	Tuvalu
800	1	7	7	Uganda
804	1	11	19	Ukraine
807	1	10	10	Macedonia
818	1	5	5	Egypt
826	1	9	9	United Kingdom
831	0	9	9	Guernsey
832	1	9	9	Jersey
833	1	9	9	Isle of Man
834	1	8	8	Tanzania
840	1	2	2	United States
850	1	3	3	Virgin Islands, U.S.
854	1	6	6	Burkina Faso
858	1	4	4	Uruguay
860	1	11	19	Uzbekistan
862	1	4	4	Venezuela
876	0	16	16	Wallis and Futuna
882	1	16	16	Samoa
887	1	12	12	Yemen
891	1	10	10	Serbia, Montenegro, Kosovo
894	1	8	8	Zambia
901	0	3	3	Clipperton Island
902	1	11	19	Caspian Sea
903	0	15	15	Spratly Islands

Table A.2: List of HID countries (sorted by country name) with country code (UN M49), presence in 30 arc-min country mask HID-COUNTRY-2000, attribution to regions of cropping intensity (GIM2002-REG_CI) and irrigation efficiency (GIM2002-REG_IE), and country name

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
4	1	13	13	Afghanistan
8	1	10	10	Albania
12	1	5	5	Algeria
16	1	16	16	American Samoa
20	0	9	18	Andorra
24	1	8	8	Angola
660	0	3	3	Anguilla
10	0	19	19	Antarctica
28	1	3	3	Antigua and Barbuda
32	1	4	4	Argentina
51	1	11	19	Armenia
533	0	3	3	Aruba
36	1	16	16	Australia
40	1	9	9	Austria
31	1	11	19	Azerbaijan
44	1	3	3	Bahamas
48	1	12	12	Bahrain
50	1	13	13	Bangladesh
52	1	3	3	Barbados
112	1	11	11	Belarus
56	1	9	9	Belgium
84	1	3	3	Belize
204	1	6	6	Benin
60	0	2	2	Bermuda
64	1	13	13	Bhutan
68	1	4	4	Bolivia
70	1	10	10	Bosnia and Herzegovina
72	1	8	8	Botswana
74	0	19	19	Bouvet Island
76	1	4	4	Brazil
86	0	13	13	British Indian Ocean Territory
92	1	3	3	British Virgin Islands
96	1	15	15	Brunei
100	1	10	10	Bulgaria
854	1	6	6	Burkina Faso
108	1	7	7	Burundi
116	1	15	15	Cambodia
120	1	6	6	Cameroon
124	1	1	1	Canada
132	1	6	6	Cape Verde
902	1	11	19	Caspian Sea
136	0	3	3	Cayman Islands
140	1	6	6	Central African Republic
148	1	6	6	Chad

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
152	1	4	4	Chile
156	1	14	14	China
162	0	15	15	Christmas Island
901	0	3	3	Clipperton Island
166	0	15	15	Cocos Islands
170	1	4	4	Colombia
174	1	7	7	Comoros
184	0	16	16	Cook Islands
188	1	3	3	Costa Rica
384	1	6	6	Côte d'Ivoire
191	1	10	10	Croatia
192	1	3	3	Cuba
196	1	12	12	Cyprus
203	1	10	10	Czech Republic
180	1	6	6	Democratic Republic of the Congo
208	1	9	9	Denmark
262	1	7	7	Djibouti
212	1	3	3	Dominica
214	1	3	3	Dominican Republic
626	1	15	15	East Timor
218	1	4	4	Ecuador
818	1	5	5	Egypt
222	1	3	3	El Salvador
226	1	6	6	Equatorial Guinea
232	1	7	7	Eritrea
233	1	11	11	Estonia
231	1	7	7	Ethiopia
238	1	4	4	Falkland Islands
234	1	9	9	Faroe Islands
242	1	16	16	Fiji
246	1	9	9	Finland
250	1	9	18	France
254	1	4	4	French Guiana
258	0	16	16	French Polynesia
260	0	19	19	French Southern Territories
266	1	6	6	Gabon
270	1	6	6	Gambia
268	1	11	19	Georgia
276	1	9	9	Germany & German Empire
288	1	6	6	Ghana
292	0	9	18	Gibraltar
300	1	9	18	Greece
304	1	18	18	Greenland
308	1	3	3	Grenada
312	1	3	3	Guadeloupe
316	0	16	16	Guam
320	1	3	3	Guatemala
831	0	9	9	Guernsey

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
324	1	6	6	Guinea
624	1	6	6	Guinea-Bissau
328	1	4	4	Guyana
332	1	3	3	Haiti
334	0	19	19	Heard Island and McDonald Islands
340	1	3	3	Honduras
344	1	14	14	Hong Kong
348	1	10	10	Hungary
352	1	9	9	Iceland
356	1	13	13	India & Indian Empire
360	1	15	15	Indonesia
364	1	12	12	Iran
368	1	12	12	Iraq
372	1	9	9	Ireland
833	1	9	9	Isle of Man
376	1	12	12	Israel
380	1	9	18	Italy
388	1	3	3	Jamaica
392	1	17	17	Japan
832	1	9	9	Jersey
400	1	12	12	Jordan
398	1	11	19	Kazakhstan
404	1	7	7	Kenya
296	0	16	16	Kiribati
414	1	12	12	Kuwait
417	1	11	19	Kyrgyzstan
418	1	15	15	Laos
428	1	11	11	Latvia
422	1	12	12	Lebanon
426	1	8	8	Lesotho
430	1	6	6	Liberia
434	1	5	5	Libya
438	0	9	9	Liechtenstein
440	1	11	11	Lithuania
442	1	9	9	Luxembourg
446	0	14	14	Macao
807	1	10	10	Macedonia
450	1	7	7	Madagascar
454	1	8	8	Malawi
458	1	15	15	Malaysia
462	0	13	13	Maldives
466	1	6	6	Mali
470	1	9	18	Malta
584	0	16	16	Marshall Islands
474	1	3	3	Martinique
478	1	6	6	Mauritania
480	1	7	7	Mauritius
175	1	7	7	Mayotte

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
484	1	3	3	Mexico
583	0	16	16	Micronesia
498	1	11	19	Moldova
492	0	9	18	Monaco
496	1	14	14	Mongolia
500	1	3	3	Montserrat
504	1	5	5	Morocco
508	1	8	8	Mozambique
104	1	15	15	Myanmar
516	1	8	8	Namibia
520	0	16	16	Nauru
524	1	13	13	Nepal
528	1	9	9	Netherlands
530	1	3	3	Netherlands Antilles
540	1	16	16	New Caledonia
554	1	16	16	New Zealand
558	1	3	3	Nicaragua
562	1	6	6	Niger
566	1	6	6	Nigeria
570	0	16	16	Niue
574	0	16	16	Norfolk Island
408	1	14	14	North Korea
580	0	16	16	Northern Mariana Islands
578	1	9	9	Norway
512	1	12	12	Oman
586	1	13	13	Pakistan
585	0	16	16	Palau
275	1	12	12	Palestine (West Bank & Gaza Strip)
591	1	3	3	Panama
598	1	16	16	Papua New Guinea
600	1	4	4	Paraguay
604	1	4	4	Peru
608	1	15	15	Philippines
612	0	16	16	Pitcairn Islands
616	1	10	10	Poland
620	1	9	18	Portugal
630	1	3	3	Puerto Rico
634	1	12	12	Qatar
178	1	6	6	Republic of Congo
638	1	7	7	Reunion
642	1	10	10	Romania
643	1	11	19	Russia
646	1	7	7	Rwanda
654	0	8	8	Saint Helena
659	1	3	3	Saint Kitts and Nevis
662	1	3	3	Saint Lucia
666	1	2	2	Saint Pierre and Miquelon
670	1	3	3	Saint Vincent and the Grenadines

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
882	1	16	16	Samoa
674	0	9	18	San Marino
678	1	6	6	Sao Tome and Principe
682	1	12	12	Saudi Arabia
686	1	6	6	Senegal
891	1	10	10	Serbia, Montenegro, Kosovo
690	0	7	7	Seychelles
694	1	6	6	Sierra Leone
702	1	15	15	Singapore
703	1	10	10	Slovakia
705	1	10	10	Slovenia
90	1	16	16	Solomon Islands
706	1	7	7	Somalia
710	1	8	8	South Africa
239	0	19	19	South Georgia and the South Sandwich Islands
410	1	14	14	South Korea
724	1	9	18	Spain
903	0	15	15	Spratly Islands
144	1	13	13	Sri Lanka
736	1	7	7	Sudan
740	1	4	4	Suriname
744	1	9	9	Svalbard and Jan Mayen
748	1	8	8	Swaziland
752	1	9	9	Sweden
756	1	9	9	Switzerland
760	1	12	12	Syria
158	1	14	14	Taiwan
762	1	11	19	Tajikistan
834	1	8	8	Tanzania
764	1	15	15	Thailand
768	1	6	6	Togo
772	0	16	16	Tokelau
776	1	16	16	Tonga
780	1	3	3	Trinidad and Tobago
788	1	5	5	Tunisia
792	1	12	12	Turkey
795	1	11	19	Turkmenistan
796	1	3	3	Turks and Caicos Islands
798	0	16	16	Tuvalu
800	1	7	7	Uganda
804	1	11	19	Ukraine
784	1	12	12	United Arab Emirates
826	1	9	9	United Kingdom
840	1	2	2	United States
581	0	16	16	United States Minor Outlying Islands
858	1	4	4	Uruguay
860	1	11	19	Uzbekistan
548	1	16	16	Vanuatu

Country code (UN M49)	Grid presence	Region CI	Region IE	Country name (HID)
336	0	9	18	Vatican City
862	1	4	4	Venezuela
704	1	15	15	Vietnam
850	1	3	3	Virgin Islands, U.S.
876	0	16	16	Wallis and Futuna
732	1	5	5	Western Sahara
887	1	12	12	Yemen
894	1	8	8	Zambia
716	1	8	8	Zimbabwe

A.2 Regional irrigation efficiencies for 1995

In Table A.3, regional irrigation efficiencies as used for HID-ACT-1995_refclim, and the calculated effective irrigation efficiencies for 1995 using the cropping periods derived from AEI for 1995 and standard climate means from 1981-2010 are listed for the effective 19 regions.

Table A.3: Regional irrigation efficiencies (IE) [Fractions ICU/IWU] for 1995, as used for HID-ACT-1995_refclim, i.e. for climate periods with HID-AEI-1995 and climate means 1981-2010

Region code (GIM)	Region	IE_NR (Non-Rice) (prescribed) (IE_R = IE_NR-0.1)	IE_NR (Non-Rice) (effective)	IE_R (Rice) (effective)
1	Canada	0.7	0.7	0.6
2	USA	0.6	0.604618	0.504618
3	Central America	0.45	0.453808	0.353808
4	South America	0.45	0.470506	0.370506
5	North Africa (“Northern Africa“)	0.7	0.70697	0.60697
6	West Africa (“Western Africa“)	0.45	0.47414	0.37414
7	East Africa (“Eastern Africa“)	0.55	0.580085	0.480085
8	South Africa (“Southern Africa“)	0.55	0.555023	0.455023
9	OECD Europe 1: Northern OECD-Europe	0.5	0.5	0.4
18	OECD Europe 2: Southern OECD-Europe	0.6	0.603356	0.503357
10	Eastern Europe	0.5	0.500223	0.400223
11	CIS 1: Baltic Republics + Belarus	0.5	0.5	0.4
19	CIS 2: Rest of former USSR (Soviet Union)	0.6	0.603204	0.503204
12	Near East Countries	0.6	0.603688	0.503688
13	India + South Asia (“South Asia“)	0.35	0.379184	0.279184
14	China + CPC (“East Asia“)	0.35	0.392745	0.292745
15	East Asia (“South East Asia“)	0.4	0.485151	0.385151
16	Oceania	0.7	0.702058	0.602058
17	Japan	0.35	0.394062	0.294062

A.3 Country-specific national HID-AEI totals, at 30 arc-min resolution

In Table A.4 country-specific national AEI totals [ha] for the 14 HID reference years (1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1985, 1990, 1995, 2000, and 2005) and their respective country mask HID-COUNTRY are listed, on basis of the 30 arc-min grid. In the electronic Appendix, the AEI for all years 1900 to 2005 are also given.

Table A.4: Country-specific national HID-AEI totals [ha] from 30 arc-min grid for the 14 HID reference years between 1900 and 2005, according to the year-specific country masks HID-COUNTRY

C cod	Country name (HID)	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000	2005
4	Afghanistan	635694	712212	788315	863004	1372512	1883440	2473359	2478917	2596736	2702994	3008272	3312736	3307521	3305059
8	Albania	613	8478	16361	25769	30568	43301	150246	284567	360181	385467	406853	333072	332646	360938
10	Antarctica	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Algeria	174020	174345	174769	211092	226754	242324	255385	243867	261252	347267	463437	568295	581229	583626
16	American Samoa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Andorra	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	Angola	37369	43517	49664	55812	61960	68107	74383	75118	80119	80119	80119	80119	80119	80119
28	Antigua and Barbuda	0	0	0	0	0	0	0	50	340	260	180	130	130	130
31	Azerbaijan	545034	553189	360394	607156	745640	943527	1120439	1136021	1188420	1241800	1380739	1420356	1421710	1428685
32	Argentina	264648	608805	963081	1119909	908636	943818	960182	1299878	1577964	1581300	1573644	1587562	1808997	1805698
36	Australia	60700	101227	141754	266190	562421	875411	1345292	2336285	2358247	2534410	2844261	3752183	3614704	3993254
40	Austria	42277	42212	40473	34612	26610	34026	42185	52925	72988	80711	99515	132343	120317	129490
44	Bahamas	0	0	0	0	0	0	0	0	1000	1000	1000	1000	1000	1000
48	Bahrain	500	582	664	746	828	910	996	996	996	996	1676	2249	2420	2420
50	Bangladesh	0	0	0	0	0	349585	559297	1159954	1577119	2125438	2765655	3496824	4235514	4656192
51	Armenia	112173	112922	74315	117720	186669	212784	243273	276210	281433	305172	305506	292436	297290	292083
52	Barbados	0	0	0	0	0	0	1000	1000	1000	3000	5000	5000	5000	5000
56	Belgium	17776	16386	15413	12637	10334	10619	13286	19438	27500	31021	44277	40141	65658	28322
60	Bermuda	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	Bhutan	5880	5880	5880	5880	5880	5655	6182	13379	19149	22026	29582	29556	30469	27907
68	Bolivia	3000	6441	10032	13512	15439	28600	67536	79504	138537	124023	123791	126641	126881	128065
70	Bosnia and Herzegovina	2005	2005	2005	2005	2005	2797	5376	6816	7540	7578	7877	5787	4380	5450
72	Botswana	215	231	249	413	500	518	1043	1250	1976	2024	1856	2029	2376	2376
74	Bouvet Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	Brazil	400	400	400	400	30808	61023	436532	766713	1435633	1912042	2290865	3048828	3073969	4135293
84	Belize	0	0	0	0	0	0	0	436	436	833	833	1093	1093	1422
86	British Indian Ocean Territory	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	Solomon Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	British Virgin Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	Brunei	0	24	56	96	135	199	252	363	1415	1433	1433	1433	1433	1433
100	Bulgaria	31414	33149	34851	36488	37695	150455	685337	1093484	1478926	1569385	1575604	951458	571232	235022
104	Myanmar	0	0	0	0	0	562851	548447	853006	1029793	1102838	1109477	1651694	1912097	2192729
108	Burundi	48	48	48	48	48	48	14063	14485	14877	15956	15975	19119	23396	23396
112	Belarus	2180	2180	1235	4390	7539	28828	50238	110848	159130	157324	147981	131414	115310	110961
116	Cambodia	4394	15228	26813	38584	50595	62891	75303	107011	148531	220518	282179	316623	350849	492326
120	Cameroon	128	246	344	424	497	570	1570	5885	11993	18133	19093	20946	23363	23714
124	Canada	32400	118800	186333	235010	271303	308039	344498	608273	859385	1078252	1035268	1259976	1153787	1205397
132	Cape Verde	0	328	656	984	1311	1639	1967	2000	2000	2000	2779	2780	3110	3110
136	Cayman Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140	Central African Republic	0	0	0	0	0	0	0	0	0	135	500	1000	1000	1000
144	Sri Lanka	100000	138525	177049	215574	254098	292622	331148	465000	457000	500000	520000	570000	570000	585365
148	Chad	872	1738	2623	3527	4437	5348	6776	9115	14007	16852	18883	23011	28505	32722
152	Chile	799250	799249	872574	985428	1014507	1043170	1072027	1179653	1255130	1349773	1602952	1899210	1899332	1899331
156	China	17627792	17610342	17934183	19433131	18500830	17580711	29783809	39776805	48723867	48200679	51818158	53840716	58746069	61779532
158	Taiwan	145640	249730	353820	457909	562000	501693	488697	521056	546646	550372	510500	525528	508990	492451
162	Christmas Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0
166	Cocos Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170	Colombia	10000	10005	10019	10035	30058	80092	220137	250365	399983	464800	648702	898702	898702	898697
174	Comoros	0	0	0	0	0	0	0	0	0	130	130	130	130	130
175	Mayotte	0	0	0	0	0	0	0	0	0	0	0	0	0	0
178	Republic of Congo	0	0	0	0	0	0	0	1000	1000	1000	1000	2000	2000	2000
180	Democratic Republic of the Congo	0	0	0	0	0	0	0	0	6830	8578	9585	10733	11664	11664
184	Cook Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
188	Costa Rica	9008	10994	13012	15035	17057	19080	23692	24428	57306	68726	72558	87098	102329	102369
191	Croatia	6721	6922	7116	7304	7488	8867	11495	21749	26443	24809	22908	21984	20793	20216
192	Cuba	30000	36122	42245	48367	54490	71333	210000	450000	762000	860999	889999	870001	870001	870000
196	Cyprus	9345	11076	12806	14537	16267	13941	25813	27000	30000	31000	36000	39938	49860	45850
203	Czech Republic	28376	27376	24252	21597	20083	19389	23051	25644	55420	71596	113915	129400	70466	37083
204	Benin	0	0	0	0	0	0	2000	2000	9275	9392	9781	10268	12390	12390
208	Denmark	9150	9150	9150	9150	9150	24185	36086	85597	374917	392629	411218	460570	427953	429872
212	Dominica	0	0	0	0	0	0	0	0	0	0	0	0	0	241
214	Dominican Republic	1000	1680	2360	3040	24308	101129	147513	173777	200078	221247	242126	270725	275133	290854
218	Ecuador	502	1616	3284	4606	148642	291556	446117	481099	631308	731182	830214	869294	874294	858062

C cod	Country name (HID)	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000	2005
222	El Salvador	1000	1120	1240	1360	1480	1600	17349	19500	34651	36579	38513	41410	43314	50370
226	Equatorial Guinea	0	0	0	0	0	0	0	0	0	0	0	0	0	0
231	Ethiopia	20715	22066	23409	24802	26264	27714	36453	58589	112283	186079	285842	289836	290245	317579
232	Eritrea	740	957	1164	1382	1596	1800	2013	4166	8087	13564	19371	21700	21700	21700
233	Estonia	135	135	77	273	470	1826	3179	7022	13410	10476	10143	4196	1365	1366
234	Faroe Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
238	Falkland Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
239	South Georgia and the South Sandwich Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
242	Fiji	0	0	0	0	0	0	0	1000	1000	1000	1000	3000	3000	3000
246	Finland	9894	7913	5935	3956	1977	0	444	15995	50945	57921	63888	85872	86044	70556
250	France	203918	253109	357501	393505	430222	462265	500270	763774	1345350	1526770	2082845	2492009	2617037	2687916
254	French Guiana	0	0	5	65	95	95	1095	1095	1095	2095	2095	3615	4896	5704
258	French Polynesia	0	0	0	0	0	0	0	0	0	0	933	933	933	933
260	French Southern Territories	0	0	0	0	0	0	0	0	0	0	0	0	0	0
262	Djibouti	0	0	0	0	0	0	675	675	675	675	675	675	676	676
266	Gabon	0	0	0	0	0	0	4000	4000	4000	4000	4000	4000	4000	4000
268	Georgia	103975	103975	63742	116731	159513	218380	269231	276830	358042	405255	443596	461868	450796	430200
270	Gambia	267	284	291	296	300	300	300	300	243	287	569	676	821	821
275	Palestine (West Bank & Gaza Strip)	1198	1888	2604	3415	4143	4859	14233	14864	15634	16849	15989	15375	15498	15353
276	Germany & German Empire	510852	500890	463881	397383	307815	277492	347868	697368	1238875	1475130	1566864	612901	587768	646128
288	Ghana	2026	2592	3158	3724	4290	4856	13776	15026	20080	25322	30346	31405	31306	59319
292	Gibraltar	0	0	0	0	0	0	0	0	0	0	0	0	0	0
296	Kiribati	0	0	0	0	0	0	0	0	0	0	0	0	0	0
300	Greece	101522	141529	181511	218723	258159	292681	568909	861075	988011	1156509	1112612	1234887	1293198	1562359
304	Greenland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
308	Grenada	0	0	0	0	0	0	0	0	0	0	200	200	200	219
312	Guadeloupe	0	0	0	0	0	0	889	2000	2000	2000	2000	2000	6000	6213
316	Guam	0	0	0	0	0	0	0	0	0	0	20	70	312	312
320	Guatemala	15989	18300	20615	23967	25236	27540	32434	54920	84630	100721	114820	126394	129563	140626
324	Guinea	5007	7565	10123	12663	15214	17762	20331	49698	89470	89563	89598	92700	95016	95016
328	Guyana	28780	35811	42666	49405	56227	65403	87886	117949	130701	136765	147230	158422	160471	160563
332	Haiti	7000	7000	13800	20600	27400	34302	35106	60069	69922	79824	80016	91866	91866	91866
334	Heard Island and McDonald Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
336	Vatican City	0	0	0	0	0	0	0	0	0	0	0	0	0	0
340	Honduras	8670	10930	13192	15449	17706	19955	38438	64819	66435	66922	73141	74341	81170	83571
344	Hong Kong	0	0	0	0	0	0	0	0	0	0	0	0	0	0
348	Hungary	19257	20643	21998	23144	24231	35046	77887	306055	434493	392257	372191	331995	282666	202431
352	Iceland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
356	India & Indian Empire	17776563	24055886	27793890	29809979	33734023	20635157	26406567	32628545	41050360	45584144	49537382	56804881	62034342	64987254
360	Indonesia	1396766	1545310	1867318	2362762	2858092	3353470	3896321	3898374	4105573	4105573	3646191	4419167	5498444	6720094
364	Iran	1136920	1698967	2256837	2829323	3400639	3974159	4559074	5753948	6068215	6509728	6723078	6969750	7592430	8043432
368	Iraq	408620	461204	514078	567120	620577	845032	1251189	1521430	1784778	1797200	3560790	3579606	3591894	3590247
372	Ireland	4807	3606	2404	1202	0	0	0	0	0	0	0	0	1086	1086
376	Israel	14873	20834	26645	32114	38748	47478	129050	160331	187173	207384	199838	196414	199527	179846
380	Italy	1300382	1407526	1625325	1875224	2115555	2271761	2427273	2944907	3500646	3678507	3856674	3701394	3855012	3972223
384	Côte d'Ivoire	1000	1492	1984	2475	2967	3459	3951	19881	43567	53444	65379	72129	72531	72531
388	Jamaica	6480	8477	10972	13468	15964	18526	21684	24000	24000	25000	25000	25214	25000	25000
392	Japan	2731306	2833659	2960280	3079126	3004240	2877201	3127600	2835729	3055001	2990300	2925702	2989572	2754200	2794579
398	Kazakhstan	1224019	1230293	1436905	1497034	1856041	2514341	2876141	3069912	3304050	3455559	3365602	3589350	3671008	2785079
400	Jordan	9311	10589	11851	13114	14400	19302	34777	39281	42852	52418	65658	78867	81485	85791
404	Kenya	5623	7098	8573	10049	11516	12981	14447	30005	42615	44848	56879	72452	86832	104650
408	North Korea	216238	248030	279763	311316	351696	388136	492810	510005	1107975	1246746	1388661	1416613	1423339	1432227
410	South Korea	284084	325841	367891	409987	463757	513055	634210	850222	907224	966689	1012209	934200	907455	866733
414	Kuwait	0	0	0	0	0	0	155	1256	1419	2314	3582	5337	7220	8377
417	Kyrgyzstan	385352	398961	480944	479375	603605	896130	1037027	1049524	1075901	1118029	1163003	1160515	1138721	1104601
418	Laos	3358	4356	5315	6257	7246	8289	10245	13903	88434	107029	124264	142829	287724	314438
422	Lebanon	6517	8389	10268	12073	13937	16726	29947	52401	68179	68612	68006	74352	84191	83144
426	Lesotho	360	363	363	486	566	658	1517	1782	1782	1782	2638	3282	3211	3211
428	Latvia	147	147	82	311	550	2275	4094	9396	14457	14663	13117	6594	743	820
430	Liberia	0	0	0	0	0	0	0	2041	2042	2142	3192	3192	3192	3192
434	Libya	40340	53619	66897	80176	93455	106733	120012	175340	225279	300164	469718	469720	469718	469424
438	Liechtenstein	0	0	0	0	0	0	0	0	0	0	0	0	0	0
440	Lithuania	430	430	564	928	1452	5313	9225	20550	29471	38905	43638	11426	7714	5054
442	Luxembourg	2826	2543	2261	1130	283	57	0	0	0	0	12	14	14	39
446	Macao	0	0	0	0	0	0	0	0	0	0	0	0	0	0
450	Madagascar	10000	57541	105082	152623	200164	247705	295246	330000	645000	826000	1000000	1086999	1086290	1086290
454	Malawi	484	484	484	484	494	523	1680	5793	22757	22788	24727	34346	55251	56963
458	Malaysia	97823	118108	138851	159489	179948	201123	222705	258630	318827	336478	342750	363359	365737	362782
462	Maldives	0	0	0	0	0	0	0	0	0	0	0	0	0	0
466	Mali	10050	12133	14219	16313	18405	51241	56698	61896	61376	61398	79408	80028	236930	236930
470	Malta	200	200	200	200	200	500	500	1000	1000	1000	1000	1000	2000	3020
474	Martinique	1000	1000	1000	1000	1000	1000	1000	1000	5000	4000	4000	5000	7000	6407
478	Mauritania	19152	22114	24562	26964	29352	31544	33865	45059	60267	66258	66539	59040	65276	68314
480	Mauritius	267	267	267	2153	4039	5925	7811	15000	16000	17000	17000	17500	21222	21400
484	Mexico	977753	983327	1310918	2071660	2121050	2156034	2683244	3395101	4899682	5203329	5518087	6116921	6308022	6569508
492	Monaco	0	0	0	0	0	0	0	0	0	0	0	0	0	0
496	Mongolia	4798	4798	4798	4798	4798	4798	5207	11775	38786	78011	98496	86428	85940	86471
498	Moldova	1930	1930	1036	4184	7429	30779	54151	129550	204583	275006	301664	355442	321737	258352
500	Montserrat	0	0	0	0	0	0	0	0	0	0	0	0	0	0
504	Morocco	399179	473907	581830	673333	748173	798119	848231	917805	1213423	1241961	1255889	1348247	1439443	1480352
508	Mozambique	10394	15394	20394	25471	30477	35449	51904	78822	119569	119173	118986	119403	125530	125530

C cod	Country name (HID)	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000	2005
512	Oman	19980	20094	20198	20318	20439	20603	20779	30507	39633	42615	58295	60830	61876	61020
516	Namibia	1208	1208	1216	1354	1594	1790	2939	5671	6111	6111	8371	9101	9824	9824
520	Nauru	0	0	0	0	0	0	0	0	0	0	0	0	0	0
524	Nepal	25938	46835	54434	58293	61870	54598	89842	132317	455313	649121	805242	1016715	1021816	1062280
528	Netherlands	216873	173741	153656	132146	131487	173202	241989	323871	408782	452507	648140	275887	416290	362865
530	Netherlands Antilles	0	0	0	0	0	0	0	0	0	0	0	0	0	0
533	Aruba	0	0	0	0	0	0	0	0	0	0	0	0	0	0
540	New Caledonia	0	0	0	0	0	1000	1000	2000	2000	2000	4000	6000	9000	9000
548	Vanuatu	0	0	0	0	0	0	0	0	0	0	0	0	0	0
554	New Zealand	53902	80853	107803	134754	161705	188656	215607	289375	441738	593233	621814	605401	577882	607462
558	Nicaragua	2129	4777	7408	10040	12673	15312	18204	40718	61120	61262	61383	62868	63990	95578
562	Niger	3178	4631	6249	7923	9632	11389	13118	14731	18613	23889	53519	53563	60447	60762
566	Nigeria	137822	148664	159342	169962	180548	191087	202653	203269	204603	206341	242386	247380	302778	305304
570	Niue	0	0	0	0	0	0	0	0	0	0	0	0	0	0
574	Norfolk Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0
578	Norway	24520	19639	14749	11811	7890	9851	17002	29559	73117	89002	95981	125855	133249	116110
580	Northern Mariana Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
581	United States Minor Outlying Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
583	Micronesia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
584	Marshall Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
585	Palau	0	0	0	0	0	0	0	0	0	0	0	0	0	0
586	Pakistan	0	0	0	0	0	9621080	10751180	13055848	14806452	15349459	15745385	16250224	16147847	16491501
591	Panama	8015	9168	10314	11453	12592	13731	15182	21346	30972	33410	34565	36922	47232	47232
598	Papua New Guinea	0	0	0	0	0	0	0	0	0	0	0	0	0	0
600	Paraguay	0	4918	9836	14754	20495	25480	30370	41469	61398	66521	67267	69236	70818	72928
604	Peru	112596	212409	311518	434324	765280	1097858	1429769	1592099	1641868	1685838	1716667	1633074	1703485	1706948
608	Philippines	50000	121453	192906	264360	335813	426208	675500	826001	1219001	1440000	1550000	1600628	1727198	1824236
612	Pitcairn Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
616	Poland	50148	41446	38407	28242	19209	19182	136061	251540	356241	341016	323080	202974	137732	125053
620	Portugal	214019	239643	273090	306254	401953	497708	618640	831579	816127	855642	868975	789968	794174	625128
624	Guinea-Bissau	1943	4268	6578	8899	11212	13519	15805	15937	15937	15937	15937	19696	23551	23551
626	East Timor	3531	5076	6686	8404	10232	12015	13905	14054	14704	15206	15522	24213	33551	35377
630	Puerto Rico	8804	12044	13731	14384	19071	28152	40469	36422	26709	28328	21519	24954	35848	37020
634	Qatar	0	0	0	0	0	0	4	992	2967	4874	5712	12369	12849	12799
638	Reunion	100	100	100	810	1510	2220	2930	5000	5000	8000	11000	12000	12000	9722
642	Romania	9248	10832	12638	14955	17205	46140	191046	653454	2014199	2594386	2802851	2849092	2335450	752369
643	Russia	234993	235079	142992	231722	324391	915613	1506921	3176608	4944982	5416103	6056880	4962696	3843722	2031968
646	Rwanda	0	0	0	0	0	0	1960	2565	2637	2733	2733	3445	5899	5899
654	Saint Helena	0	0	0	0	0	0	0	0	0	0	0	0	0	0
659	Saint Kitts and Nevis	18	18	18	18	18	18	18	18	18	18	18	18	18	18
660	Anguilla	0	0	0	0	0	0	0	0	0	0	0	0	0	0
662	Saint Lucia	0	0	0	0	0	0	1000	1000	1000	1000	2000	3321	3321	3321
666	Saint Pierre and Miquelon	0	0	0	0	0	0	0	0	0	0	0	0	0	0
670	Saint Vincent and the Grenadines	0	0	0	0	0	0	0	1000	1000	1000	1000	1000	1000	1000
674	San Marino	0	0	0	0	0	0	0	0	0	0	0	0	0	0
678	Sao Tome and Principe	2000	3262	4525	5787	7049	8311	9574	9700	9700	9700	9700	9700	9700	9700
682	Saudi Arabia	14917	67896	119836	170187	222923	276110	328336	355556	583020	1115936	1537665	1622754	1673251	1409763
686	Senegal	26582	30981	35917	40900	45898	51094	56158	63747	51596	73561	77669	64845	89444	97797
690	Seychelles	0	0	0	0	0	0	0	0	0	0	0	0	260	260
694	Sierra Leone	1000	1000	1000	1000	1000	1000	1000	6441	20446	28417	28417	29777	30787	30787
702	Singapore	0	0	0	0	0	0	0	0	0	0	0	0	0	0
703	Slovakia	1157	1911	3123	4702	6663	5756	11129	49742	67196	63052	148039	156543	175094	134845
704	Vietnam	298434	412302	525763	639313	753015	866646	985439	1195348	1687788	2470139	2858953	2959168	3595313	4510263
705	Slovenia	737	737	737	744	933	1976	1708	2152	2572	2839	2939	6322	15236	15681
706	Somalia	44285	51588	58900	66161	73362	80577	88063	94135	124392	200159	174892	200911	200954	175205
710	South Africa	160373	193620	226855	359272	502954	646778	794934	1000357	1128698	1128799	1200712	1355855	1501393	1501389
716	Zimbabwe	180	191	207	2795	5283	7750	20211	46080	80246	90051	108641	116248	170312	170312
724	Spain	1161229	1275026	1379455	1448414	1477269	1551934	2090587	2625536	2783075	2800182	2828748	2897737	3476198	3755906
732	Western Sahara	0	0	0	0	0	0	0	0	0	0	0	0	0	0
736	Sudan	200000	233912	267823	301734	395562	759797	1387526	1625084	1700163	1763257	1800321	1946322	1863322	1863322
740	Suriname	550	2257	4133	6072	7957	9788	11597	23428	34692	36602	37916	38854	39048	39048
744	Svalbard and Jan Mayen	0	0	0	0	0	0	0	0	0	0	0	0	0	0
748	Swaziland	0	0	0	4	6	6	27882	36297	36297	41297	41297	45297	46157	46143
752	Sweden	85482	68697	51920	35191	18445	13001	19621	33441	71124	100242	115278	124053	137997	168149
756	Switzerland	29160	23129	17197	14400	11712	13989	15456	14909	27516	30031	32722	35346	37664	42735
760	Syria	64614	74609	84664	94932	162441	288009	460429	410693	492509	592317	741055	964693	1115630	1322522
762	Tajikistan	199816	205916	235272	247069	307429	399130	452795	558702	654908	676205	694931	721659	719447	732541
764	Thailand	53559	76701	380690	684457	988130	1290919	1592638	1961214	3028110	4096337	4215348	4964394	5526868	6090783
768	Togo	974	974	974	974	974	974	974	974	1149	6735	6839	7129	7130	7217
772	Tokelau	0	0	0	0	0	0	0	0	0	0	0	0	0	0
776	Tonga	0	0	0	0	0	0	0	0	0	0	0	0	0	0
780	Trinidad and Tobago	0	179	536	893	1250	1607	1964	2000	3510	3676	3629	3601	5001	3601
784	United Arab Emirates	5477	9390	13324	17246	21167	25048	28903	43585	51495	56511	65601	90526	220289	226705
788	Tunisia	101350	100870	100389	99950	99481	99013	98539	196546	238504	294075	294625	377436	385389	435078
792	Turkey	598608	649827	701567	753594	814866	882236	1191443	1848197	2756146	3435001	3690500	4423503	5151135	5310597
795	Turkmenistan	183384	190408	223514	238368	296514	392277	452738	664020	980700	1319695	1602833	1635406	1741530	2014765
796	Turks and Caicos Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0
798	Tuvalu	0	0	0	0	0	0	0	0	0	0	0	0	0	0
800	Uganda	0	0	0	0	0	0	1600	3862	5775	8761	8769	8783	8805	8805
804	Ukraine	18535	18535	25722	52328	78906	258873	439984	953825	1913228	2374352	2526143	2582796	2407412	2404425

C cod	Country name (HID)	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000	2005
807	Macedonia	3003	3121	3252	4348	3514	12108	26364	70670	93704	108078	129959	116792	101748	101875
818	Egypt	2311292	2329139	2346988	2364957	2382773	2400472	2695712	2868452	3013438	3122639	3230909	3266410	3398959	3440686
826	United Kingdom	40193	32366	24540	16714	8889	36667	100000	88000	140000	152000	157120	235899	246734	208004
831	Guernsey	0	0	0	0	0	0	0	0	0	0	0	0	0	0
832	Jersey	0	0	0	0	0	0	0	0	0	0	0	0	0	0
833	Isle of Man	0	0	0	0	0	0	0	0	0	0	0	0	0	0
834	Tanzania	16845	16845	16845	16845	16845	16845	18071	36530	112671	119516	136326	142634	174406	178801
840	United States	4476382	8264746	10607306	10665230	11533732	14726436	15978629	20282281	24776712	24510307	25976096	26531523	28003472	28322954
850	Virgin Islands, U.S.	0	0	0	0	0	0	25	62	62	62	62	62	185	185
854	Burkina Faso	500	746	992	1238	1484	1730	1975	4000	10000	12000	19999	24949	24965	24965
858	Uruguay	0	0	0	0	1906	16117	34193	68909	92473	113782	139324	183349	269467	267439
860	Uzbekistan	966441	1133680	1262365	1388128	1668415	1974298	2374679	2412028	3245256	3657718	4017127	3975147	3975836	3904686
862	Venezuela	40000	55995	71981	87965	103942	119908	192475	275248	370004	449829	463052	530053	608133	702785
876	Wallis and Futuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
882	Samoa	0	0	0	0	0	0	0	0	0	0	0	0	0	0
887	Yemen	100088	118415	137772	158716	177271	195374	214446	269378	305920	336153	410988	547920	562920	728150
891	Serbia, Montenegro, Kosovo	5963	6207	6458	6711	6959	25480	116655	143502	165330	166782	175592	120011	72386	158961
894	Zambia	0	0	0	0	0	1000	2025	9136	19522	28682	46902	100259	154525	154525
901	Clipperton Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0
902	Caspian Sea	71041	81080	74493	98639	114534	138289	146776	167865	182905	217825	227776	226494	207581	200453
903	Spratly Islands	0	0	0	0	0	0	0	0	0	0	0	0	0	0

A.4 Country-specific AHI Rice for 2000 from MIRCA2000

In Table A.5, the country-specific annual harvested area of irrigated rice (AHI Rice) from MIRCA2000, representative for the year 2000 is listed. Using the country-specific national AEI totals of Table A.4, these values were scaled to respective annual AHI Rice totals for the other years 1900 to 2005.

Table A.5: AHI Rice [ha a^{-1}] for 2000 from MIRCA2000 (Portmann et al., 2010)

Country code	Country name	AHI Rice [ha a^{-1}]
4	Afghanistan	128667
8	Albania	0
10	Antarctica	0
12	Algeria	0
16	American Samoa	0
20	Andorra	0
24	Angola	14000
28	Antigua and Barbuda	0
31	Azerbaijan	3591
32	Argentina	114700
36	Australia	129851
40	Austria	0
44	Bahamas	0
48	Bahrain	0
50	Bangladesh	5671068
51	Armenia	1480
52	Barbados	0
56	Belgium	0
60	Bermuda	0
64	Bhutan	39278
68	Bolivia	10000
70	Bosnia and Herzegovina	0
72	Botswana	0
74	Bouvet Island	0
76	Brazil	993095
84	Belize	700
86	British Indian Ocean Territory	0
90	Solomon Islands	0
92	British Virgin Islands	0
96	Brunei	375
100	Bulgaria	2611
104	Myanmar	1884762
108	Burundi	17380
112	Belarus	0
116	Cambodia	330654
120	Cameroon	20388
124	Canada	0
132	Cape Verde	0
136	Cayman Islands	0
140	Central African Republic	40
144	Sri Lanka	661700
148	Chad	10000
152	Chile	25748
156	China	38081024
158	Taiwan	440492
162	Christmas Island	0

Country code	Country name	AHI Rice [ha a^{-1}]
166	Cocos Islands	0
170	Colombia	306000
174	Comoros	0
175	Mayotte	0
178	Republic of Congo	0
180	Democratic Republic of the Congo	1943
184	Cook Islands	0
188	Costa Rica	39892
191	Croatia	0
192	Cuba	0
196	Cyprus	0
203	Czech Republic	0
204	Benin	636
208	Denmark	0
212	Dominica	0
214	Dominican Republic	111000
218	Ecuador	193000
222	El Salvador	8000
226	Equatorial Guinea	0
231	Ethiopia	3343
232	Eritrea	0
233	Estonia	0
234	Faroe Islands	0
238	Falkland Islands	0
239	South Georgia and the South Sandwich Islands	0
242	Fiji	0
246	Finland	0
250	France	19000
254	French Guiana	4765
258	French Polynesia	0
260	French Southern Territories	0
262	Djibouti	0
266	Gabon	4450
268	Georgia	0
270	Gambia	2149
275	Palestine (West Bank & Gaza Strip)	0
276	Germany & German Empire	0
288	Ghana	5238
292	Gibraltar	0
296	Kiribati	0
300	Greece	22279
304	Greenland	0
308	Grenada	0
312	Guadeloupe	0
316	Guam	0
320	Guatemala	6989
324	Guinea	13726
328	Guyana	126593
332	Haiti	41000
334	Heard Island and McDonald Islands	0
336	Vatican City	0
340	Honduras	15000
344	Hong Kong	0
348	Hungary	1786
352	Iceland	0
356	India & Indian Empire	24006386
360	Indonesia	6048758

Country code	Country name	AHI Rice [ha a^{-1}]
364	Iran	559652
368	Iraq	126000
372	Ireland	0
376	Israel	0
380	Italy	220029
384	Côte d'Ivoire	1750
388	Jamaica	0
392	Japan	1820344
398	Kazakhstan	83152
400	Jordan	0
404	Kenya	13229
408	North Korea	420000
410	South Korea	628630
414	Kuwait	0
417	Kyrgyzstan	2975
418	Laos	286002
422	Lebanon	0
426	Lesotho	0
428	Latvia	0
430	Liberia	0
434	Libya	0
438	Liechtenstein	0
440	Lithuania	0
442	Luxembourg	0
446	Macao	0
450	Madagascar	1062398
454	Malawi	5611
458	Malaysia	433553
462	Maldives	0
466	Mali	144514
470	Malta	0
474	Martinique	0
478	Mauritania	16879
480	Mauritius	0
484	Mexico	63782
492	Monaco	0
496	Mongolia	0
498	Moldova	0
500	Montserrat	0
504	Morocco	6180
508	Mozambique	4130
512	Oman	0
516	Namibia	0
520	Nauru	0
524	Nepal	501751
528	Netherlands	0
530	Netherlands Antilles	0
533	Aruba	0
540	New Caledonia	0
548	Vanuatu	0
554	New Zealand	0
558	Nicaragua	20785
562	Niger	18000
566	Nigeria	7000
570	Niue	0
574	Norfolk Island	0
578	Norway	0

Country code	Country name	AHI Rice [ha a^{-1}]
580	Northern Mariana Islands	0
581	United States Minor Outlying Islands	0
583	Micronesia	0
584	Marshall Islands	0
585	Palau	0
586	Pakistan	2919551
591	Panama	4346
598	Papua New Guinea	0
600	Paraguay	18000
604	Peru	202561
608	Philippines	1810000
612	Pitcairn Islands	0
616	Poland	0
620	Portugal	25107
624	Guinea-Bissau	661
626	East Timor	7000
630	Puerto Rico	0
634	Qatar	0
638	Reunion	0
642	Romania	1277
643	Russia	165370
646	Rwanda	3500
654	Saint Helena	0
659	Saint Kitts and Nevis	0
660	Anguilla	0
662	Saint Lucia	0
666	Saint Pierre and Miquelon	0
670	Saint Vincent and the Grenadines	0
674	San Marino	0
678	Sao Tome and Principe	0
682	Saudi Arabia	0
686	Senegal	56412
690	Seychelles	0
694	Sierra Leone	19000
702	Singapore	0
703	Slovakia	0
704	Vietnam	4500000
705	Slovenia	0
706	Somalia	5000
710	South Africa	1339
716	Zimbabwe	230
724	Spain	117000
732	Western Sahara	0
736	Sudan	3620
740	Suriname	49350
744	Svalbard and Jan Mayen	0
748	Swaziland	50
752	Sweden	0
756	Switzerland	0
760	Syria	0
762	Tajikistan	11850
764	Thailand	4514437
768	Togo	314
772	Tokelau	0
776	Tonga	0
780	Trinidad and Tobago	300
784	United Arab Emirates	0

Country code	Country name	AHI Rice [ha a^{-1}]
788	Tunisia	0
792	Turkey	58000
795	Turkmenistan	33150
796	Turks and Caicos Islands	0
798	Tuvalu	0
800	Uganda	1650
804	Ukraine	21190
807	Macedonia	3167
818	Egypt	650026
826	United Kingdom	0
831	Guernsey	0
832	Jersey	0
833	Isle of Man	0
834	Tanzania	89000
840	United States	1293289
850	Virgin Islands, U.S.	0
854	Burkina Faso	9470
858	Uruguay	174728
860	Uzbekistan	173905
862	Venezuela	158000
876	Wallis and Futuna	0
882	Samoa	0
887	Yemen	0
891	Serbia, Montenegro, Kosovo	0
894	Zambia	8000
901	Clipperton Island	0
902	Caspian Sea	0
903	Spratly Islands	0

A.5 Country-specific (national-level) HID-POTHIST AEI scaling factors

In Table A.6, the country-specific national AEI scaling factors for HID reference years (1900, 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1985, 1990, 1995, 2000, and 2005), based on HID-COUNTRY-2000 country mask and HID-AEI-2000 AEI grid are given. Together with the application of grid-cell specific AAI/AEI ratios, HID-POTHIST becomes HID-ACTHIST2000. In the electronic Appendix, the factors for all years 1900 to 2005 are also given.

Table A.6: HID-POTHIST country-specific national AEI scaling factors relative to HID-AEI-2000 and for country mask HID-COUNTRY-2000, for HID reference years

C code	Country name (HID)	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000	2005
4	Afghanistan	0.1922	0.2152	0.2381	0.2605	0.4143	0.5687	0.7478	0.7512	0.7851	0.8172	0.9095	1.0016	1.0000	0.9986
8	Albania	0.0022	0.0261	0.0502	0.0775	0.0940	0.1302	0.4517	0.8555	1.1042	1.1848	1.2513	1.0013	1.0000	1.0851
10	Antarctica	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
12	Algeria	0.2994	0.3000	0.3007	0.3632	0.3901	0.4169	0.4394	0.4194	0.4490	0.5970	0.7968	0.9777	1.0000	1.0013
16	American Samoa	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	Andorra	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	Angola	0.4664	0.5432	0.6199	0.6966	0.7733	0.8501	0.9284	0.9376	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
28	Antigua and Barbuda	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3846	2.6154	2.0000	1.3846	1.0000	1.0000	1.0000
31	Azerbaijan	0.3834	0.3891	0.2535	0.4271	0.5245	0.6637	0.7881	0.7991	0.8359	0.8735	0.9712	0.9990	1.0000	0.9818
32	Argentina	0.1463	0.3365	0.5324	0.6191	0.5023	0.5217	0.5308	0.7186	0.8723	0.8741	0.8699	0.8776	1.0000	0.9982
36	Australia	0.0168	0.0280	0.0392	0.0736	0.1556	0.2422	0.3722	0.6463	0.6524	0.7011	0.7869	1.0380	1.0000	1.1047
40	Austria	0.3999	0.3971	0.3756	0.3221	0.2527	0.2828	0.3506	0.4399	0.6066	0.6708	0.8271	1.1000	1.0000	1.0762
44	Bahamas	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
48	Bahrain	0.2066	0.2405	0.2744	0.3082	0.3421	0.3760	0.4115	0.4115	0.4115	0.4115	0.6927	0.9292	1.0000	1.0000
50	Bangladesh	0.0041	0.0526	0.0709	0.0910	0.1015	0.0901	0.1320	0.2739	0.3724	0.5018	0.6530	0.8564	1.0000	1.1175
51	Armenia	0.3773	0.3798	0.2500	0.3960	0.6279	0.7157	0.8183	0.9291	0.9467	1.0265	1.0276	0.9837	1.0000	0.9825
52	Barbados	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.2000	0.6000	1.0000	1.0000	1.0000	1.0000
56	Belgium	0.2707	0.2496	0.2347	0.1925	0.1574	0.1617	0.2024	0.2961	0.4188	0.4725	0.6744	0.6114	1.0000	0.7211
60	Bermuda	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
64	Bhutan	0.1930	0.1930	0.1930	0.1930	0.1930	0.1930	0.2029	0.4391	0.6285	0.7229	0.9709	0.9700	1.0000	0.9159
68	Bolivia	0.0236	0.0508	0.0791	0.1065	0.1217	0.2254	0.5323	0.6266	1.0919	0.9775	0.9756	0.9981	1.0000	1.0013
70	Bosnia and Herzegovina	0.4578	0.4578	0.4578	0.4578	0.4578	0.6385	1.2274	1.5561	1.7213	1.7301	1.7983	1.3213	1.0000	1.2443
72	Botswana	0.0903	0.0973	0.1048	0.1739	0.2105	0.2178	0.4390	0.5259	0.8317	0.8516	0.7809	0.8537	1.0000	0.9999
74	Bouvet Island	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
76	Brazil	0.0001	0.0001	0.0001	0.0001	0.0100	0.0199	0.1420	0.2494	0.4670	0.6220	0.7452	0.9918	1.0000	1.3453
84	Belize	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.3992	0.3992	0.7618	0.7618	1.0000	1.0000	1.3011
86	British Indian Ocean Territory	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
90	Solomon Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
92	British Virgin Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
96	Brunei	0.0000	0.0166	0.0388	0.0669	0.0939	0.1387	0.1761	0.2530	0.9871	1.0000	1.0000	1.0000	1.0000	1.0000
100	Bulgaria	0.0550	0.0580	0.0610	0.0639	0.0660	0.2627	1.1968	1.8625	2.5077	2.6516	2.5764	1.6656	1.0000	0.4114
104	Myanmar	0.1373	0.2189	0.2702	0.3070	0.3208	0.2946	0.2871	0.4465	0.5398	0.5768	0.5802	0.8638	1.0000	1.1502
108	Burundi	0.0021	0.0021	0.0021	0.0021	0.0021	0.0021	0.6011	0.6191	0.6359	0.6820	0.6828	0.8172	1.0000	1.0000
112	Belarus	0.0189	0.0189	0.0107	0.0381	0.0654	0.2500	0.4357	0.9613	1.3800	1.3644	1.2833	1.1397	1.0000	0.9623
116	Cambodia	0.0125	0.0434	0.0764	0.1100	0.1442	0.1793	0.2146	0.3050	0.4233	0.6285	0.8043	0.9024	1.0000	1.4032
120	Cameroon	0.0055	0.0105	0.0147	0.0181	0.0213	0.0244	0.0672	0.2519	0.5133	0.7761	0.8172	0.8965	1.0000	1.0150
124	Canada	0.0281	0.1030	0.1615	0.2037	0.2351	0.2667	0.2983	0.5264	0.7446	0.9341	0.8969	1.0902	1.0000	1.0433
132	Cape Verde	0.0000	0.1054	0.2109	0.3163	0.4217	0.5271	0.6325	0.6431	0.6431	0.6431	0.8936	0.8939	1.0000	1.0000
136	Cayman Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
140	Central African Republic	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1350	0.5000	1.0000	1.0000	1.0000
144	Sri Lanka	0.1754	0.2430	0.3106	0.3782	0.4458	0.5134	0.5810	0.8158	0.8018	0.8772	0.9123	1.0000	1.0000	1.0270
148	Chad	0.0306	0.0610	0.0920	0.1237	0.1557	0.1876	0.2377	0.3198	0.4914	0.5912	0.6624	0.8072	1.0000	1.1479
152	Chile	0.4208	0.4208	0.4594	0.5188	0.5341	0.5492	0.5644	0.6211	0.6608	0.7107	0.8440	0.9999	1.0000	1.0000
156	China	0.3001	0.2998	0.3053	0.3308	0.3149	0.2993	0.5070	0.6771	0.8294	0.8205	0.8821	0.9165	1.0000	1.0516
158	Taiwan	0.2861	0.4906	0.6951	0.8996	1.1041	0.9857	0.9601	1.0237	1.0740	1.0813	1.0030	1.0325	1.0000	0.9675
162	Christmas Island	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
166	Cocos Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
170	Colombia	0.0111	0.0111	0.0111	0.0112	0.0334	0.0891	0.2449	0.2786	0.4451	0.5172	0.7218	1.0000	1.0000	1.0000
174	Comoros	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000
175	Mayotte	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
178	Republic of Congo	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5000	0.5000	0.5000	0.5000	1.0000	1.0000	1.0000
180	Democratic Republic of the	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5855	0.7354	0.8218	0.9202	1.0000	1.0000

C code	Country name (HID)	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000	2005
	Congo														
184	Cook Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
188	Costa Rica	0.0880	0.1074	0.1272	0.1469	0.1667	0.1865	0.2315	0.2387	0.5600	0.6716	0.7091	0.8512	1.0000	1.0004
191	Croatia	0.3232	0.3329	0.3422	0.3513	0.3601	0.4265	0.5528	1.0460	1.2717	1.1931	1.1017	1.0572	1.0000	0.9722
192	Cuba	0.0345	0.0415	0.0486	0.0556	0.0626	0.0820	0.2414	0.5172	0.8759	0.9897	1.0230	1.0000	1.0000	1.0000
196	Cyprus	0.1874	0.2221	0.2568	0.2915	0.3263	0.2796	0.5177	0.5415	0.6017	0.6217	0.7220	0.8010	1.0000	0.9196
203	Czech Republic	0.3198	0.3095	0.2772	0.2476	0.2312	0.2752	0.3271	0.3639	0.7865	1.0160	1.6166	1.8363	1.0000	0.5263
204	Benin	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1614	0.1614	0.7486	0.7580	0.7894	0.8287	1.0000	1.0000
208	Denmark	0.0243	0.0243	0.0251	0.0248	0.0240	0.0565	0.0843	0.2000	0.8761	0.9175	0.9609	1.0762	1.0000	1.0045
212	Dominica	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
214	Dominican Republic	0.0036	0.0061	0.0086	0.0110	0.0883	0.3676	0.5362	0.6316	0.7272	0.8041	0.8800	0.9840	1.0000	1.0571
218	Ecuador	0.0006	0.0018	0.0038	0.0053	0.1700	0.3335	0.5103	0.5503	0.7221	0.8363	0.9496	0.9943	1.0000	0.9814
222	El Salvador	0.0231	0.0259	0.0286	0.0314	0.0342	0.0369	0.4005	0.4502	0.8000	0.8445	0.8892	0.9560	1.0000	1.1629
226	Equatorial Guinea	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
231	Ethiopia	0.0714	0.0760	0.0807	0.0855	0.0905	0.0955	0.1256	0.2019	0.3869	0.6411	0.8955	0.9986	1.0000	1.0048
232	Eritrea	0.0341	0.0441	0.0536	0.0637	0.0736	0.0829	0.0928	0.1920	0.3727	0.6251	0.8927	1.0000	1.0000	1.0000
233	Estonia	0.0987	0.0987	0.0562	0.1999	0.3446	1.3379	2.3292	5.1444	9.8245	7.6749	7.4313	3.0745	1.0000	1.0008
234	Faroe Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
238	Falkland Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
239	South Georgia and the South Sandwich Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
242	Fiji	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3333	0.3333	0.3333	0.3333	1.0000	1.0000	1.0000
246	Finland	0.1150	0.0920	0.0690	0.0460	0.0230	0.0000	0.0052	0.1859	0.5921	0.6732	0.7425	0.9980	1.0000	0.8200
250	France	0.0924	0.1112	0.1366	0.1504	0.1644	0.1766	0.1912	0.2918	0.5141	0.5834	0.7959	0.9522	1.0000	1.0269
254	French Guiana	0.0000	0.0000	0.0010	0.0133	0.0195	0.0195	0.2237	0.2237	0.2237	0.4280	0.4280	0.7383	1.0000	1.1650
258	French Polynesia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000
260	French Southern Territories	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
262	Djibouti	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9980	0.9980	0.9980	0.9980	0.9980	0.9980	1.0000	1.0000
266	Gabon	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
268	Georgia	0.2306	0.2306	0.1414	0.2589	0.3538	0.4844	0.5972	0.6141	0.7942	0.8967	0.9799	1.0246	1.0000	0.9543
270	Gambia	0.3248	0.3466	0.3552	0.3608	0.3653	0.3653	0.3653	0.3660	0.2965	0.3503	0.6936	0.8241	1.0000	1.0000
275	Palestine (West Bank & Gaza Strip)	0.0773	0.1218	0.1680	0.2204	0.2673	0.3135	0.9184	0.9591	1.0088	1.0872	1.0317	0.9921	1.0000	0.9906
276	Germany & German Empire	0.7545	0.7398	0.7286	0.6357	0.4886	0.4721	0.5918	1.1865	2.1078	2.5097	2.6658	1.0428	1.0000	1.0993
288	Ghana	0.0647	0.0828	0.1009	0.1189	0.1370	0.1551	0.4400	0.4800	0.6414	0.8088	0.9693	1.0032	1.0000	1.8948
292	Gibraltar	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
296	Kiribati	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
300	Greece	0.0784	0.1093	0.1401	0.1699	0.1991	0.2283	0.4450	0.6826	0.7585	0.8876	0.8851	0.9549	1.0000	1.2081
304	Greenland	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
308	Grenada	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0950
312	Guadeloupe	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1481	0.3333	0.3333	0.3333	0.3333	0.3333	1.0000	1.0354
316	Guam	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0640	0.2241	1.0000	1.0000
320	Guatemala	0.1234	0.1412	0.1591	0.1850	0.1948	0.2126	0.2503	0.4239	0.6532	0.7774	0.8862	0.9755	1.0000	1.0854
324	Guinea	0.0527	0.0796	0.1065	0.1333	0.1601	0.1869	0.2140	0.5230	0.9416	0.9426	0.9430	0.9756	1.0000	1.0000
328	Guyana	0.1793	0.2232	0.2659	0.3079	0.3504	0.4076	0.5477	0.7350	0.8145	0.8523	0.9175	0.9872	1.0000	1.0006
332	Haiti	0.0762	0.0762	0.1502	0.2242	0.2983	0.3734	0.3821	0.6539	0.7611	0.8689	0.8710	1.0000	1.0000	1.0000
334	Heard Island and McDonald Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
336	Vatican City	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
340	Honduras	0.1068	0.1347	0.1625	0.1903	0.2181	0.2458	0.4736	0.7986	0.8185	0.8245	0.9011	0.9159	1.0000	1.0296
344	Hong Kong	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
348	Hungary	0.0681	0.0730	0.0778	0.0819	0.0857	0.1240	0.2755	1.0778	1.5281	1.3784	1.2969	1.1522	1.0000	0.7062
352	Iceland	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
356	India & Indian Empire	0.2030	0.2890	0.3302	0.3448	0.3808	0.3306	0.4257	0.5260	0.6617	0.7348	0.7975	0.9136	1.0000	1.0442
360	Indonesia	0.2540	0.2810	0.3396	0.4297	0.5198	0.6099	0.7086	0.7090	0.7467	0.7467	0.6631	0.8037	1.0000	1.2222
364	Iran	0.1498	0.2238	0.2974	0.3729	0.4483	0.5240	0.6005	0.7579	0.7992	0.8574	0.8855	0.9180	1.0000	1.0643
368	Iraq	0.1138	0.1284	0.1431	0.1579	0.1728	0.2353	0.3483	0.4236	0.4969	0.5003	0.9913	0.9966	1.0000	0.9995
372	Ireland	4.4252	3.3197	2.2134	1.1068	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000
376	Israel	0.0745	0.1044	0.1335	0.1610	0.1942	0.2380	0.6468	0.8036	0.9381	1.0394	1.0016	0.9844	1.0000	0.9014
380	Italy	0.3373	0.3651	0.4216	0.4864	0.5488	0.5893	0.6297	0.7639	0.9081	0.9542	1.0004	0.9602	1.0000	1.0304
384	Côte d'Ivoire	0.0138	0.0206	0.0273	0.0341	0.0409	0.0477	0.0545	0.2741	0.6007	0.7368	0.9014	0.9945	1.0000	1.0000
388	Jamaica	0.2592	0.3391	0.4389	0.5387	0.6386	0.7410	0.8674	0.9600	0.9600	1.0000	1.0000	1.0086	1.0000	1.0000
392	Japan	0.9917	1.0289	1.0748	1.1180	1.0908	1.0447	1.1356	1.0296	1.1092	1.0857	1.0623	1.0855	1.0000	1.0147
398	Kazakhstan	0.3281	0.3298	0.3849	0.4015	0.4978	0.6743	0.7835	0.8363	0.9000	0.9373	0.9136	0.9778	1.0000	0.7452
400	Jordan	0.1143	0.1299	0.1454	0.1609	0.1767	0.2369	0.4268	0.4821	0.5259	0.6433	0.8058	1.0040	1.0000	1.0528
404	Kenya	0.0648	0.0817	0.0987	0.1157	0.1326	0.1495	0.1664	0.3456	0.4908	0.5165	0.6551	0.8344	1.0000	1.2052
408	North Korea	0.1519	0.1743	0.1966	0.2187	0.2471	0.2727	0.3462	0.3583	0.7784	0.8759	0.9756	0.9953	1.0000	1.0062
410	South Korea	0.3131	0.3591	0.4054	0.4518	0.5111	0.5654	0.6989	0.9369	0.9997	1.0653	1.1154	1.0295	1.0000	0.9551
414	Kuwait	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0214	0.1740	0.1965	0.3204	0.4961	0.7392	1.0000	1.1601
417	Kyrgyzstan	0.3541	0.3660	0.4409	0.4389	0.5518	0.8150	0.9107	0.9217	0.9448	0.9818	1.0213	1.0191	1.0000	1.0147
418	Laos	0.0123	0.0159	0.0195	0.0230	0.0273	0.0322	0.0404	0.0565	0.3385	0.3720	0.4319	0.4964	1.0000	1.0676

C code	Country name (HID)	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000	2005
422	Lebanon	0.0774	0.0996	0.1220	0.1434	0.1655	0.1987	0.3557	0.6224	0.8098	0.8150	0.8078	0.8831	1.0000	0.9876
426	Lesotho	0.1121	0.1129	0.1129	0.1515	0.1764	0.2051	0.4724	0.5549	0.5549	0.5549	0.8216	1.0222	1.0000	1.0000
428	Latvia	0.1973	0.1973	0.1098	0.4190	0.7402	3.0633	5.5111	12.649	19.461	19.740	17.658	8.8770	1.0000	1.1039
430	Liberia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6395	0.6397	0.6711	1.0000	1.0000	1.0000	1.0000
434	Libya	0.0859	0.1142	0.1424	0.1707	0.1990	0.2272	0.2555	0.3733	0.4796	0.6390	1.0000	1.0000	1.0000	0.9994
438	Liechtenstein	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
440	Lithuania	0.0658	0.0658	0.0731	0.1203	0.1882	0.6888	1.1959	2.6641	3.8206	5.0436	5.6572	1.4813	1.0000	0.6552
442	Luxembourg	199.44	179.48	159.54	79.771	19.944	3.9885	0.0000	0.0000	0.0000	0.0000	0.8119	1.0119	1.0000	2.7269
446	Macao	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
450	Madagascar	0.0092	0.0530	0.0967	0.1405	0.1843	0.2280	0.2718	0.3038	0.5938	0.7604	0.9206	1.0007	1.0000	1.0000
454	Malawi	0.0088	0.0088	0.0088	0.0088	0.0089	0.0095	0.0304	0.1048	0.4119	0.4125	0.4475	0.6216	1.0000	1.0310
458	Malaysia	0.2675	0.3229	0.3796	0.4361	0.4920	0.5499	0.6089	0.7071	0.8717	0.9200	0.9371	0.9935	1.0000	0.9919
462	Maldives	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
466	Mali	0.0424	0.0512	0.0600	0.0689	0.0777	0.2163	0.2393	0.2612	0.2590	0.2591	0.3352	0.3378	1.0000	1.0000
470	Malta	0.1000	0.1000	0.1000	0.1000	0.1000	0.2500	0.2500	0.5000	0.5000	0.5000	0.5000	0.5000	1.0000	1.5100
474	Martinique	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.7143	0.5714	0.5714	0.7143	1.0000	0.9153
478	Mauritania	0.2934	0.3388	0.3763	0.4131	0.4497	0.4833	0.5188	0.6903	0.9233	1.0151	1.0194	0.9045	1.0000	1.0465
480	Mauritius	0.0126	0.0126	0.0126	0.1014	0.1903	0.2792	0.3681	0.7068	0.7539	0.8011	0.8011	0.8246	1.0000	1.0084
484	Mexico	0.1550	0.1558	0.2076	0.3284	0.3362	0.3420	0.4256	0.5384	0.7769	0.8246	0.8744	0.9697	1.0000	1.0413
492	Monaco	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
496	Mongolia	0.0558	0.0558	0.0558	0.0558	0.0558	0.0558	0.0606	0.1370	0.4513	0.9077	1.1461	1.0057	1.0000	0.9823
498	Moldova	0.0060	0.0060	0.0032	0.0130	0.0231	0.0957	0.1683	0.4027	0.6359	0.8548	0.9376	1.1048	1.0000	0.8030
500	Montserrat	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
504	Morocco	0.2773	0.3292	0.4042	0.4678	0.5198	0.5545	0.5893	0.6377	0.8432	0.8630	0.8727	0.9366	1.0000	1.0286
508	Mozambique	0.0828	0.1226	0.1625	0.2029	0.2428	0.2824	0.4135	0.6279	0.9525	0.9494	0.9479	0.9512	1.0000	1.0000
512	Oman	0.3229	0.3248	0.3264	0.3284	0.3303	0.3330	0.3358	0.4930	0.6405	0.6887	0.9421	0.9831	1.0000	0.9862
516	Namibia	0.1230	0.1230	0.1238	0.1378	0.1622	0.1822	0.2992	0.5772	0.6220	0.6220	0.8521	0.9263	1.0000	1.0000
520	Nauru	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
524	Nepal	0.0146	0.0363	0.0417	0.0456	0.0478	0.0534	0.0879	0.1295	0.4456	0.6353	0.8524	0.9950	1.0000	1.0396
528	Netherlands	0.5210	0.4174	0.3691	0.3174	0.3159	0.4161	0.5813	0.7780	0.9820	1.0870	1.5569	0.6627	1.0000	0.8260
530	Netherlands Antilles	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
533	Aruba	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
540	New Caledonia	0.0000	0.0000	0.0000	0.0000	0.0000	0.1111	0.1111	0.2222	0.2222	0.2222	0.4444	0.6667	1.0000	1.0000
548	Vanuatu	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
554	New Zealand	0.0933	0.1399	0.1865	0.2332	0.2798	0.3265	0.3731	0.5008	0.7644	1.0266	1.0760	1.0476	1.0000	1.0512
558	Nicaragua	0.0333	0.0746	0.1158	0.1569	0.1980	0.2393	0.2845	0.6363	0.9552	0.9574	0.9593	0.9825	1.0000	1.4936
562	Niger	0.0526	0.0766	0.1034	0.1311	0.1594	0.1884	0.2170	0.2437	0.3079	0.3952	0.8854	0.8861	1.0000	1.0052
566	Nigeria	0.4552	0.4910	0.5263	0.5613	0.5963	0.6311	0.6693	0.6713	0.6758	0.6815	0.8005	0.8170	1.0000	1.0083
570	Niue	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
574	Norfolk Island	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
578	Norway	0.1840	0.1474	0.1107	0.0886	0.0592	0.0739	0.1276	0.2218	0.5487	0.6679	0.7203	0.9445	1.0000	0.8714
580	Northern Mariana Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
581	United States Minor Outlying Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
583	Micronesia	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
584	Marshall Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
585	Palau	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
586	Pakistan	0.3044	0.3403	0.4028	0.4620	0.5622	0.6015	0.6658	0.8085	0.9169	0.9506	0.9751	1.0063	1.0000	1.0297
591	Panama	0.1697	0.1941	0.2184	0.2425	0.2666	0.2907	0.3214	0.4519	0.6557	0.7074	0.7318	0.7817	1.0000	1.0000
598	Papua New Guinea	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
600	Paraguay	0.0000	0.0694	0.1389	0.2083	0.2894	0.3598	0.4288	0.5856	0.8670	0.9393	0.9499	0.9777	1.0000	1.0298
604	Peru	0.0661	0.1247	0.1829	0.2550	0.4492	0.6445	0.8393	0.9346	0.9638	0.9896	1.0077	0.9587	1.0000	1.0026
608	Philippines	0.0289	0.0703	0.1117	0.1531	0.1944	0.2468	0.3911	0.4782	0.7058	0.8337	0.8974	0.9267	1.0000	1.0562
612	Pitcairn Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
616	Poland	0.5573	0.4847	0.4936	0.3550	0.2729	0.1393	0.9879	1.8263	2.5865	2.4759	2.3457	1.4737	1.0000	0.9079
620	Portugal	0.2695	0.3018	0.3439	0.3856	0.5061	0.6267	0.7790	1.0695	1.0498	1.0774	1.0942	0.9947	1.0000	0.7871
624	Guinea-Bissau	0.0825	0.1812	0.2793	0.3779	0.4761	0.5740	0.6711	0.6767	0.6767	0.6767	0.6767	0.8363	1.0000	1.0000
626	East Timor	0.1052	0.1513	0.1993	0.2505	0.3050	0.3581	0.4144	0.4189	0.4383	0.4532	0.4627	0.7217	1.0000	1.0544
630	Puerto Rico	0.2456	0.3360	0.3830	0.4012	0.5320	0.7853	1.1289	1.0160	0.7451	0.7902	0.6003	0.6961	1.0000	1.0327
634	Qatar	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0772	0.2309	0.3793	0.4445	0.9626	1.0000	0.9960
638	Reunion	0.0083	0.0083	0.0083	0.0675	0.1258	0.1850	0.2442	0.4167	0.4167	0.6667	0.9167	1.0000	1.0000	0.8102
642	Romania	0.0040	0.0046	0.0054	0.0064	0.0074	0.0198	0.0818	0.2916	0.8873	1.1397	1.2390	1.2199	1.0000	0.3222
643	Russia	0.0620	0.0621	0.0391	0.0614	0.0857	0.2403	0.3920	0.8264	1.2865	1.4131	1.5793	1.2911	1.0000	0.5292
646	Rwanda	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3322	0.4348	0.4471	0.4633	0.4633	0.5839	1.0000	1.0000
654	Saint Helena	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
659	Saint Kitts and Nevis	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
660	Anguilla	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
662	Saint Lucia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3011	0.3011	0.3011	0.3011	0.6022	1.0000	1.0000	1.0000
666	Saint Pierre and Miquelon	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
670	Saint Vincent and	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

C code	Country name (HID)	1900	1910	1920	1930	1940	1950	1960	1970	1980	1985	1990	1995	2000	2005
	the Grenadines														
674	San Marino	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
678	Sao Tome and Principe	0.2062	0.3363	0.4665	0.5966	0.7267	0.8569	0.9870	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
682	Saudi Arabia	0.0089	0.0406	0.0716	0.1017	0.1332	0.1650	0.1962	0.2125	0.3484	0.6669	0.9190	0.9681	1.0000	0.8425
686	Senegal	0.2972	0.3464	0.4016	0.4573	0.5131	0.5712	0.6279	0.7127	0.5769	0.8224	0.8683	0.7250	1.0000	1.0934
690	Seychelles	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000
694	Sierra Leone	0.0325	0.0325	0.0325	0.0325	0.0325	0.0325	0.0325	0.2092	0.6641	0.9230	0.9230	0.9672	1.0000	1.0000
702	Singapore	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
703	Slovakia	0.0066	0.0109	0.0178	0.0269	0.0381	0.0329	0.0636	0.2921	0.3953	0.3703	0.8774	0.9301	1.0000	0.7862
704	Vietnam	0.0830	0.1147	0.1462	0.1778	0.2094	0.2410	0.2741	0.3325	0.4694	0.6870	0.7952	0.8231	1.0000	1.2545
705	Slovenia	0.0483	0.0483	0.0483	0.0489	0.0613	0.1297	0.1121	0.1413	0.1688	0.1863	0.1929	0.4149	1.0000	1.0293
706	Somalia	0.2204	0.2567	0.2931	0.3292	0.3651	0.4010	0.4382	0.4684	0.6190	0.9960	0.9994	0.9998	1.0000	1.0009
710	South Africa	0.1068	0.1290	0.1511	0.2393	0.3350	0.4308	0.5295	0.6663	0.7518	0.7518	0.7997	0.9031	1.0000	1.0000
716	Zimbabwe	0.0011	0.0011	0.0012	0.0164	0.0310	0.0455	0.1187	0.2706	0.4712	0.5287	0.6379	0.6826	1.0000	1.0000
724	Spain	0.3341	0.3668	0.3968	0.4167	0.4250	0.4464	0.6014	0.7502	0.7955	0.8055	0.8137	0.8336	1.0000	1.0806
732	Western Sahara	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
736	Sudan	0.1073	0.1255	0.1437	0.1619	0.2123	0.4078	0.7447	0.8721	0.9124	0.9463	0.9662	1.0445	1.0000	1.0000
740	Suriname	0.0141	0.0578	0.1059	0.1555	0.2038	0.2507	0.2970	0.6000	0.8884	0.9374	0.9710	0.9950	1.0000	1.0000
744	Svalbard and Jan Mayen	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
748	Swaziland	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.6041	0.7864	0.7864	0.8947	0.8947	0.9814	1.0000	0.9997
752	Sweden	0.6194	0.4978	0.3762	0.2550	0.1337	0.0942	0.1422	0.2423	0.5154	0.7264	0.8354	0.8990	1.0000	1.2185
756	Switzerland	0.7742	0.6141	0.4566	0.3823	0.3110	0.3714	0.4033	0.3959	0.7306	0.7973	0.8688	0.9385	1.0000	1.1346
760	Syria	0.0587	0.0679	0.0770	0.0863	0.1470	0.2579	0.4139	0.3702	0.4443	0.5341	0.6601	0.8761	1.0000	1.1752
762	Tajikistan	0.2777	0.2862	0.3270	0.3434	0.4273	0.5534	0.6294	0.7766	0.9103	0.9399	0.9659	1.0031	1.0000	1.0163
764	Thailand	0.0097	0.0138	0.0688	0.1238	0.1786	0.2333	0.2878	0.3543	0.5458	0.7412	0.7627	0.8982	1.0000	1.1022
768	Togo	0.1367	0.1367	0.1367	0.1367	0.1367	0.1367	0.1367	0.1367	0.1611	0.9447	0.9592	1.0000	1.0000	1.0123
772	Tokelau	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
776	Tonga	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
780	Trinidad and Tobago	0.0000	0.0357	0.1071	0.1785	0.2500	0.3214	0.3928	0.3999	0.7019	0.7350	0.7257	0.7201	1.0000	0.7201
784	United Arab Emirates	0.0249	0.0426	0.0605	0.0783	0.0961	0.1137	0.1312	0.1979	0.2338	0.2565	0.2978	0.4109	1.0000	1.0291
788	Tunisia	0.2630	0.2617	0.2605	0.2593	0.2581	0.2569	0.2557	0.5100	0.6189	0.7631	0.7646	0.9794	1.0000	1.1324
792	Turkey	0.1160	0.1259	0.1360	0.1460	0.1579	0.1713	0.2310	0.3583	0.5344	0.6662	0.7173	0.8563	1.0000	1.0332
795	Turkmenistan	0.1075	0.1119	0.1311	0.1399	0.1739	0.2293	0.2600	0.3783	0.5631	0.7578	0.9204	0.9391	1.0000	1.1385
796	Turks and Caicos Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
798	Tuvalu	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
800	Uganda	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1817	0.4386	0.6559	0.9950	0.9960	0.9975	1.0000	1.0000
804	Ukraine	0.0077	0.0077	0.0107	0.0217	0.0328	0.1075	0.1828	0.3962	0.7947	0.9863	1.0493	1.0729	1.0000	0.9988
807	Macedonia	0.0295	0.0307	0.0320	0.0332	0.0345	0.0978	0.2117	0.5895	0.9209	1.0622	1.0997	1.1479	1.0000	1.0012
818	Egypt	0.6800	0.6853	0.6905	0.6958	0.7010	0.7062	0.7931	0.8439	0.8866	0.9187	0.9506	0.9610	1.0000	1.0123
826	United Kingdom	0.1629	0.1312	0.0995	0.0677	0.0360	0.1486	0.4053	0.3567	0.5674	0.6160	0.6368	0.9561	1.0000	0.8430
831	Guernsey	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
832	Jersey	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
833	Isle of Man	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
834	Tanzania	0.0966	0.0966	0.0966	0.0966	0.0966	0.0966	0.1036	0.2095	0.6460	0.6853	0.7817	0.8178	1.0000	1.0252
840	United States	0.1599	0.2952	0.3788	0.3809	0.4119	0.5258	0.5706	0.7243	0.8847	0.8753	0.9277	0.9475	1.0000	1.0115
850	Virgin Islands, U.S.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1334	0.3333	0.3333	0.3333	0.3333	0.3333	1.0000	1.0016
854	Burkina Faso	0.0200	0.0299	0.0397	0.0496	0.0594	0.0693	0.0791	0.1602	0.4006	0.4807	0.8011	0.9994	1.0000	1.0000
858	Uruguay	0.0000	0.0000	0.0000	0.0000	0.0071	0.0598	0.1269	0.2557	0.3432	0.4222	0.5170	0.6804	1.0000	0.9925
860	Uzbekistan	0.2421	0.2840	0.3162	0.3477	0.4178	0.4944	0.5973	0.6067	0.8162	0.9200	1.0104	0.9998	1.0000	0.9897
862	Venezuela	0.0658	0.0921	0.1184	0.1446	0.1709	0.1972	0.3165	0.4526	0.6084	0.7397	0.7614	0.8716	1.0000	1.1556
876	Wallis and Futuna	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
882	Samoa	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
887	Yemen	0.1778	0.2104	0.2447	0.2820	0.3149	0.3471	0.3810	0.4785	0.5435	0.5972	0.7301	0.9734	1.0000	1.2935
891	Serbia, Montenegro, Kosovo	0.0824	0.0857	0.0892	0.0927	0.0961	0.3520	1.6116	1.8566	2.1309	2.1428	2.2854	1.6579	1.0000	2.1960
894	Zambia	0.0000	0.0000	0.0000	0.0000	0.0000	0.0065	0.0131	0.0591	0.1263	0.1856	0.3035	0.6488	1.0000	1.0000
901	Clipperton Island	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
902	Caspian Sea	0.3422	0.3906	0.3589	0.4752	0.5518	0.6662	0.7071	0.8087	0.8811	1.0494	1.0973	1.0911	1.0000	0.9657
903	Spratly Islands	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

A.6 Country sums of irrigation consumptive use for selected evaluation years for runs HID-ACT and HID-ACTHIST

In the following Table A.7, country sums of irrigation consumptive use, for runs HID-ACT and HID-ACTHIST and the ICU difference HID-ACTHIST minus HID-ACT are listed for selected evaluation years 1910, 1960, 1995, and 2005. It includes results of runs HID-ACT-1910_refclim, HID-ACTHIST-1910_clim1985, HID-ACT-1960_refclim, HID-ACTHIST-1960_clim1985, HID-ACT-1995_refclim, HID-ACTHIST-1995_clim1985, HID-ACT-2005_refclim, and HID-ACTHIST-2005_clim1985.

Table A.7: Irrigation consumptive use (ICU) [km^3 a^{-1}] for selected evaluation years 1910, 1960, 1995, and 2005, by country (sorted by UNM49 country code), for runs HID-ACT and HID-ACTHIST and difference HID-ACTHIST minus HID-ACT [km^3 a^{-1} and % of HID-ACT_refclim]

	Year	**1910**	1910	1910	1910	**1960**	1960	1960	1960	**1995**	1995	1995	1995	**2005**	2005	2005	2005
	Run	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT
Ctry cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]
4	Afghanistan	4.045	3.528	-0.516	-12.8	10.581	11.466	0.885	8.4	16.313	15.908	-0.404	-2.5	14.082	14.073	-0.010	-0.1
8	Albania	0.013	0.013	0.001	5.9	0.225	0.228	0.002	1.0	0.401	0.412	0.011	2.9	0.478	0.479	0.001	0.3
10	Antarctica	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
12	Algeria	1.070	1.097	0.027	2.5	1.654	1.695	0.041	2.5	4.194	4.019	-0.175	-4.2	4.413	4.332	-0.081	-1.8
16	American Samoa	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
20	Andorra	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
24	Angola	0.091	0.083	-0.008	-9.0	0.132	0.128	-0.003	-2.6	0.143	0.147	0.004	2.8	0.171	0.171	0.000	0.0
28	Antigua and Barbuda	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
31	Azerbaijan	2.419	2.303	-0.116	-4.8	4.524	4.419	-0.105	-2.3	6.140	6.077	-0.062	-1.0	6.170	5.977	-0.193	-3.1
32	Argentina	2.690	1.867	-0.824	-30.6	3.415	3.058	-0.357	-10.5	4.967	4.947	-0.020	-0.4	5.448	5.459	0.011	0.2
36	Australia	0.785	0.535	-0.250	-31.9	8.493	7.531	-0.961	-11.3	19.948	18.873	-1.075	-5.4	22.483	23.034	0.551	2.4
40	Austria	0.024	0.025	0.001	3.3	0.013	0.015	0.001	8.9	0.092	0.089	-0.003	-3.3	0.075	0.076	0.001	1.6
44	Bahamas	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.001	0.001	0.000	-7.7	0.001	0.001	0.000	0.0
48	Bahrain	0.004	0.004	0.000	0.0	0.007	0.007	0.000	0.0	0.015	0.015	0.000	0.0	0.016	0.016	0.000	0.0
50	Bangladesh	0.000	1.295	1.295	0.0	3.642	3.740	0.098	2.7	14.659	15.812	1.153	7.9	18.633	18.656	0.023	0.1
51	Armenia	0.275	0.269	-0.006	-2.1	0.518	0.540	0.022	4.2	0.707	0.717	0.010	1.4	0.634	0.632	-0.003	-0.4
52	Barbados	0.000	0.000	0.000	0.0	0.002	0.002	0.001	42.8	0.010	0.010	0.000	0.0	0.014	0.014	0.000	0.0
56	Belgium	0.005	0.006	0.001	10.3	0.003	0.004	0.001	19.4	0.028	0.029	0.002	5.7	0.013	0.022	0.009	70.2
60	Bermuda	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
64	Bhutan	0.008	0.010	0.003	33.7	0.009	0.012	0.002	21.1	0.022	0.022	0.000	1.1	0.038	0.030	-0.007	-19.8
68	Bolivia	0.014	0.016	0.002	13.2	0.204	0.181	-0.023	-11.1	0.347	0.347	0.000	0.1	0.329	0.329	0.001	0.3
70	Bosnia and Herzegovina	0.005	0.003	-0.002	-41.5	0.004	0.009	0.004	100.4	0.006	0.007	0.002	30.1	0.006	0.006	0.000	-1.4
72	Botswana	0.001	0.001	0.000	-23.1	0.005	0.004	-0.001	-18.5	0.009	0.008	-0.001	-13.2	0.010	0.010	0.000	0.0
74	Bouvet Island	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
76	Brazil	0.001	0.001	0.000	-14.7	0.754	0.911	0.157	20.8	5.887	5.900	0.014	0.2	9.012	9.238	0.226	2.5
84	Belize	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.003	0.003	0.000	-3.0	0.003	0.003	0.000	1.1
86	British Indian Ocean Territory	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
90	Solomon Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
92	British Virgin Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
96	Brunei	0.000	0.000	0.000	18.7	0.000	0.000	0.000	4.4	0.000	0.000	0.000	-0.2	0.001	0.001	0.000	2.7
100	Bulgaria	0.024	0.020	-0.004	-16.9	0.314	0.301	-0.013	-4.2	0.415	0.462	0.047	11.2	0.123	0.088	-0.035	-28.5
104	Myanmar	0.000	1.110	1.110	0.0	1.496	1.679	0.183	12.3	3.963	3.987	0.024	0.6	5.157	5.232	0.075	1.5
108	Burundi	0.000	0.000	0.000	69.5	0.025	0.030	0.005	18.9	0.045	0.044	0.000	-0.9	0.059	0.059	0.000	0.0
112	Belarus	0.001	0.001	0.000	-9.6	0.012	0.011	0.000	-4.2	0.042	0.042	0.000	0.9	0.040	0.040	0.000	-0.5
116	Cambodia	0.039	0.037	-0.001	-3.2	0.214	0.208	-0.006	-2.6	0.620	0.621	0.002	0.3	1.195	1.195	0.001	0.1
120	Cameroon	0.000	0.001	0.000	47.0	0.004	0.003	-0.001	-14.0	0.036	0.035	-0.001	-3.0	0.045	0.044	-0.001	-1.9
124	Canada	0.446	0.339	-0.107	-24.1	1.183	0.997	-0.187	-15.8	2.592	2.661	0.068	2.6	2.497	2.506	0.010	0.4
132	Cape Verde	0.001	0.001	0.000	-3.4	0.006	0.006	0.000	-0.9	0.008	0.008	0.000	-2.0	0.009	0.009	0.000	0.2
136	Cayman Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
140	Central	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	9.1	0.000	0.000	0.000	0.1

	Year	**1910**	1910	1910	1910	**1960**	1960	1960	1960	**1995**	1995	1995	1995	**2005**	2005	2005	2005
	Run	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT
Ctry cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]
	African Republic																
144	Sri Lanka	0.608	0.568	-0.040	-6.5	1.487	1.457	-0.030	-2.0	2.055	2.029	-0.026	-1.3	2.388	2.379	-0.008	-0.4
148	Chad	0.006	0.007	0.000	7.5	0.028	0.027	0.000	-1.0	0.089	0.089	0.000	0.0	0.139	0.132	-0.006	-4.5
152	Chile	3.832	3.313	-0.519	-13.5	4.107	4.617	0.510	12.4	8.098	8.170	0.072	0.9	7.798	7.841	0.044	0.6
156	China	62.972	64.109	1.137	1.8	108.42	106.70	-1.720	-1.6	183.81	184.66	0.849	0.5	213.53	212.46	-1.067	-0.5
158	Taiwan	1.302	1.275	-0.027	-2.1	2.115	2.110	-0.005	-0.2	2.326	2.305	-0.021	-0.9	1.536	1.530	-0.006	-0.4
162	Christmas Island	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
166	Cocos Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
170	Colombia	0.019	0.012	-0.007	-35.3	0.409	0.403	-0.006	-1.5	0.826	0.841	0.015	1.8	0.796	0.798	0.003	0.3
174	Comoros	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	-0.4	0.000	0.000	0.000	0.0
175	Mayotte	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
178	Republic of Congo	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	-0.6	0.001	0.001	0.000	0.2
180	Democratic Republic of the Congo	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.006	0.006	0.001	9.7	0.010	0.010	0.000	0.1
184	Cook Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
188	Costa Rica	0.019	0.019	0.000	0.2	0.040	0.039	-0.001	-2.8	0.057	0.058	0.001	2.0	0.096	0.096	0.000	0.0
191	Croatia	0.011	0.012	0.001	6.1	0.017	0.021	0.004	26.1	0.041	0.042	0.000	0.8	0.039	0.029	-0.010	-25.7
192	Cuba	0.014	0.018	0.004	32.1	0.062	0.077	0.015	24.5	0.266	0.271	0.005	2.0	0.357	0.357	0.000	0.0
196	Cyprus	0.074	0.076	0.003	3.5	0.196	0.189	-0.007	-3.3	0.308	0.294	-0.014	-4.4	0.336	0.337	0.000	0.1
203	Czech Republic	0.014	0.012	-0.002	-16.0	0.011	0.010	-0.001	-13.2	0.093	0.096	0.003	2.8	0.022	0.021	-0.001	-4.6
204	Benin	0.000	0.000	0.000	0.0	0.002	0.001	-0.001	-32.0	0.004	0.005	0.000	7.4	0.006	0.006	0.000	0.2
208	Denmark	0.005	0.004	-0.001	-14.7	0.015	0.014	0.000	-2.6	0.441	0.425	-0.016	-3.6	0.244	0.245	0.000	0.1
212	Dominica	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	-100.0
214	Dominican Republic	0.005	0.005	-0.001	-10.0	0.392	0.402	0.009	2.4	0.889	0.894	0.005	0.6	0.647	0.652	0.005	0.7
218	Ecuador	0.005	0.002	-0.003	-66.3	0.607	0.561	-0.046	-7.5	0.996	1.015	0.019	1.9	0.828	0.835	0.007	0.9
222	El Salvador	0.001	0.001	0.000	12.5	0.018	0.020	0.002	9.0	0.016	0.016	0.000	1.3	0.038	0.038	0.000	0.0
226	Equatorial Guinea	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
231	Ethiopia	0.036	0.051	0.014	39.1	0.072	0.087	0.015	20.9	0.736	0.721	-0.015	-2.0	0.685	0.627	-0.058	-8.5
232	Eritrea	0.003	0.003	0.000	-4.4	0.007	0.007	0.000	-2.0	0.072	0.072	-0.001	-0.7	0.075	0.074	0.000	0.0
233	Estonia	0.000	0.000	0.000	-3.8	0.001	0.001	0.000	-12.8	0.002	0.002	0.000	1.3	0.001	0.001	0.000	-0.1
234	Faroe Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
238	Falkland Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
239	South Georgia and the South Sandwich Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
242	Fiji	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.007	0.007	0.000	6.7	0.007	0.007	0.000	0.0
246	Finland	0.002	0.001	0.000	-17.8	0.000	0.000	0.000	-29.6	0.020	0.020	0.000	-1.5	0.011	0.011	0.000	0.0
250	France	0.474	0.435	-0.040	-8.3	0.777	0.707	-0.070	-9.0	4.900	4.885	-0.016	-0.3	5.566	5.608	0.043	0.8
254	French Guiana	0.000	0.000	0.000	0.0	0.001	0.001	0.000	-9.6	0.004	0.004	0.000	3.5	0.004	0.004	0.000	-9.3
258	French Polynesia	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
260	French Southern Territories	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
262	Djibouti	0.000	0.000	0.000	0.0	0.002	0.002	0.000	-10.1	0.002	0.002	0.000	1.1	0.002	0.002	0.000	0.0
266	Gabon	0.000	0.000	0.000	0.0	0.002	0.002	0.000	4.4	0.002	0.002	0.000	8.2	0.002	0.002	0.000	0.0
268	Georgia	0.075	0.072	-0.003	-3.7	0.144	0.139	-0.005	-3.7	0.315	0.319	0.003	1.0	0.281	0.280	-0.001	-0.5
270	Gambia	0.003	0.003	0.000	2.3	0.003	0.003	0.000	0.0	0.006	0.006	0.000	-1.1	0.008	0.008	0.000	0.0
275	Palestine (West Bank & Gaza Strip)	0.011	0.011	0.000	-2.2	0.102	0.092	-0.011	-10.3	0.097	0.097	0.000	0.0	0.097	0.102	0.004	4.3
276	Germany & German Empire	0.274	0.220	-0.054	-19.8	0.187	0.185	-0.003	-1.4	0.602	0.588	-0.014	-2.3	0.505	0.524	0.019	3.7
288	Ghana	0.003	0.003	0.000	4.7	0.019	0.018	-0.001	-6.1	0.023	0.024	0.000	2.0	0.069	0.069	0.000	0.6
292	Gibraltar	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
296	Kiribati	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
300	Greece	0.618	0.596	-0.021	-3.5	2.414	2.291	-0.123	-5.1	4.986	5.016	0.030	0.6	6.521	6.497	-0.024	-0.4
304	Greenland	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0

	Year	**1910**	1910	1910	1910	**1960**	1960	1960	1960	**1995**	1995	1995	1995	**2005**	2005	2005	2005
	Run	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT
Ctry cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]
308	Grenada	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	1.7	0.000	0.000	0.000	4.7
312	Guadeloupe	0.000	0.000	0.000	0.0	0.000	0.001	0.000	86.0	0.003	0.002	-0.001	-25.2	0.003	0.003	0.000	2.7
316	Guam	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
320	Guatemala	0.026	0.022	-0.004	-15.5	0.027	0.031	0.004	16.0	0.052	0.053	0.001	1.6	0.118	0.118	-0.001	-0.7
324	Guinea	0.006	0.006	0.000	-7.8	0.013	0.011	-0.002	-14.0	0.047	0.045	-0.002	-4.3	0.067	0.067	0.000	0.1
328	Guyana	0.020	0.026	0.006	31.8	0.157	0.145	-0.012	-7.7	0.379	0.380	0.001	0.3	0.201	0.202	0.000	0.2
332	Haiti	0.014	0.015	0.001	7.7	0.068	0.061	-0.007	-9.9	0.265	0.261	-0.004	-1.7	0.184	0.184	0.000	0.0
334	Heard Island and McDonald Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
336	Vatican City	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
340	Honduras	0.026	0.022	-0.004	-14.5	0.042	0.047	0.005	12.2	0.062	0.065	0.003	4.1	0.111	0.110	-0.001	-1.3
344	Hong Kong	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
348	Hungary	0.014	0.019	0.005	36.8	0.060	0.067	0.007	11.7	0.309	0.304	-0.005	-1.6	0.160	0.150	-0.010	-6.3
352	Iceland	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
356	India & Indian Empire	119.92	78.358	-41.56	-34.7	137.02	125.63	-11.38	-8.3	228.86	227.68	-1.181	-0.5	264.27	266.33	2.055	0.8
360	Indonesia	5.057	4.655	-0.402	-7.9	12.798	11.521	-1.278	-10.0	8.427	8.241	-0.186	-2.2	12.158	12.373	0.214	1.8
364	Iran	10.975	10.491	-0.484	-4.4	28.058	27.943	-0.115	-0.4	42.279	41.960	-0.319	-0.8	51.175	51.477	0.302	0.6
368	Iraq	2.890	2.630	-0.259	-9.0	8.151	7.511	-0.640	-7.9	19.710	19.367	-0.343	-1.7	20.429	20.412	-0.017	-0.1
372	Ireland	0.003	0.003	0.000	4.9	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.001	0.001	0.000	0.0
376	Israel	0.123	0.124	0.002	1.2	0.891	0.867	-0.024	-2.7	1.335	1.306	-0.029	-2.1	1.250	1.253	0.003	0.2
380	Italy	3.184	3.330	0.145	4.6	4.820	5.338	0.518	10.7	8.450	8.342	-0.108	-1.3	10.786	10.745	-0.041	-0.4
384	Côte d'Ivoire	0.001	0.001	0.000	49.5	0.002	0.003	0.001	36.3	0.032	0.034	0.002	4.7	0.039	0.039	0.000	0.2
388	Jamaica	0.014	0.018	0.004	26.5	0.042	0.042	0.000	0.4	0.045	0.046	0.001	1.4	0.035	0.035	0.000	0.0
392	Japan	4.312	4.111	-0.201	-4.7	5.795	5.801	0.007	0.1	5.146	5.042	-0.103	-2.0	5.317	5.317	0.001	0.0
398	Kazakhstan	6.027	5.896	-0.131	-2.2	8.289	8.947	0.657	7.9	16.966	17.191	0.226	1.3	12.952	12.070	-0.882	-6.8
400	Jordan	0.087	0.084	-0.003	-3.1	0.296	0.303	0.008	2.5	0.680	0.715	0.035	5.1	0.751	0.749	-0.002	-0.3
404	Kenya	0.018	0.023	0.005	27.3	0.043	0.047	0.003	7.7	0.224	0.231	0.007	3.2	0.377	0.378	0.000	0.1
408	North Korea	0.406	0.378	-0.028	-6.8	0.656	0.623	-0.033	-5.0	1.388	1.374	-0.014	-1.0	1.643	1.644	0.001	0.0
410	South Korea	0.647	0.671	0.024	3.8	1.826	1.838	0.012	0.7	2.049	2.052	0.003	0.2	1.720	1.710	-0.010	-0.6
414	Kuwait	0.000	0.000	0.000	0.0	0.001	0.001	0.000	18.0	0.040	0.039	0.000	-0.8	0.066	0.065	0.000	-0.4
417	Kyrgyzstan	1.620	1.616	-0.003	-0.2	3.253	3.624	0.371	11.4	4.116	4.108	-0.007	-0.2	3.658	3.875	0.217	5.9
418	Laos	0.007	0.008	0.001	14.1	0.015	0.017	0.002	14.4	0.200	0.178	-0.022	-11.1	0.374	0.351	-0.022	-6.0
422	Lebanon	0.047	0.043	-0.004	-7.8	0.177	0.161	-0.016	-9.1	0.396	0.399	0.003	0.7	0.456	0.456	0.000	-0.1
426	Lesotho	0.000	0.000	0.000	-46.9	0.001	0.001	0.000	-21.8	0.002	0.002	0.000	5.2	0.002	0.002	0.000	0.0
428	Latvia	0.000	0.000	0.000	7.2	0.002	0.001	0.000	-6.0	0.004	0.004	0.000	-6.2	0.000	0.000	0.000	-1.3
430	Liberia	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	-2.9	0.000	0.000	0.000	0.2
434	Libya	0.340	0.401	0.061	18.0	0.845	0.928	0.083	9.8	3.533	3.456	-0.077	-2.2	3.632	3.634	0.002	0.0
438	Liechten-stein	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
440	Lithuania	0.000	0.000	0.000	14.9	0.001	0.001	0.000	-16.4	0.004	0.003	0.000	-5.0	0.002	0.002	0.000	-1.3
442	Luxembourg	0.004	0.004	0.000	4.3	0.000	0.000	0.000	0.0	0.000	0.000	0.000	11.3	0.000	0.000	0.000	0.0
446	Macao	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
450	Madagascar	0.165	0.157	-0.008	-4.9	0.986	0.874	-0.112	-11.4	3.001	2.985	-0.016	-0.5	3.211	3.210	-0.001	0.0
454	Malawi	0.001	0.001	0.000	20.2	0.003	0.003	0.000	-1.1	0.058	0.049	-0.009	-15.8	0.117	0.116	-0.001	-0.9
458	Malaysia	0.282	0.292	0.010	3.7	0.576	0.564	-0.012	-2.1	0.508	0.516	0.008	1.6	0.603	0.609	0.006	0.9
462	Maldives	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
466	Mali	0.059	0.057	-0.002	-3.2	0.269	0.267	-0.003	-0.9	0.378	0.385	0.007	2.0	1.138	1.139	0.000	0.0
470	Malta	0.002	0.002	0.000	-2.8	0.004	0.004	0.000	-3.7	0.007	0.008	0.001	12.5	0.023	0.024	0.002	7.4
474	Martinique	0.001	0.001	0.000	-15.3	0.002	0.002	0.000	-5.7	0.007	0.007	0.000	1.1	0.010	0.010	0.000	-0.6
478	Mauritania	0.092	0.095	0.003	3.4	0.126	0.147	0.021	16.5	0.237	0.249	0.012	4.9	0.289	0.292	0.004	1.2
480	Mauritius	0.000	0.000	0.000	-63.7	0.004	0.002	-0.002	-59.8	0.002	0.001	0.000	-15.1	0.001	0.001	0.000	0.8
484	Mexico	3.659	3.642	-0.017	-0.5	11.811	9.216	-2.595	-22.0	19.593	18.713	-0.880	-4.5	22.392	21.600	-0.792	-3.5
492	Monaco	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
496	Mongolia	0.017	0.015	-0.002	-14.0	0.013	0.012	-0.001	-8.9	0.226	0.237	0.011	5.0	0.273	0.262	-0.011	-4.0
498	Moldova	0.000	0.001	0.000	59.1	0.011	0.015	0.004	34.2	0.092	0.088	-0.004	-3.9	0.049	0.056	0.007	14.4
500	Montserrat	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
504	Morocco	3.966	4.060	0.093	2.4	7.414	7.430	0.016	0.2	12.304	12.196	-0.107	-0.9	14.911	14.786	-0.125	-0.8
508	Mozambique	0.010	0.011	0.001	5.0	0.035	0.036	0.000	1.2	0.098	0.099	0.001	1.0	0.099	0.099	0.000	0.0
512	Oman	0.171	0.164	-0.007	-4.2	0.168	0.162	-0.006	-3.6	0.466	0.461	-0.004	-0.9	0.465	0.466	0.001	0.1
516	Namibia	0.007	0.008	0.001	15.0	0.019	0.019	0.001	4.1	0.063	0.064	0.001	1.9	0.065	0.065	0.000	0.0
520	Nauru	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
524	Nepal	0.178	0.085	-0.093	-52.3	0.334	0.218	-0.116	-34.8	1.616	1.666	0.050	3.1	1.981	1.961	-0.019	-1.0
528	Netherlands	0.051	0.042	-0.009	-17.0	0.056	0.048	-0.008	-15.0	0.155	0.153	-0.002	-1.3	0.114	0.104	-0.010	-8.8
530	Netherlands Antilles	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
533	Aruba	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
540	New Caledonia	0.000	0.000	0.000	0.0	0.003	0.002	0.000	-5.7	0.014	0.015	0.000	0.5	0.023	0.023	0.000	0.0

	Year	**1910**	1910	1910	1910	**1960**	1960	1960	1960	**1995**	1995	1995	1995	**2005**	2005	2005	2005
	Run	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT
Ctry cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT]
548	Vanuatu	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
554	New Zealand	0.110	0.101	-0.009	-7.8	0.371	0.368	-0.003	-0.8	0.899	0.890	-0.009	-1.0	1.038	1.052	0.014	1.4
558	Nicaragua	0.012	0.012	0.000	0.5	0.024	0.027	0.003	10.4	0.055	0.054	0.000	-0.7	0.134	0.135	0.001	0.9
562	Niger	0.029	0.029	0.000	-1.1	0.075	0.074	-0.002	-2.1	0.310	0.303	-0.007	-2.4	0.344	0.345	0.000	0.1
566	Nigeria	0.463	0.417	-0.046	-9.9	0.605	0.535	-0.070	-11.6	0.624	0.599	-0.025	-4.0	0.799	0.796	-0.003	-0.4
570	Niue	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
574	Norfolk Island	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
578	Norway	0.007	0.006	-0.001	-14.9	0.006	0.006	-0.001	-8.5	0.056	0.070	0.013	23.8	0.056	0.054	-0.002	-4.1
580	Northern Mariana Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
581	United States Minor Outlying Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
583	Micronesia	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
584	Marshall Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
585	Palau	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
586	Pakistan	0.000	23.536	23.536	0.0	58.142	47.774	-10.37	-17.8	69.873	64.461	-5.412	-7.7	63.431	65.110	1.679	2.6
591	Panama	0.002	0.001	0.000	-17.0	0.005	0.004	0.000	-5.1	0.002	0.002	0.000	0.2	0.016	0.016	0.000	0.0
598	Papua New Guinea	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
600	Paraguay	0.011	0.007	-0.003	-31.4	0.057	0.069	0.012	21.0	0.093	0.088	-0.005	-5.7	0.186	0.188	0.001	0.8
604	Peru	1.183	0.804	-0.379	-32.0	5.312	5.387	0.075	1.4	6.125	6.338	0.213	3.5	6.490	6.621	0.131	2.0
608	Philippines	0.371	0.359	-0.012	-3.2	2.082	2.086	0.004	0.2	3.403	3.462	0.059	1.7	4.550	4.597	0.047	1.0
612	Pitcairn Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
616	Poland	0.036	0.049	0.013	36.4	0.065	0.064	-0.001	-1.2	0.197	0.198	0.002	0.9	0.125	0.125	0.000	0.2
620	Portugal	0.589	0.623	0.034	5.8	1.595	1.712	0.117	7.4	2.145	2.301	0.157	7.3	2.008	1.980	-0.028	-1.4
624	Guinea-Bissau	0.002	0.002	0.000	2.6	0.009	0.009	0.000	-4.3	0.008	0.009	0.001	7.7	0.005	0.005	0.000	0.1
626	East Timor	0.004	0.005	0.001	16.6	0.014	0.015	0.000	2.8	0.027	0.028	0.001	2.2	0.038	0.038	0.001	2.1
630	Puerto Rico	0.008	0.010	0.003	37.0	0.022	0.030	0.008	34.5	0.025	0.024	-0.001	-4.3	0.029	0.029	0.000	0.0
634	Qatar	0.000	0.000	0.000	0.0	0.000	0.000	0.000	-15.7	0.041	0.041	0.000	0.3	0.048	0.048	0.000	0.0
638	Reunion	0.000	0.000	0.000	-3.5	0.002	0.002	0.000	-4.4	0.005	0.005	0.000	-0.4	0.002	0.002	0.000	0.5
642	Romania	0.005	0.005	0.000	4.0	0.076	0.079	0.003	3.8	1.095	1.089	-0.006	-0.5	0.205	0.208	0.004	1.8
643	Russia	0.453	0.240	-0.213	-47.1	2.141	1.336	-0.805	-37.6	4.519	4.935	0.416	9.2	2.588	2.082	-0.506	-19.6
646	Rwanda	0.000	0.000	0.000	0.0	0.003	0.003	0.000	5.4	0.003	0.004	0.000	15.1	0.009	0.008	-0.001	-7.4
654	Saint Helena	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
659	Saint Kitts and Nevis	0.000	0.000	0.000	-22.7	0.000	0.000	0.000	-0.1	0.000	0.000	0.000	-0.1	0.000	0.000	0.000	0.0
660	Anguilla	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
662	Saint Lucia	0.000	0.000	0.000	0.0	0.001	0.003	0.002	183.4	0.008	0.008	0.000	0.0	0.008	0.008	0.000	0.0
666	Saint Pierre and Miquelon	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
670	Saint Vincent and the Grenadines	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.001	0.003	0.002	203.6	0.003	0.003	0.000	0.0
674	San Marino	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
678	Sao Tome and Principe	0.005	0.005	0.000	-2.7	0.015	0.012	-0.004	-25.2	0.023	0.023	0.000	-0.6	0.024	0.024	0.000	0.2
682	Saudi Arabia	0.470	0.485	0.015	3.3	2.204	2.366	0.163	7.4	11.124	11.033	-0.091	-0.8	10.099	10.026	-0.074	-0.7
686	Senegal	0.143	0.152	0.009	6.2	0.234	0.258	0.024	10.1	0.305	0.304	-0.001	-0.4	0.451	0.448	-0.002	-0.6
690	Seychelles	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
694	Sierra Leone	0.001	0.000	0.000	-11.8	0.000	0.000	0.000	-25.8	0.009	0.009	0.000	-1.2	0.017	0.017	0.000	0.1
702	Singapore	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
703	Slovakia	0.001	0.001	0.000	-10.3	0.004	0.004	0.000	3.3	0.103	0.104	0.001	0.8	0.071	0.070	-0.001	-1.9
704	Vietnam	1.377	1.345	-0.031	-2.3	3.442	3.461	0.018	0.5	8.704	8.719	0.016	0.2	13.534	12.975	-0.558	-4.1
705	Slovenia	0.001	0.001	0.000	-2.1	0.001	0.001	0.000	13.6	0.004	0.005	0.000	5.0	0.013	0.013	0.000	0.0
706	Somalia	0.099	0.106	0.007	6.8	0.173	0.176	0.002	1.3	0.378	0.387	0.008	2.1	0.330	0.386	0.056	17.0
710	South Africa	0.767	0.909	0.142	18.5	3.522	3.981	0.459	13.0	6.346	6.483	0.137	2.2	7.715	7.718	0.004	0.0
716	Zimbabwe	0.001	0.001	0.000	-36.8	0.061	0.053	-0.008	-12.5	0.434	0.384	-0.050	-11.5	0.603	0.603	0.000	0.0
724	Spain	8.265	8.278	0.013	0.2	13.437	14.189	0.752	5.6	20.652	20.949	0.297	1.4	29.452	29.329	-0.124	-0.4
732	Western Sahara	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
736	Sudan	0.631	0.617	-0.013	-2.1	4.210	3.935	-0.275	-6.5	5.234	5.252	0.018	0.3	5.431	5.430	-0.001	0.0
740	Suriname	0.004	0.003	-0.001	-18.1	0.024	0.024	0.000	-0.3	0.111	0.109	-0.002	-1.9	0.062	0.062	0.000	0.1

	Year	**1910**	1910	1910	1910	**1960**	1960	1960	1960	**1995**	1995	1995	1995	**2005**	2005	2005	2005
	Run	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT	ACT	ACT HIST	ACT HIST - ACT	ACT HIST - ACT
Ctry cde	Country name	ICU [km^3a^{-1}]	ICU [km^3a^{-1}]	ICU [km^3a^{-1}]	[% ACT]	ICU [km^3a^{-1}]	ICU [km^3a^{-1}]	ICU [km^3a^{-1}]	[% ACT]	ICU [km^3a^{-1}]	ICU [km^3a^{-1}]	ICU [km^3a^{-1}]	[% ACT]	ICU [km^3a^{-1}]	ICU [km^3a^{-1}]	ICU [km^3a^{-1}]	[% ACT]
744	Svalbard and Jan Mayen	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
748	Swaziland	0.000	0.000	0.000	0.0	0.061	0.060	-0.001	-1.7	0.116	0.118	0.002	1.5	0.092	0.092	0.000	0.1
752	Sweden	0.027	0.022	-0.005	-17.7	0.008	0.006	-0.002	-26.0	0.080	0.079	-0.001	-1.3	0.087	0.088	0.000	0.4
756	Switzerland	0.011	0.007	-0.005	-40.8	0.006	0.006	0.000	1.8	0.033	0.034	0.001	2.6	0.035	0.035	0.000	-0.9
760	Syria	0.597	0.605	0.008	1.4	3.911	3.744	-0.167	-4.3	7.772	7.805	0.033	0.4	11.125	10.857	-0.267	-2.4
762	Tajikistan	1.170	1.123	-0.047	-4.0	1.888	1.853	-0.035	-1.9	3.772	3.794	0.022	0.6	3.621	3.659	0.039	1.1
764	Thailand	0.155	0.157	0.002	1.4	3.590	3.457	-0.133	-3.7	7.782	7.748	-0.033	-0.4	9.816	9.851	0.035	0.4
768	Togo	0.001	0.001	0.000	32.2	0.001	0.001	0.000	-8.6	0.004	0.004	0.000	-4.8	0.005	0.005	0.000	0.0
772	Tokelau	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
776	Tonga	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
780	Trinidad and Tobago	0.000	0.000	0.000	868.9	0.002	0.006	0.004	228.7	0.010	0.010	0.000	-1.1	0.010	0.010	0.000	-0.9
784	United Arab Emirates	0.057	0.073	0.016	28.0	0.195	0.219	0.024	12.3	0.622	0.647	0.025	4.1	1.719	1.717	-0.003	-0.2
788	Tunisia	0.725	0.719	-0.005	-0.7	0.677	0.668	-0.010	-1.4	2.955	2.850	-0.106	-3.6	3.452	3.418	-0.034	-1.0
792	Turkey	2.684	2.722	0.039	1.4	5.331	4.941	-0.390	-7.3	18.463	18.225	-0.238	-1.3	22.573	23.008	0.435	1.9
795	Turkmenistan	1.479	1.418	-0.062	-4.2	2.931	2.356	-0.575	-19.6	11.913	11.834	-0.079	-0.7	14.383	14.095	-0.288	-2.0
796	Turks and Caicos Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
798	Tuvalu	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
800	Uganda	0.000	0.000	0.000	0.0	0.001	0.001	0.000	7.3	0.006	0.006	0.000	3.3	0.008	0.008	0.000	0.0
804	Ukraine	0.015	0.015	0.000	-2.4	0.328	0.303	-0.024	-7.5	1.942	1.957	0.014	0.7	1.967	1.963	-0.004	-0.2
807	Macedonia	0.008	0.008	0.000	4.6	0.063	0.050	-0.014	-21.9	0.195	0.194	-0.001	-0.6	0.215	0.216	0.000	0.1
818	Egypt	33.096	33.596	0.500	1.5	39.608	39.720	0.112	0.3	47.362	47.646	0.284	0.6	50.490	50.592	0.102	0.2
826	United Kingdom	0.028	0.025	-0.004	-12.4	0.074	0.063	-0.011	-14.7	0.316	0.319	0.004	1.2	0.172	0.172	0.000	-0.2
831	Guernsey	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
832	Jersey	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
833	Isle of Man	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
834	Tanzania	0.065	0.051	-0.014	-21.0	0.058	0.051	-0.007	-12.4	0.428	0.413	-0.015	-3.5	0.575	0.577	0.002	0.3
840	United States	45.555	37.201	-8.354	-18.3	83.983	71.707	-12.28	-14.6	107.53	104.91	-2.617	-2.4	116.56	117.80	1.246	1.1
850	Virgin Islands, U.S.	0.000	0.000	0.000	0.0	0.0001	0.0002	0.0001	155.4	0.0005	0.0005	0.0000	-0.1	0.0002	0.0002	0.0000	0.0
854	Burkina Faso	0.004	0.003	-0.001	-26.9	0.009	0.006	-0.002	-24.2	0.081	0.081	0.000	-0.4	0.085	0.085	0.000	0.1
858	Uruguay	0.000	0.000	0.000	0.0	0.152	0.132	-0.020	-12.9	0.535	0.531	-0.003	-0.6	0.927	0.927	0.000	0.0
860	Uzbekistan	6.840	6.954	0.114	1.7	8.449	6.159	-2.290	-27.1	24.100	24.068	-0.032	-0.1	23.481	23.742	0.261	1.1
862	Venezuela	0.152	0.117	-0.036	-23.3	0.595	0.517	-0.078	-13.1	0.820	0.787	-0.033	-4.0	0.937	0.992	0.055	5.9
876	Wallis and Futuna	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
882	Samoa	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
887	Yemen	0.801	0.705	-0.096	-12.0	1.327	1.230	-0.097	-7.3	3.450	3.391	-0.060	-1.7	4.498	4.539	0.041	0.9
891	Serbia, Montenegro, Kosovo	0.013	0.011	-0.002	-17.5	0.187	0.229	0.042	22.5	0.162	0.172	0.011	6.5	0.226	0.246	0.020	8.7
894	Zambia	0.000	0.000	0.000	0.0	0.008	0.005	-0.002	-32.2	0.337	0.323	-0.014	-4.2	0.573	0.573	0.000	0.0
901	Clipperton Island	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0
902	Caspian Sea	0.415	0.404	-0.012	-2.8	0.701	0.557	-0.144	-20.5	1.134	1.142	0.008	0.7	0.990	0.985	-0.004	-0.4
903	Spratly Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0

A.7 *Country sums of irrigation consumptive use for 1995 from HID-ACT-1995 with cropping periods from different climate means*

In the following Table A.8 country sums of irrigation consumptive use, for runs HID-ACT-1995_refclim, HID-ACT-1995_clim1901, HID-ACT-1995_clim1921, HID-ACT-1995_clim1946, and HID-ACT-1995_clim1951 are listed for evaluation year 1995, together with the absolute and percent differences of the non-standard climate periods to HID-ACT-1995_refclim.

Table A.8: Irrigation consumptive use (ICU) [km^3 a^{-1}] for year 1995,
by country (sorted by UNM49 country code),
for runs HID-ACT-1995_refclim, clim1901, clim1921, clim1946, clim1951 and
their difference to standard reference climate period refclim (1981-2010)
[km^3 a^{-1} and % of HID-ACT-1995_refclim]

	Climate period	**Stdclim 1981**	**Clim 1901**	Clim 1901 – Stdclim 1981	Clim 1901 – Stdclim 1981	**Clim 1921**	Clim 1921 – Stdclim 1981	Clim 1921 – Stdclim 1981	**Clim 1946**	Clim 1946 – Stdclim 1981	Clim 1946 – Stdclim 1981	**Clim 1951**	Clim 1951 – Stdclim 1981	Clim 1951 – Stdclim 1981
	Run	ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT
Cty cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT 1981]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]
4	Afghanistan	16.313	17.123	0.811	5.0	16.230	-0.082	-0.5	17.133	0.820	5.0	16.946	0.633	3.9
8	Albania	0.401	0.390	-0.011	-2.6	0.394	-0.007	-1.6	0.406	0.005	1.2	0.403	0.002	0.4
10	Antarctica	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
12	Algeria	4.194	4.228	0.034	0.8	4.142	-0.052	-1.2	4.147	-0.047	-1.1	4.127	-0.066	-1.6
16	American Samoa	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
20	Andorra	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
24	Angola	0.143	0.149	0.007	4.6	0.151	0.009	6.0	0.147	0.005	3.2	0.149	0.006	4.2
28	Antigua and Barbuda	0.000	0.000	0.000	-22.4	0.000	0.000	-35.4	0.000	0.000	-5.4	0.000	0.000	0.1
31	Azerbaijan	6.140	6.057	-0.083	-1.3	6.093	-0.047	-0.8	6.060	-0.080	-1.3	6.015	-0.124	-2.0
32	Argentina	4.967	5.519	0.552	11.1	5.367	0.400	8.1	5.313	0.346	7.0	5.490	0.523	10.5
36	Australia	19.948	20.105	0.157	0.8	20.000	0.052	0.3	20.005	0.057	0.3	19.999	0.051	0.3
40	Austria	0.092	0.091	-0.001	-1.0	0.095	0.003	3.2	0.085	-0.007	-7.9	0.088	-0.004	-4.6
44	Bahamas	0.001	0.000	0.000	-40.1	0.000	0.000	-39.2	0.001	0.000	-17.4	0.001	0.000	-25.6
48	Bahrain	0.015	0.015	0.000	0.0	0.013	-0.002	-12.3	0.015	0.000	0.0	0.015	0.000	0.0
50	Bangladesh	14.659	13.472	-1.187	-8.1	13.682	-0.977	-6.7	14.647	-0.011	-0.1	13.988	-0.671	-4.6
51	Armenia	0.707	0.701	-0.006	-0.8	0.699	-0.007	-1.1	0.707	0.000	0.0	0.704	-0.002	-0.3
52	Barbados	0.010	0.005	-0.005	-47.9	0.007	-0.003	-25.0	0.004	-0.006	-63.0	0.004	-0.006	-63.0
56	Belgium	0.028	0.027	0.000	-1.7	0.026	-0.001	-5.3	0.027	0.000	-1.0	0.027	0.000	-1.5
60	Bermuda	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
64	Bhutan	0.022	0.019	-0.003	-12.1	0.018	-0.004	-16.6	0.018	-0.004	-17.1	0.018	-0.004	-17.8
68	Bolivia	0.347	0.352	0.005	1.5	0.356	0.010	2.8	0.351	0.004	1.2	0.355	0.008	2.4
70	Bosnia and Herzegovina	0.006	0.005	0.000	-4.7	0.006	0.000	8.3	0.006	0.000	8.2	0.006	0.000	6.0
72	Botswana	0.009	0.008	-0.001	-7.7	0.007	-0.002	-17.8	0.009	0.000	-2.3	0.008	-0.001	-10.9
74	Bouvet Island	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
76	Brazil	5.887	6.706	0.819	13.9	6.495	0.609	10.3	5.964	0.077	1.3	5.976	0.089	1.5
84	Belize	0.003	0.003	0.000	-7.3	0.002	-0.001	-20.2	0.002	-0.001	-31.1	0.003	0.000	-3.1
86	British Indian Ocean Territory	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
90	Solomon Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
92	British Virgin Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
96	Brunei	0.000	0.001	0.000	5.4	0.000	0.000	-1.5	0.000	0.000	-3.6	0.000	0.000	-8.0
100	Bulgaria	0.415	0.418	0.002	0.6	0.430	0.015	3.6	0.422	0.007	1.7	0.443	0.027	6.6
104	Myanmar	3.963	3.534	-0.429	-10.8	3.606	-0.357	-9.0	3.627	-0.336	-8.5	3.730	-0.233	-5.9
108	Burundi	0.045	0.042	-0.003	-5.8	0.045	0.001	1.9	0.038	-0.006	-13.9	0.039	-0.006	-12.5
112	Belarus	0.042	0.042	0.000	0.4	0.041	-0.001	-3.6	0.043	0.000	1.1	0.043	0.001	2.8
116	Cambodia	0.620	0.677	0.057	9.2	0.669	0.050	8.0	0.647	0.028	4.5	0.631	0.011	1.8
120	Cameroon	0.036	0.033	-0.003	-7.2	0.037	0.001	2.1	0.034	-0.002	-4.7	0.035	-0.001	-2.5
124	Canada	2.592	2.670	0.077	3.0	2.649	0.057	2.2	2.638	0.046	1.8	2.632	0.040	1.5
132	Cape Verde	0.008	0.008	0.000	-3.4	0.009	0.000	2.8	0.008	0.000	-3.7	0.008	0.000	0.0
136	Cayman	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0

	Climate period	**Stdclim 1981**	**Clim 1901**	Clim 1901 – Stdclim 1981	Clim 1901 – Stdclim 1981	**Clim 1921**	Clim 1921 – Stdclim 1981	Clim 1921 – Stdclim 1981	**Clim 1946**	Clim 1946 – Stdclim 1981	Clim 1946 – Stdclim 1981	**Clim 1951**	Clim 1951 – Stdclim 1981	Clim 1951 – Stdclim 1981
	Run	ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT
Cty cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT 1981]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]
	Islands													
140	Central African Republic	0.000	0.000	0.000	-16.4	0.000	0.000	-61.6	0.000	0.000	-7.8	0.000	0.000	-20.7
144	Sri Lanka	2.055	2.216	0.161	7.9	2.182	0.127	6.2	2.183	0.129	6.3	2.154	0.099	4.8
148	Chad	0.089	0.094	0.004	5.0	0.093	0.004	4.2	0.100	0.011	11.9	0.090	0.001	0.8
152	Chile	8.098	7.896	-0.202	-2.5	7.979	-0.118	-1.5	8.022	-0.076	-0.9	8.080	-0.018	-0.2
156	China	183.811	183.948	0.137	0.1	183.641	-0.170	-0.1	183.936	0.125	0.1	184.278	0.467	0.3
158	Taiwan	2.326	2.342	0.016	0.7	2.267	-0.059	-2.5	2.276	-0.050	-2.2	2.306	-0.020	-0.9
162	Christmas Island	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
166	Cocos Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
170	Colombia	0.826	0.819	-0.007	-0.8	0.863	0.036	4.4	0.778	-0.048	-5.8	0.869	0.042	5.1
174	Comoros	0.000	0.000	0.000	-2.0	0.000	0.000	-2.6	0.000	0.000	-1.5	0.000	0.000	0.9
175	Mayotte	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
178	Republic of Congo	0.000	0.002	0.002	1057.2	0.000	0.000	-0.5	0.000	0.000	135.7	0.000	0.000	-2.3
180	Democratic Republic of the Congo	0.006	0.008	0.002	36.5	0.008	0.002	34.4	0.012	0.006	103.3	0.011	0.006	99.3
184	Cook Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
188	Costa Rica	0.057	0.033	-0.024	-41.6	0.038	-0.020	-34.1	0.049	-0.008	-13.5	0.045	-0.012	-21.3
191	Croatia	0.041	0.039	-0.002	-5.8	0.045	0.004	8.9	0.040	-0.001	-2.9	0.044	0.002	6.0
192	Cuba	0.266	0.250	-0.016	-5.9	0.255	-0.011	-4.0	0.237	-0.028	-10.6	0.270	0.004	1.5
196	Cyprus	0.308	0.284	-0.023	-7.6	0.288	-0.020	-6.4	0.301	-0.006	-2.1	0.286	-0.022	-7.0
203	Czech Republic	0.093	0.093	0.000	-0.3	0.091	-0.002	-2.1	0.093	0.000	0.1	0.093	0.000	0.1
204	Benin	0.004	0.005	0.001	15.5	0.004	0.000	-11.3	0.006	0.002	51.3	0.004	0.000	2.5
208	Denmark	0.441	0.442	0.001	0.3	0.406	-0.035	-7.9	0.430	-0.010	-2.3	0.402	-0.039	-8.8
212	Dominica	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
214	Dominican Republic	0.889	0.870	-0.019	-2.1	0.844	-0.045	-5.0	0.823	-0.065	-7.4	0.795	-0.093	-10.5
218	Ecuador	0.996	0.995	0.000	0.0	0.992	-0.004	-0.4	1.014	0.019	1.9	1.016	0.020	2.1
222	El Salvador	0.016	0.017	0.001	3.1	0.018	0.001	9.0	0.015	-0.001	-7.8	0.017	0.001	5.5
226	Equatorial Guinea	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
231	Ethiopia	0.736	0.705	-0.030	-4.1	0.742	0.007	0.9	0.731	-0.004	-0.6	0.775	0.039	5.4
232	Eritrea	0.072	0.069	-0.003	-4.6	0.073	0.001	0.8	0.070	-0.002	-2.8	0.072	0.000	-0.5
233	Estonia	0.002	0.002	0.000	2.9	0.002	0.000	6.6	0.002	0.000	2.2	0.002	0.000	6.2
234	Faroe Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
238	Falkland Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
239	South Georgia and the South Sandwich Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
242	Fiji	0.007	0.007	0.000	4.5	0.006	-0.001	-7.6	0.007	0.000	-4.0	0.007	0.000	-1.2
246	Finland	0.020	0.023	0.003	13.7	0.023	0.002	12.1	0.023	0.003	13.5	0.022	0.002	11.2
250	France	4.900	4.668	-0.232	-4.7	4.756	-0.144	-2.9	4.652	-0.248	-5.1	4.578	-0.322	-6.6
254	French Guiana	0.004	0.004	0.000	-6.4	0.004	0.000	-7.8	0.004	0.000	-7.1	0.004	0.000	-8.2
258	French Polynesia	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
260	French Southern Territories	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
262	Djibouti	0.002	0.002	0.000	6.1	0.002	0.000	7.9	0.002	0.000	6.0	0.002	0.000	9.2
266	Gabon	0.002	0.002	-0.001	-26.4	0.001	-0.001	-35.7	0.002	-0.001	-28.9	0.001	-0.001	-36.7
268	Georgia	0.315	0.288	-0.028	-8.8	0.312	-0.003	-1.0	0.319	0.003	1.0	0.307	-0.009	-2.8
270	Gambia	0.006	0.006	0.000	-1.8	0.006	0.000	1.2	0.006	0.000	-1.0	0.006	0.000	-1.0
275	Palestine (West Bank & Gaza Strip)	0.097	0.098	0.002	1.6	0.109	0.012	12.7	0.109	0.012	12.7	0.108	0.012	12.1
276	Germany & German Empire	0.602	0.589	-0.013	-2.2	0.581	-0.021	-3.5	0.589	-0.013	-2.1	0.600	-0.002	-0.4

	Climate period	**Stdclim 1981**	**Clim 1901**	Clim 1901 – Stdclim 1981	Clim 1901 – Stdclim 1981	**Clim 1921**	Clim 1921 – Stdclim 1981	Clim 1921 – Stdclim 1981	**Clim 1946**	Clim 1946 – Stdclim 1981	Clim 1946 – Stdclim 1981	**Clim 1951**	Clim 1951 – Stdclim 1981	Clim 1951 – Stdclim 1981
	Run	ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT
Cty cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT 1981]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]
288	Ghana	0.023	0.022	-0.001	-3.4	0.026	0.003	10.8	0.022	-0.001	-4.5	0.025	0.001	6.2
292	Gibraltar	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
296	Kiribati	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
300	Greece	4.986	5.027	0.041	0.8	5.060	0.074	1.5	5.026	0.040	0.8	5.025	0.038	0.8
304	Greenland	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
308	Grenada	0.000	0.000	0.000	-57.7	0.000	0.000	-40.3	0.000	0.000	-38.5	0.000	0.000	-56.8
312	Guadeloupe	0.003	0.002	-0.001	-19.7	0.001	-0.002	-67.5	0.001	-0.002	-67.9	0.002	-0.001	-24.0
316	Guam	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
320	Guatemala	0.052	0.050	-0.003	-5.4	0.046	-0.007	-13.0	0.043	-0.009	-17.8	0.051	-0.001	-2.0
324	Guinea	0.047	0.054	0.007	15.4	0.052	0.005	10.9	0.055	0.008	16.7	0.049	0.002	4.5
328	Guyana	0.379	0.366	-0.013	-3.4	0.360	-0.019	-4.9	0.386	0.007	1.8	0.371	-0.008	-2.1
332	Haiti	0.265	0.229	-0.036	-13.6	0.241	-0.024	-9.1	0.229	-0.036	-13.7	0.243	-0.022	-8.5
334	Heard Island and McDonald Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
336	Vatican City	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
340	Honduras	0.062	0.083	0.021	32.9	0.045	-0.017	-27.6	0.039	-0.023	-37.1	0.041	-0.022	-34.4
344	Hong Kong	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
348	Hungary	0.309	0.303	-0.006	-1.9	0.300	-0.009	-2.9	0.293	-0.016	-5.1	0.293	-0.016	-5.2
352	Iceland	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
356	India & Indian Empire	228.857	235.963	7.106	3.1	241.288	12.431	5.4	237.006	8.149	3.6	235.964	7.107	3.1
360	Indonesia	8.427	8.830	0.403	4.8	8.951	0.524	6.2	8.992	0.565	6.7	8.965	0.537	6.4
364	Iran	42.279	43.566	1.287	3.0	43.509	1.230	2.9	43.255	0.976	2.3	43.217	0.938	2.2
368	Iraq	19.710	21.094	1.385	7.0	20.797	1.087	5.5	20.883	1.173	6.0	20.801	1.091	5.5
372	Ireland	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
376	Israel	1.335	1.349	0.014	1.1	1.373	0.038	2.9	1.362	0.027	2.0	1.382	0.047	3.5
380	Italy	8.450	8.457	0.007	0.1	8.489	0.039	0.5	8.432	-0.018	-0.2	8.402	-0.048	-0.6
384	Côte d'Ivoire	0.032	0.024	-0.008	-26.2	0.016	-0.016	-49.6	0.020	-0.013	-38.8	0.025	-0.007	-22.9
388	Jamaica	0.045	0.039	-0.006	-12.4	0.023	-0.022	-48.2	0.042	-0.003	-6.3	0.043	-0.002	-4.9
392	Japan	5.146	5.284	0.138	2.7	5.275	0.130	2.5	5.207	0.061	1.2	5.183	0.037	0.7
398	Kazakhstan	16.966	17.189	0.223	1.3	17.112	0.146	0.9	17.150	0.184	1.1	17.164	0.198	1.2
400	Jordan	0.680	0.709	0.029	4.3	0.710	0.030	4.4	0.685	0.005	0.8	0.685	0.005	0.7
404	Kenya	0.224	0.211	-0.012	-5.6	0.217	-0.006	-2.9	0.222	-0.002	-0.8	0.221	-0.002	-1.0
408	North Korea	1.388	1.318	-0.070	-5.1	1.347	-0.041	-3.0	1.329	-0.059	-4.3	1.326	-0.062	-4.5
410	South Korea	2.049	1.923	-0.126	-6.2	1.932	-0.117	-5.7	1.967	-0.082	-4.0	1.957	-0.092	-4.5
414	Kuwait	0.040	0.042	0.003	6.9	0.043	0.004	9.1	0.041	0.002	4.1	0.041	0.001	2.6
417	Kyrgyzstan	4.116	4.137	0.021	0.5	4.130	0.015	0.4	4.102	-0.014	-0.3	4.091	-0.025	-0.6
418	Laos	0.200	0.181	-0.019	-9.3	0.177	-0.023	-11.3	0.178	-0.022	-11.2	0.175	-0.025	-12.3
422	Lebanon	0.396	0.415	0.019	4.7	0.415	0.019	4.9	0.432	0.036	9.1	0.430	0.034	8.7
426	Lesotho	0.002	0.002	0.000	15.0	0.002	0.000	16.5	0.002	0.000	6.1	0.002	0.000	7.5
428	Latvia	0.004	0.004	0.000	-1.8	0.004	0.000	-1.7	0.004	0.000	0.1	0.005	0.000	5.3
430	Liberia	0.000	0.000	0.000	-35.8	0.000	0.000	-48.4	0.000	0.000	-57.1	0.000	0.000	-39.9
434	Libya	3.533	3.640	0.107	3.0	3.489	-0.044	-1.2	3.565	0.032	0.9	3.561	0.028	0.8
438	Liechtenstein	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
440	Lithuania	0.004	0.004	0.000	-2.2	0.004	0.000	-2.0	0.004	0.000	1.9	0.004	0.000	3.5
442	Luxembourg	0.000	0.000	0.000	4.1	0.000	0.000	-5.3	0.000	0.000	4.1	0.000	0.000	1.7
446	Macao	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
450	Madagascar	3.001	3.889	0.888	29.6	3.529	0.528	17.6	3.539	0.538	17.9	3.486	0.485	16.2
454	Malawi	0.058	0.062	0.003	5.4	0.058	0.000	-0.1	0.056	-0.002	-4.2	0.054	-0.004	-7.3
458	Malaysia	0.508	0.536	0.029	5.6	0.537	0.029	5.7	0.540	0.032	6.3	0.530	0.022	4.3
462	Maldives	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
466	Mali	0.378	0.392	0.014	3.7	0.391	0.014	3.6	0.393	0.015	4.0	0.395	0.017	4.4
470	Malta	0.007	0.008	0.001	15.5	0.008	0.001	17.3	0.008	0.001	17.9	0.007	0.000	0.6
474	Martinique	0.007	0.007	0.000	0.0	0.006	-0.001	-11.1	0.007	0.000	0.1	0.007	0.000	0.1
478	Mauritania	0.237	0.239	0.001	0.6	0.245	0.008	3.2	0.228	-0.009	-3.9	0.227	-0.011	-4.4
480	Mauritius	0.002	0.001	0.000	-4.2	0.001	0.000	-2.7	0.001	0.000	-1.8	0.001	0.000	-1.5
484	Mexico	19.593	19.896	0.303	1.5	19.438	-0.155	-0.8	19.559	-0.034	-0.2	19.542	-0.051	-0.3
492	Monaco	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
496	Mongolia	0.226	0.224	-0.002	-1.0	0.212	-0.014	-6.1	0.219	-0.007	-3.2	0.214	-0.012	-5.1
498	Moldova	0.092	0.083	-0.009	-10.0	0.099	0.007	8.1	0.081	-0.011	-11.9	0.080	-0.011	-12.2
500	Montserrat	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
504	Morocco	12.304	12.049	-0.255	-2.1	11.653	-0.650	-5.3	12.070	-0.233	-1.9	12.286	-0.017	-0.1
508	Mozambique	0.098	0.089	-0.009	-9.4	0.081	-0.017	-17.4	0.090	-0.008	-8.0	0.103	0.004	4.5
512	Oman	0.466	0.481	0.015	3.3	0.457	-0.008	-1.8	0.480	0.015	3.1	0.472	0.007	1.5
516	Namibia	0.063	0.063	0.001	1.0	0.064	0.001	2.0	0.063	0.000	-0.1	0.064	0.001	1.5
520	Nauru	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
524	Nepal	1.616	1.325	-0.291	-18.0	1.325	-0.291	-18.0	1.276	-0.340	-21.0	1.223	-0.393	-24.3

	Climate period	**Stdclim 1981**	**Clim 1901**	Clim 1901 – Stdclim 1981	Clim 1901 – Stdclim 1981	**Clim 1921**	Clim 1921 – Stdclim 1981	Clim 1921 – Stdclim 1981	**Clim 1946**	Clim 1946 – Stdclim 1981	Clim 1946 – Stdclim 1981	**Clim 1951**	Clim 1951 – Stdclim 1981	Clim 1951 – Stdclim 1981
	Run	ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT
Cty cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT 1981]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]
528	Netherlands	0.155	0.155	0.000	0.0	0.155	0.000	-0.3	0.158	0.003	1.8	0.159	0.003	2.2
530	Netherlands Antilles	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
533	Aruba	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
540	New Caledonia	0.014	0.016	0.001	8.5	0.017	0.002	15.8	0.016	0.002	12.5	0.015	0.001	5.5
548	Vanuatu	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
554	New Zealand	0.899	0.829	-0.070	-7.8	0.951	0.052	5.8	0.849	-0.051	-5.6	0.877	-0.022	-2.5
558	Nicaragua	0.055	0.053	-0.002	-3.8	0.052	-0.002	-4.1	0.051	-0.004	-7.3	0.047	-0.007	-13.4
562	Niger	0.310	0.313	0.002	0.8	0.312	0.002	0.6	0.309	-0.001	-0.4	0.309	-0.002	-0.6
566	Nigeria	0.624	0.685	0.060	9.7	0.676	0.052	8.3	0.689	0.064	10.3	0.664	0.040	6.4
570	Niue	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
574	Norfolk Island	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
578	Norway	0.056	0.074	0.017	30.5	0.067	0.010	17.8	0.071	0.015	26.0	0.066	0.009	16.6
580	Northern Mariana Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
581	United States Minor Outlying Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
583	Micronesia	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
584	Marshall Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
585	Palau	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
586	Pakistan	69.873	83.331	13.458	19.3	85.670	15.797	22.6	81.316	11.443	16.4	80.753	10.880	15.6
591	Panama	0.002	0.002	0.000	-21.9	0.004	0.002	80.9	0.003	0.001	55.3	0.002	0.000	-15.7
598	Papua New Guinea	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
600	Paraguay	0.093	0.119	0.026	27.7	0.094	0.001	1.5	0.090	-0.003	-2.9	0.101	0.008	8.7
604	Peru	6.125	6.024	-0.101	-1.7	5.963	-0.162	-2.6	6.341	0.215	3.5	6.254	0.129	2.1
608	Philippines	3.403	3.446	0.043	1.3	3.197	-0.206	-6.1	3.304	-0.099	-2.9	3.129	-0.274	-8.0
612	Pitcairn Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
616	Poland	0.197	0.199	0.002	1.1	0.192	-0.004	-2.1	0.196	0.000	-0.1	0.194	-0.002	-1.2
620	Portugal	2.145	2.137	-0.008	-0.4	2.127	-0.018	-0.8	2.134	-0.011	-0.5	2.145	0.000	0.0
624	Guinea-Bissau	0.008	0.010	0.001	14.3	0.009	0.001	6.7	0.009	0.001	6.7	0.009	0.001	6.5
626	East Timor	0.027	0.026	-0.001	-4.1	0.026	-0.001	-5.4	0.028	0.000	1.5	0.028	0.000	0.9
630	Puerto Rico	0.025	0.020	-0.005	-18.4	0.019	-0.006	-22.8	0.017	-0.008	-30.7	0.018	-0.007	-26.8
634	Qatar	0.041	0.037	-0.004	-10.1	0.031	-0.010	-24.6	0.030	-0.011	-25.7	0.034	-0.007	-16.0
638	Reunion	0.005	0.005	0.000	-4.2	0.005	0.000	-2.7	0.005	0.000	-1.8	0.005	0.000	-1.5
642	Romania	1.095	1.045	-0.050	-4.6	1.075	-0.020	-1.8	1.089	-0.006	-0.5	1.079	-0.016	-1.5
643	Russia	4.519	4.555	0.036	0.8	4.505	-0.014	-0.3	4.671	0.152	3.4	4.610	0.091	2.0
646	Rwanda	0.003	0.003	0.000	4.5	0.003	0.000	0.0	0.004	0.000	16.2	0.003	0.000	7.6
654	Saint Helena	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
659	Saint Kitts and Nevis	0.000	0.000	0.000	-4.9	0.000	0.000	0.0	0.000	0.000	0.1	0.000	0.000	-28.8
660	Anguilla	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
662	Saint Lucia	0.008	0.002	-0.005	-68.3	0.003	-0.005	-67.2	0.003	-0.005	-63.9	0.004	-0.004	-45.6
666	Saint Pierre and Miquelon	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
670	Saint Vincent and the Grenadines	0.001	0.000	-0.001	-68.1	0.000	-0.001	-81.4	0.001	0.000	-25.8	0.001	0.000	-25.8
674	San Marino	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
678	Sao Tome and Principe	0.023	0.023	0.000	-0.1	0.021	-0.002	-9.5	0.024	0.001	2.7	0.024	0.001	2.7
682	Saudi Arabia	11.124	11.277	0.153	1.4	11.302	0.179	1.6	11.100	-0.023	-0.2	10.996	-0.128	-1.1
686	Senegal	0.305	0.304	-0.001	-0.3	0.299	-0.006	-1.8	0.294	-0.010	-3.4	0.292	-0.013	-4.1
690	Seychelles	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
694	Sierra Leone	0.009	0.013	0.004	45.2	0.014	0.004	46.2	0.015	0.006	65.1	0.012	0.003	33.4
702	Singapore	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
703	Slovakia	0.103	0.100	-0.003	-2.6	0.103	-0.001	-0.5	0.100	-0.003	-2.6	0.100	-0.003	-2.7

	Climate period	**Stdclim 1981**	**Clim 1901**	Clim 1901 – Stdclim 1981	Clim 1901 – Stdclim 1981	**Clim 1921**	Clim 1921 – Stdclim 1981	Clim 1921 – Stdclim 1981	**Clim 1946**	Clim 1946 – Stdclim 1981	Clim 1946 – Stdclim 1981	**Clim 1951**	Clim 1951 – Stdclim 1981	Clim 1951 – Stdclim 1981
	Run	ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT	ACT	ACT - ACT	ACT - ACT
Cty cde	Country name	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT 1981]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]	ICU [km^{3}a^{-1}]	ICU [km^{3}a^{-1}]	[% ACT refclim]
704	Vietnam	8.704	8.891	0.187	2.2	8.987	0.283	3.3	8.617	-0.087	-1.0	8.431	-0.273	-3.1
705	Slovenia	0.004	0.004	0.000	-6.4	0.004	0.000	0.5	0.004	0.000	0.4	0.004	0.000	-0.5
706	Somalia	0.378	0.332	-0.046	-12.2	0.357	-0.021	-5.6	0.361	-0.017	-4.6	0.363	-0.016	-4.1
710	South Africa	6.346	6.696	0.350	5.5	6.460	0.114	1.8	6.423	0.077	1.2	6.469	0.123	1.9
716	Zimbabwe	0.434	0.399	-0.035	-8.0	0.382	-0.052	-11.9	0.395	-0.038	-8.8	0.393	-0.041	-9.5
724	Spain	20.652	20.549	-0.104	-0.5	20.473	-0.179	-0.9	20.525	-0.128	-0.6	20.537	-0.115	-0.6
732	Western Sahara	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
736	Sudan	5.234	5.033	-0.201	-3.8	4.975	-0.259	-5.0	5.060	-0.174	-3.3	5.061	-0.173	-3.3
740	Suriname	0.111	0.097	-0.014	-12.7	0.105	-0.007	-6.0	0.105	-0.007	-6.1	0.104	-0.008	-7.1
744	Svalbard and Jan Mayen	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
748	Swaziland	0.116	0.111	-0.005	-4.2	0.110	-0.006	-4.9	0.111	-0.005	-4.0	0.115	-0.001	-1.0
752	Sweden	0.080	0.080	0.000	-0.6	0.071	-0.009	-11.8	0.079	-0.001	-1.6	0.077	-0.003	-3.7
756	Switzerland	0.033	0.029	-0.004	-11.0	0.030	-0.002	-7.2	0.023	-0.009	-28.7	0.029	-0.004	-12.7
760	Syria	7.772	8.132	0.359	4.6	8.239	0.467	6.0	8.107	0.335	4.3	8.099	0.327	4.2
762	Tajikistan	3.772	3.771	-0.002	0.0	3.787	0.015	0.4	3.768	-0.004	-0.1	3.724	-0.049	-1.3
764	Thailand	7.782	7.913	0.131	1.7	7.883	0.102	1.3	7.904	0.123	1.6	7.849	0.068	0.9
768	Togo	0.004	0.003	-0.001	-18.3	0.003	-0.001	-24.4	0.003	-0.001	-24.9	0.003	-0.001	-25.9
772	Tokelau	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
776	Tonga	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
780	Trinidad and Tobago	0.010	0.002	-0.009	-85.1	0.002	-0.008	-78.7	0.002	-0.008	-80.8	0.002	-0.009	-83.1
784	United Arab Emirates	0.622	0.586	-0.036	-5.8	0.575	-0.047	-7.6	0.616	-0.006	-1.0	0.606	-0.016	-2.6
788	Tunisia	2.955	2.966	0.010	0.3	2.934	-0.022	-0.7	2.961	0.005	0.2	2.986	0.030	1.0
792	Turkey	18.463	18.982	0.519	2.8	18.953	0.490	2.7	18.931	0.468	2.5	18.922	0.459	2.5
795	Turkmenistan	11.913	12.702	0.789	6.6	12.741	0.828	6.9	12.694	0.781	6.6	12.453	0.539	4.5
796	Turks and Caicos Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
798	Tuvalu	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
800	Uganda	0.006	0.005	0.000	-6.8	0.005	0.000	-6.5	0.005	0.000	-6.0	0.005	0.000	-7.6
804	Ukraine	1.942	2.005	0.062	3.2	2.116	0.174	9.0	2.016	0.074	3.8	2.028	0.085	4.4
807	Macedonia	0.195	0.179	-0.016	-8.4	0.180	-0.015	-7.8	0.190	-0.006	-3.0	0.190	-0.005	-2.6
818	Egypt	47.362	50.123	2.761	5.8	49.760	2.398	5.1	49.700	2.339	4.9	49.816	2.454	5.2
826	United Kingdom	0.316	0.336	0.021	6.6	0.318	0.003	0.8	0.341	0.025	8.0	0.342	0.026	8.3
831	Guernsey	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
832	Jersey	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
833	Isle of Man	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
834	Tanzania	0.428	0.432	0.004	0.8	0.435	0.007	1.6	0.429	0.001	0.2	0.426	-0.002	-0.4
840	United States	107.528	108.833	1.305	1.2	108.766	1.238	1.2	108.244	0.716	0.7	108.483	0.955	0.9
850	Virgin Islands, U.S.	0.00005	0.00002	-0.00004	-68.0	0.000	0.000	0.0	0.00002	-0.00004	-68.0	0.00001	-0.00004	-78.5
854	Burkina Faso	0.081	0.103	0.023	27.9	0.104	0.023	28.6	0.106	0.025	31.2	0.102	0.021	26.6
858	Uruguay	0.535	0.573	0.039	7.2	0.622	0.088	16.4	0.625	0.091	16.9	0.629	0.095	17.7
860	Uzbekistan	24.100	25.034	0.934	3.9	25.094	0.995	4.1	24.725	0.626	2.6	24.862	0.763	3.2
862	Venezuela	0.820	0.856	0.036	4.4	0.858	0.038	4.7	0.901	0.081	9.9	0.847	0.027	3.3
876	Wallis and Futuna	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
882	Samoa	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
887	Yemen	3.450	3.473	0.023	0.7	3.366	-0.084	-2.4	3.448	-0.002	-0.1	3.443	-0.007	-0.2
891	Serbia, Montenegro, Kosovo	0.162	0.157	-0.005	-2.9	0.156	-0.006	-3.9	0.158	-0.004	-2.4	0.159	-0.003	-1.6
894	Zambia	0.337	0.337	0.000	0.1	0.336	-0.001	-0.2	0.337	0.000	-0.1	0.337	0.000	-0.1
901	Clipperton Island	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0
902	Caspian Sea	1.134	1.193	0.059	5.2	1.136	0.002	0.2	1.187	0.053	4.7	1.187	0.053	4.6
903	Spratly Islands	0.000	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0	0.000	0.000	0.0

Appendix B: Documentation on GIM code refinement

In this Appendix, an overview of the structure and changes of the GIM code is given and how this task was organized. Shell and other scripts used for starting GIM and data preprocessing are described in Appendix C, while selected data postprocessing steps and associated scripts are described in Appendix D.

B.1 Organization of recoding and running GIM

For encoding/changes in code, debugging, and running, the code was run on a SUSE Linux platform, with the following software development environment:

(1) Qt Creator for developing and debugging code (Wikipedia, 2017i; The Qt Company, 2017),
(2) Git as local version control system (Wikipedia, 2017c),
(3) A web-based external GitLab server as code and file repository (Wikipedia, 2017d), in order to give easy access to other members of Working Group Hydrology. There, also the previously available GIM code with status from 2012 was introduced as first commit.

The GIM runs were controlled via a hierarchical set of shell scripts with two hierarchies, the lower one for directly starting GIM with selectable options and control files, e.g. for a specific year or period of time, and a higher one for starting GIM with selected options for a sequence of years, e.g. HID reference years or a full list of years 1901-2014 (see Appendix C). Input data files resided either, for basic input data, on the same platform or, for climate data, on another drive mounted via Network File System (NFS) protocol (Wikipedia, 2017g). Input data were treated in preprocessing steps using scripts and tools as documented in Appendix C, e.g. for calculation of climate averages which was started via a shell script.

Software engineering (SE) quality control was done in two categories:

(1) For constructive SE quality control, the changes in the code were checked visually several times for logical consistency and correctness.
(2) For analytical SE quality control, the results of a new code step were checked against previous results. In some cases, new methods to write text output files arrays with read-in or newly compiled lists (e.g. lists of countries, regions, regional cropping intensities, regional irrigation efficiencies for non-rice and rice crops) were introduced in order to check more efficiently the results via a direct view on differences via automated check of differences through external (e.g. WinMerge) or built-in (e.g. TotalCommander XE) file comparison tools on a Windows platform.

B.2 Main changes in the GIM code

The GIM code consists of a mixture of code in ANSI-C and ANSI-C++, mostly written in a non-object based procedural structure.

There are 3 basic categories of files:

1) The file “def.h” mainly defines the static numerical values like dimensions of key arrays (e.g. number of grid cells) and number of header lines in input or control files via “#define …” statements that area replacing the placeholders during compilation. It is made accessible within the other files and program code via “#include …” statements used during compilation.
2) The file wg_irrigation.cpp where the main() program resides and global variables and arrays are declared.
3) A set of further files (code .cpp / header .h) where code of additional methods is contained which mostly also address global variables and arrays implicitly (via “extern …”) or explicitly (in the method calls). The methods are made accessible within the other files and program code via “#include …” statements used during compilation.

The following Table B.1 provides an overview of tasks located in the different GIM code files, with overall method update status. Any change in code is marked, irrespective whether it concerns one or more locations. Table B.2, provides, by pair of code files (.cpp/.h), a detailed record which methods were updated or not.

Table B.1: Overview of tasks performed by the different GIM code files and update status of refined code version

Code file name	Task	Method status
def.h	Definitions of dimensions of key arrays (e.g. number of grid cells) and number of header lines in input or control files	updated
wg_irrigation.cpp	Location of main() program, declarations of global variables and arrays	updated
area.cpp/h	Calculation of areas of spatial units (e.g. countries)	updated
countries.cpp/h	Reading list of countries and new creation of regions from country grid	updated
croppat.cpp/h	Calculation of cropping patterns	no changes
cropstart.cpp/h	Calculation of start day of growing periods	no changes
daily.cpp/h	Calculation of daily Irrigation Consumptive Use (ICU)	no changes
daily_prec_nrd.cpp/h	Calculation of daily precipitation from monthly precipitation and number of rain days	no changes
dry+wet.cpp/h	Statistics: Calculation of 75% and 90% quantiles for dry and wet years from ICU output files	updated
gridio.cpp/h	Reading and writing of binary grids (proprietary formats for float, character, short integer, long integer: "UNF0/1/2/4") and related methods	no changes
indexing.cpp/h	Calculate sorting indexes for statistics	no changes
interpolate.cpp/h	Interpolation from monthly to daily values	no changes
irrigation.cpp/h	Core methods for (1) reading, shifting, and writing AEI; (2) calculating ICU for rice and non-rice crops; (3) calculation Irrigation Withdrawal Use (IWU)	updated
kcvalues.cpp/h	Routines to read data from refcrop.dat and ricecrop.dat and calculating daily kc-values for irrigated rice and irrigated non-rice crop	no changes
raindays.cpp/h	Produce synthetic wet and dry days for WaterGAP & GIM, following (Geng et al., 1986), based on number of wet days in each month of 28, 30 or 31 days length.	no changes
ua_sa.cpp/h	Methods for uncertainty analysis (UA) and sensitivity analysis (SA) with SIMLAB-Software performed by (Siebert, 2002)	updated

Table B.2: Detailed list of tasks and update status of methods included in the different GIM code files

Method status	File / Method name	File / Method remark
	area.cpp/h	**Calculation of areas of spatial units (e.g. countries)**
new method	void write_grid_areas(char *output_dir)	Write grids of characteristic basic areas of grid cells (data type: float)
no changes	void calc_area(int max, short int *Grid, float *object_area)	Calculate area [land area] of geographic objects such as basins, countries, etc.
updated	void irrig_area_grid(float irrigrid[][nrow], float *G_irrigation)	Calculate irrigated area [AEI] as percentage of cellarea
updated	void irrig_area_region(int nrmax, short int *G_region, float *G_irrigation, float *irrig_area_reg)	Calculate irrigated area [AEI] of regions
no changes	void irrig_area_country(int ncountries, short int *G_country, float *G_irrigation, float *irrig_area_ct)	Calculate irrigated area [AEI] of countries
	countries.cpp/h	**Reading list of countries and new creation of regions from country grid**
updated	void read_list_countries(void)	Reading list of countries, previously named 'countries()'
new method (not used)	void read_list_country_pct_aai_aei(void)	Read country-average percentage AAI of AEI
new method	void create_grid_regions_from_countries(void)	Create grid of regions from list and grid of countries [grid for cropping intensity, REG_CI, later modified for irrigation efficiency, REG_IE]
new method	void write_grid_regions_standard(void)	Write current grid of standard regions [for cropping intensity, REG_CI]
new method	void write_grid_regions_modified(void)	Write current grid of modified regions [for irrigation efficiency, REG_IE]
	croppat.cpp/h	**Calculation of cropping patterns**
no changes	void cropping_pattern(short int raindays_opt)	Calculation of cropping patterns
	cropstart.cpp/h	**Calculation of start day of growing periods**
no changes	void crop_start(short int raindays_opt)	Calculation of start day of growing periods
	daily.cpp/h	**Calculation of daily Irrigation Consumptive Use (ICU)**
no changes	void daily_calculations(int n, short int day_store_opt)	Calculation of daily ICU
	daily_prec_nrd.cpp/h	**Calculation of daily precipitation from monthly precipitation and number of rain days**
no changes	void daily_prec_nrd(int n, short int G_precipitation[][12], float*** G_precipitation_daily, float *daily_prec)	Calculation of daily precipitation from monthly precipitation and number of rain days

Method status	File / Method name	File / Method remark
	dry+wet.cpp/h	**Statistics: Calculation of 75% and 90% quantiles for dry and wet years from ICU output files**
updated	void dry_wet_year_calculations(void)	Statistics: Calculation of 75% and 90% quantiles for dry and wet years from ICU output files
	gridio.cpp/h	**Reading and writing of binary grids (proprietary formats for float, character, short integer, long integer: "UNF0/1/2/4") and related methods**
no changes	template <class T> void read_grid(char *file, int n_values, T *grid)	Reading binary grid
no changes	template <class T> void write_grid(char *file, int n_values, T *grid)	Writing binary grid
no changes	void setFileEndianType(short endianType)	Set Endian type within program for reading/writing binary files, possibly swapping bytes
no changes	short getEndianType()	Get machine Endian type
no changes	bool getSwapFlag()	Unknown
no changes	void memSwap(char* array, const unsigned short dataTypeSize, const unsigned int arrayByteSize)	Swap bytes
	indexing.cpp/h	**Calculate sorting indexes for statistics**
no changes	void index(int nn, short int arr[], int indx[])	Numerical Recipes in C, 2nd edition, chapter 8.4
no changes	void longindex(int nn, short int arr[], int indx[])	Numerical Recipes in C, 2nd edition, chapter 8.4
	interpolate.cpp/h	**Interpolation from monthly to daily values**
no changes	void interpolate_temp(int n, short int G_temperature[][12], float*** G_temperature_daily, float *daily_temp)	Interpolation of temperature
no changes	void interpolate_radiation(int n, float G_radiation[][12], float*** G_radiation_daily, float *daily_radiation)	Interpolation of radiation
no changes	void interpolate_prec(int n, short int G_precipitation[][12], float*** G_precipitation_daily, float *daily_prec)	Interpolation of precipitation
no changes	void interpolate_vappres(int n, short int G_vappres[][12], float *daily_vappres)	Interpolation of vapor pressure
no changes	void interpolate_windspeed(int n, char G_windspeed[][12], float *daily_windspeed)	Interpolation of wind speed
	irrigation.cpp/h	**Core methods for (1) reading, shifting, and writing AEI; (2) calculating ICU for rice and non-rice crops;**

Method status	File / Method name	File / Method remark
		(3) calculation Irrigation Withdrawal Use (IWU)
updated	void check_irrigation_map(short int reference_year)	Check AEI grid and potentially shift between grid cells - Call: irri_area_grid()
updated	void irrigation_files(short int reference_year)	Calculate & write irrigated area [AEI] per region and country - Call: irri_area_region(), irri_area_country()
updated	void read_hist_irrig_area(short int reference_year)	Read national (country) scaling factors for application to Area Equipped for Irrigation (AEI) in irrigation map
new method	void write_hist_irrig_area_fullarray(short int reference_year)	Write national (country) scaling factors for application to Area Equipped for Irrigation (AEI) in irrigation map - Variant 1: Write full array
new method	void write_hist_irrig_area_countries(short int reference_year)	Write national (country) scaling factors for application to Area Equipped for Irrigation (AEI) in irrigation map - Variant 2: Write only for countries present in country list
updated	void usda_rice_irrigation (int n, int day, int growday)	Calculation of daily consumptive use in rice growing areas without a soil water balance
no changes	void usda_nonrice_irrigation (int n, int day, int growday, int ta=0)	Calculation of daily consumptive use in nonrice growing areas without a soil water balance
updated	void irrigation_withdrawal_wateruse (void)	Calculation of irrigation withdrawal water use per grid cell, simple values and monthly sums
updated	short apply_factor_irri_area_to_grids(short int factor_irrig_area_opt, short int actual_year, float* array, float* Outarray, short valuesPerCell)	Former name: adapt_irri_area(), Application of factors of HIST_IRRIG_AREA to grids with annual or monthly data, e.g. of water use before writing. Factors (ratios) are also used when they are zero.
new method	short apply_aai_pct_aei_to_grids(short int aai_pct_aei_opt, float* array, float* Outarray, short valuesPerCell)	Method to apply the percentage ratios of AAIpctAEI grid to grids with annual or monthly data e.g. of water use before writing. Percentage ratios are also applied when they are zero!
	kcvalues.cpp/h	**Routines to read data from refcrop.dat and ricecrop.dat and calculating daily kc-values for irrigated rice and irrigated non-rice crop**
no changes	void rice_daily_kc_values(void)	Calculation of daily kc-values for irrigated rice
no changes	void nonrice_daily_kc_values(void)	Calculation of daily kc-values for

Method status	File / Method name	File / Method remark
		irrigated non-rice
	raindays.cpp/h	Produce synthetic wet and dry days for WaterGAP & GIM, following Geng et al. (1986), based on number of wet days in each month of 28, 30 or 31 days length (Numerical Recipes Software 7)
no changes	float ran1(int *idum)	Calculate random value
no changes	void raindays(int idum)	Calculate and write sequence of wet days and dry days for 28, 30, and 31 days
	ua_sa.cpp/h	**Methods for uncertainty analysis (UA) and sensitivity analysis (SA) with SIMLAB-Software performed by Siebert (2002)**
no changes	float rand2(int *idum)	Generator for random numbers in interval 0-1, same generator as used for generation of daily precipitation (in raindays.cpp)
updated	void ua_sa_change_longterminput(int sim_counter)	Changing of longterm variables and parameters by using sample file INPUT.SAM generated by using SIMLAB-software
no changes	void ua_sa_change_yearlyinput(int sim_counter)	Remark Stefan Siebert 2002: This procedure has to be developed for future uncertainty analysis using time series. At the moment there is only uncertainty analysis based on longterm climate possible.

Appendix C: Scripts for starting GIM and data preprocessing

In this Appendix, the used scripts (Shell, Python, R) for starting GIM or auxiliary programs, and for data preprocessing are listed. In the electronic part, the overview is listed in an Excel file with spreadsheet, and the full files are contained.

Columns of the tables have the following meaning:

Software	Software / Interpreter used or concerned (e.g. ksh, Python, R)
Type	Type of document/file used for software, e.g. Script
Topic	Concerned category, e.g. Climate, GIM, GMIA, HID, name of sub directory with document/files
Data	Data concerned for input and/or output, e.g. AEI
Sequence	Sequence of treatment applied or necessary
Name	Name of document/file used for Software (e.g. .py, .r)
Short description	Short description of tasks executed (input, methods, output)

C.1 Scripts used for starting and controlling GIM

The GIM runs were controlled via a hierarchical set of shell scripts with two hierarchies, as listed in

Table C.1:

(1) The lower level 1 for directly starting GIM with selectable options and control files, e.g. for a specific year or period of time
(2) The higher level 2 for starting GIM level 1 script with selected options for a sequence of years, e.g. HID reference years or a full list of years 1901-2014.

Table C.1: Shell scripts used for starting and controlling GIM

Soft-ware	Type	Topic	Data	Se-quence	Name	Short description
ksh	Script	GIM	Climate, HID, GMIA4, GMIA5	Level 1 (low)	start_GIM22HID.sh	GIM: Start GIM execution (cropping periods or water use) for a defined period of time, using either (1) Historical Irrigation Data set (HID) for temporal development of Area Equipped for Irrigation (AEI), (2) GMIA4, (3) GMIA5, all with optional application of country-specific scaling (HIST) or of fraction AAI/AEI. Attention: When individual years are started, starting, if possible, one year earlier ensures approriate spin-up of snow storage. Explicit start modes overriding settings in OPTIONS.DAT: "croppattern" = cropping periods (cropping patterns & growing periods), "wateruse" = water use from cropping periods, "waterusehistory" = wateruse with HIST, "waterusehistorystats" = wateruse with HIST and final multi-annual statistics, "statistics" = only multi-annual statistics, based on previous wateruse runs.
ksh	Script	GIM	Climate, HID	Level 2 (high)	start_GIM22HID_loop_over_list.sh	GIM: Start GIM execution (cropping periods or water use) using HID via start_GIM22HID.sh, for years of 14 HID time slices 1900, 1910 (ommited because of no climate data), 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1985, 1990, 1995, 2000, and 2005. Used for calculations of first set of years for Master thesis presentation.
ksh	Script	GIM	Climate, HID	Level 2 (high)	start_GIM22HID_loop_yearly.sh	GIM: Start GIM execution (cropping periods or water use) using HID via start_GIM22HID.sh, backwards for any period of years, e.g. between 1901 and 2005, starting, if possible, one year earlier because of spin-up of snow storage. Used for second step of calculations after treating first data for years 2006-2014 with startGIM22.sh.

C.2 Scripts used for preprocessing climate data

The daily climate data had to be averaged for 30-year-climate periods from 1901-1930 to 1985-2014. This was done via an already existing C^{++} program started by a shell script mentioned in Table C.2.

Table C.2: Shell scripts used for data preprocessing of daily climate data

Software	Type	Topic	Data	Sequence	Name	Short description
ksh	Script	Climate	Climate	1	start_calculate_climatemeans.sh	GIM: Start program "calc_monthly_climate_means_from_daily__SLM" to calculate climate means from daily input data of bias-corrected WATCH Forcing Data (WFD) combined with WFD-ERA-Interim, output: average monthly temperature, precipitation, number of raindays, shortwave downwelling radiation for 30-year periods from 1901 to 2014, in proprietary binary data format for use with GIM.

C.3 Scripts used for preprocessing GMIA data

Data of GMIA5 on AAI and AEI were used to generate new grids with 30 arc-min spatial resolution, and through an intermediate point shapefile of ratios AAI / AEI, a final interpolated grid was generated. A 30 arc-min grid of GMIA4 AEI was already available. The scripts are mentioned in Table C.3.

Table C.3: Scripts used for preprocessing GMIA data

Soft-ware	Type	Topic	Data	Se-quence	Name	Short description
Python	Script	GMIA5	AEI	1	ASCII2RasterAEIhaAggregate_GMIAv5_AEI__ag10p4.py	GMIA5: Convert AEI as ASCII grid to ArcGIS GRID and aggregate from 5 arc-min to 30 arc-sec (0.5 degree), from file gmia_v5_aei_ha.asc, reference year 2005, export to ASCII grid
Python	Script	GMIA5	AAI	2	ASCII2RasterAAIpctMultiplyAEI_GMIAv5_AAI__ag10p4.py	GMIA5: Convert AAIpct (AAI as a percentage of AEI) as ASCII grid to ArcGIS GRID, calculate absolute AAI in hectare via multiplication with AEI, aggregate from 5 arc-min to 30 arc-sec (0.5 degree), calculate AAIpct at 30 arc-sec, export to ASCII grid
Python	Script	GMIA5	AAI	3	GMIA5_AAI_InterpolateIDW_pnt2raster__ag10p4.py	GMIA5: Interpolate AAIpct (AAI as a percentage of AEI) from point file to ArcGIS GRID, using inverse distance weighting (IDW, power=2, numPoints=5, distanceMapunits=150, searchRadius = RadiusVariable(numPoints, distanceMapunits)), aggregate from 5 arc-min to 30 arc-sec (0.5 degree), from shapefile gmia5aai05pc__pnt_lonlatwgs84.shp, export to ASCII grid
R	Script	GMIA5	AAI, AEI	4	GMIA_Extract_AAIAEIcountrysums_from_AAIAEIGridsCountryGrids.r	GMIA5: Script to calculate percentage ratio AAI/AEI from GMIA5 AAI grid, GMIA5 AEI grid (2005) and HID Country grid (2005) and join as additional column to country-specific extracted data of script HID_Extract_homogenize_Countrycodes_AEI_from_HIDSuppl3Excel.r

C.4 *Scripts used for preprocessing HID data*

Most ample preprocessing was applied to HID data, to get e.g. 30 arc-min grids for every year with AEI and with UN M49 country codes, and a related list of countries and their AEI totals. Also AEI scaling factors (HID-POTHIST, Table A.6) and AHI Rice for each year were produced. The used scripts are mentioned in Table C.4.

Table C.4: Scripts used for preprocessing HID data

Software	Type	Topic	Data	Sequence	Name	Short description
Python	Script	HID	AEI	1	HID_AEIHYDEFINALIR_ASCII2RasterAggregate__ag10p4.py	HID: Convert AEI as ASCII grids to ArcGIS GRIDs and aggregate from 5 arc-min to 30 arc-sec (0.5 degree), from files AEI_HYDE_FINAL_IR_yyyy.asc for 14 time slices, export to ASCII grids
Python	Script	HID	AEI	2	HID_AEIHYDEFINALIR_Interpol30arcmin_Years__ag10p4.py	HID: Interpolate linearly AEI as ArcGIS GRIDs 30 arc-sec (0.5 degree) from 14 time slices to every year 1900-2005, export to ASCII grids
Python	Script	HID	Country codes (sub-national units)	3	HID_AEISU_ASCII2RasterBlockStatisticsAggregate__ag10p4.py	HID: Convert subnational country unit codes AEI_SU as ASCII grids to ArcGIS GRIDs and aggregate from 5 arc-min to 30 arc-sec (0.5 degree), from files AEI_SU_yyyy.asc for 14 time slices
R	Script	HID	Country codes & names; AEI	4	HID_Extract_homogenize_Countrycodes_AEI_from_HIDSuppl3Excel.r	HID: Extract and homogenize HID subnational/national and UN national country codes list. Sum subnational AEI to national totals. Input data: Country codes (integerID in grids, ISO-ALPHA3, full names) , AEI subnational sums for 14 time slices from HID Supplement S3 "Supplement_S3_AEI per_region_country_subnational.xls"; United Nations (UN) M49 Country codes (integerID, ISO-ALPHA2); export as text list
Python	Script	HID	Country codes (sub-national	5	HID_AEISU_Raster2ASCII_30arcmin__ag10p4.py	HID: Export subnational country unit codes AEI_SU as ArcGIS GRIDs at 30 arc-sec (0.5 degree), for 14 time slices, to ASCII grids

Soft-ware	Type	Topic	Data	Se-quence	Name	Short description
			units)			
R	Script	HID, GIM	Country codes grids	6	HIDGIM_Fill_missing_grid_UNM49_Countrycodes.r	HID, GIM: Script to fill missing UNM49 country codes in grid cell without HID country information - For 14 time slices from 1900 to 2005, from previously generated grid files - Evaluate codes in 3x3 surrounding grid cells, use preferrably mode of code - Compare result to reference UN M49 country numerical codes of GIM GCOUNTRY.UNF2 (2012-08-26) ("GIM2002") (corresponds to WaterGAP mother_polys.shp, field COUNTRY_NR)
R	Script	HID	AEI	7	HID_Extract_AEIcountrysums_from_AEIGridsCountryGrids.r	HID: Script to extract and validate AEI country sums from AEI grid and Country grid
R	Script	HID	AEI	8	HID_Extract_AEIcountrysums_from_AEIGridsCountryGrids__CountryRefYear.r	HID: Script to extract and validate AEI country sums from AEI grid and Country grid for COUNTRY GRID of a ***selected reference year*** e.g. year 2000
R	Script	HID, GIM	AEI	9	HIDGIM_GenerateHISTIRRIGAREA_POT__ResultAEIGridsCountryGrid2000.r	HID, GIM: Script to generate HIST_IRRIG_AREA_yyyy.DAT - with AEI historical development from established __reference year HID country mask grid__(e.g. 2000) applied to interpolated yearly HID AEI grids - Using result file from R_script HID_Extract_AEIcountrysums_from_AEIGridsCountryGrids__CountryRefYear.r: HID_mCountrywithNamesAEIfromGrid_COUNTRYGRID2000_full_1900to2005.txt
R	Script	HID, GIM	AHI Rice (MIRCA 2000)	10	HIDGIM_GenerateAHIRice_by_AEIScaling__AEISuppl3.r	HID, GIM: Script to generate input file RICEAREA_yyyy.DAT by scaling MIRCA2000 data from year 2000 with AEI historical development from HID (Result from R_script HID_Extract_homogenize_Countrycodes_AEI_from_HIDSuppl3Excel.r)
R	Script	HID, GIM	AHI Rice (MIRCA 2000)	11	HIDGIM_GenerateAHIRice_by_AEIScaling__ResultAEIGridsCountryGrids.r	HID, GIM: Script to generate input file RICEAREA_yyyy.DAT by scaling MIRCA2000 data from year 2000 with AEI historical development from established yearly HID country mask grids applied to interpolated yearly HID AEI grids Result from R_script HID_Extract_AEIcountrysums_from_AEIGridsCountryGrids.r: HID_mCountrywithNamesAEIfromGrid_full_1900to2005.txt

Appendix D: Scripts for GIM data postprocessing

In this Appendix, the used procedures (IPG UNF Tools) and scripts (R) for GIM data postprocessing are listed in

Table D.1. The aim was to generate shapefiles for maps of Figure 4.1 to Figure 4.8 and Figure 5.1 to Figure 5.5. In the electronic part, the overview is listed in an Excel file with spreadsheet, and the full files are contained.

Columns of the table have the following meaning:

Software	Software / Interpreter used or concerned (e.g. ksh, Python, R)
Type	Type of document/file used for software, e.g. Script
Topic	Concerned category, e.g. Climate, GIM, GMIA, HID, name of sub directory with document/files
Data	Data concerned for input and/or output, e.g. AEI
Sequence	Sequence of treatment applied or necessary
Name	Name of document/file used for Software (e.g. .py, .r)
Short description	Short description of tasks executed (input, methods, output)

Table D.1: Procedures and R scripts used for GIM data postprocessing to obtain shapefiles for map generation

Software	Type	Topic	Data	Sequence	Name	Short description
IPG UNF Tools	VBA-Application	GIM	ICU, IWU	1	IPG UNF Tools (ArcGIS10-VBA-Extension)	GIM: Interactive conversion of GIM/WaterGAP proprietary binary output format (UNF0/2/4 x = 0,2,4,) for grid files (annual (.UNFx) and monthly (.12.UNFx) data of one year) (0.5 degree), direct conversion into shapefiles, without setting spatial reference
Python	Script	GIM	ICU, IWU	2	ListFC_Polygons_DefineProjectionWGS1984EPSG4326__ag10p4.py	GIM: List all polygon shapefiles in a list of directories and set their spatial reference to WGS1984 (EPSG 4326)

Soft-ware	Type	Topic	Data	Se-quence	Name	Short description
R	Script	GIM	ICU	3	join_WaterGAP_output_tables_to_fatherpolys__SLM__GIMandHID__ICU_1910_60_95_05__LA2010_FelixPortmann170211.r	GIM: Script to join selected columns of dbf-attributes files of shapefiles converted by IPG UNF Tools from results of Global Irrigation Model (GIM), Standard landmask (SLM): From refined GIM with Historical Irrigation Data set (HID) for individual years with standard climate periods: - Irrigation Consumptive Use (ICU) for selected years 1910, 1960, 1995, 2005 - HID-ACT (hist_ACT19012014) & HID-ACTHIST (hist_ACTHIST19012014) - Forcing: WFD_bc_WFDEI, 1901-2014 - Units: (1) mm/m^2 and (2) km^3/grid cell
R	Script	GIM	ICU, IWU	4	join_WaterGAP_output_tables_to_fatherpolys__SLM__GIMandHID__ICU_IWU_1995___LA2010_FelixPortmann170211.r	GIM: Script to join selected columns of dbf-attributes files of shapefiles converted by IPG UNF Tools from results of Global Irrigation Model (GIM), Standard landmask (SLM): From refined GIM with Historical Irrigation Data set (HID) for individual years with standard climate periods: - Irrigation Consumptive Use (ICU) & Irrigation Withdrawal Use (IWU) for selected year 1995 for calculating percent irrigation efficiency (IE) as ICU*100/IWU - HID-ACT (hist_ACT19012014) & HID-ACTHIST (hist_ACTHIST19012014) - Forcing: WFD_bc_WFDEI, 1901-2014 - Units: (1) mm/m^2, (2) km^3/grid cell, (3) % AAI/AEI
R	Script	GIM	ICU, IWU	5	join_WaterGAP_output_tables_to_fatherpolys__SLM__GIMandHID__ICU_IWU_1960___LA2010_FelixPortmann170213.r	GIM: Script to join selected columns of dbf-attributes files of shapefiles converted by IPG UNF Tools from results of Global Irrigation Model (GIM), Standard landmask (SLM): From refined GIM with Historical Irrigation Data set (HID) for individual years with standard climate periods: - Irrigation Consumptive Use (ICU) & Irrigation Withdrawal Use (IWU) for selected year 1960 for calculating percent irrigation efficiency (IE) as ICU*100/IWU - HID-ACT (hist_ACT19012014) & HID-ACTHIST (hist_ACTHIST19012014) - Forcing: WFD_bc_WFDEI, 1901-2014 - Units: (1) mm/m^2, (2) km^3/grid cell, (3) % AAI/AEI

Soft-ware	Type	Topic	Data	Se-quence	Name	Short description
R	Script	GIM	ICU	6	join_WaterGAP_output_tables_to_fatherpolys__SLM__GIMandHID__ICU_1995_variousCLIM1abs___LA2010_FelixPortmann170212.r	GIM: Script to join selected columns of dbf-attributes files of shapefiles converted by IPG UNF Tools from results of Global Irrigation Model (GIM), Standard landmask (SLM): From refined GIM with Historical Irrigation Data set (HID) for selected year 1995 - Irrigation Consumptive Use (ICU) and ***absolute*** differences to ICU from refclim - with various cropping patterns from climate - 1901-1930 (as for AEI year 1910), - 1921-1950, - 1946-1975 (as for AEI year 1960), - 1951-1980, and - 1981-2010 (as standard for AEI year 1995, refclim) - HID-ACT (hist_ACT19012014) - Forcing: WFD_bc_WFDEI, 1901-2014 - Units: (1) mm/m2, (2) km3/grid cell
R	Script	GIM	ICU	7	join_WaterGAP_output_tables_to_fatherpolys__SLM__GIMandHID__ICU_1995_variousCLIM2abspct___LA2010_FelixPortmann170214.r	GIM: Script to join selected columns of dbf-attributes files of shapefiles converted by IPG UNF Tools from results of Global Irrigation Model (GIM), Standard landmask (SLM): From refined GIM with Historical Irrigation Data set (HID) for selected year 1995 - Irrigation Consumptive Use (ICU) and ***percent*** differences to ICU from refclim - with various cropping patterns from climate - 1901-1930 (as for AEI year 1910), - 1921-1950, - 1946-1975 (as for AEI year 1960), - 1951-1980, and - 1981-2010 (as standard for AEI year 1995, refclim) - HID-ACT (hist_ACT19012014) - Forcing: WFD_bc_WFDEI, 1901-2014 - Units: (1) mm/m2, (2) km3/grid cell, (3) percent changes (from ICU mm), with special code replacement for Inf (max. valid value), increase from zero ("-995"), and NAs (because of division by zero) ("-999")

Appendix E: Poster

In this Appendix, the poster about the master thesis is included which is also contained in the electronic Appendix.

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

TECHNIK
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APPLIED SCIENCES

DR. FELIX T. PORTMANN (GOETHE UNIVERSITÄT FRANKFURT)

GLOBAL IRRIGATION IN THE 20TH CENTURY:

EXTENSION OF THE WATERGAP GLOBAL IRRIGATION MODEL (GIM) WITH THE SPATIALLY EXPLICIT HISTORICAL IRRIGATION DATA SET (HID)

BETREUER:
PROF. DR. FREDIE KERN (HOCHSCHULE MAINZ)
PD DR. STEFAN SIEBERT (FRIEDRICH-WILHELMS-UNIVERSITÄT BONN)

Motivation

For the global hydrological model WaterGAP, the Global Irrigation Model (GIM) calculates monthly Irrigation Consumptive Use (ICU) on a 0.5 degrees grid for rice and non-rice crops. The new Historical Irrigation Data set (HID) with cell-specific Area Equipped for Irrigation (AEI) for 14 time slices between 1900 and 2005 may provide better representation of historic ICU development than the current country-specific scaling with a static AEI grid of a reference year, e.g. 2000.

Methods

GIM C^{++} code was refined to process yearly HID grids of temporally interpolated AEI (Fig. 2) and related country masks valid for one time slice (Fig. 1). Data preprocessing was done mainly with ArcPy-Scripts, R-scripts, and an ArcGIS VBA-Plugin. The time series 1901-2014 with new mode vs. scaled, was evaluated for years 1910 (Fig. 3), 1960, 1995, and 2005, and validated with US state data (Fig. 4).

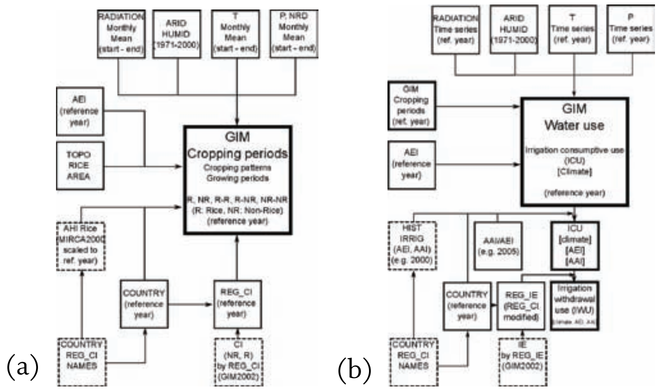

Fig. 1: Refined GIM steps (a) cropping periods, (b) water use
(Boxes solid: grids; dashed: tables; **bold: procedures**, input **previous step** & **final output**)

Results

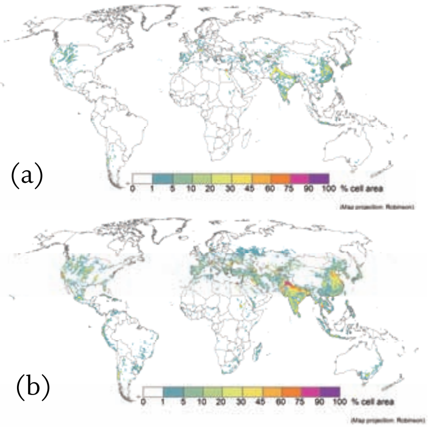

Fig. 2: AEI for (a) 1910 (b) 1995

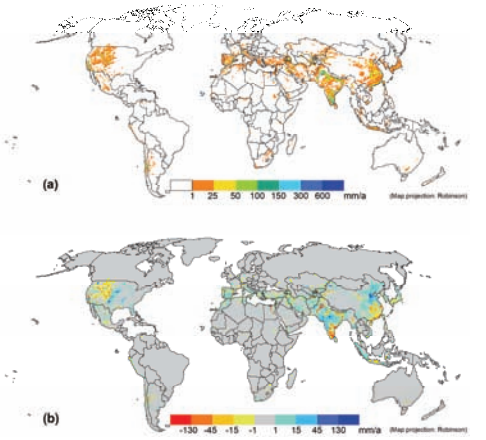

Fig. 3: ICU 1910 (a) new mode (b) scaled - new

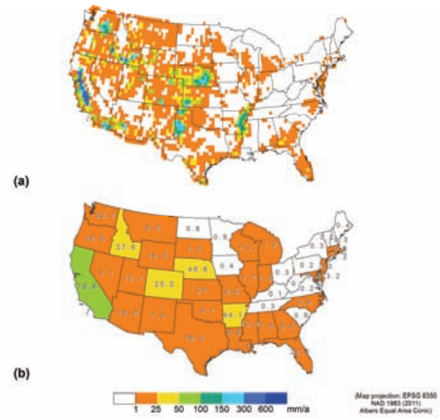

Fig. 4: ICU 1995 (a) GIM (b) USGS

MASTERARBEIT - WEITERBILDUNGSSTUDIENGANG GEOINFORMATIK - WINTERSEMESTER 2016/2017 - STANDNUMMER: 182

Appendix F: Homepage

In this electronic Appendix, the HTML website about the master thesis is included.

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Masterarbeit

„Global irrigation in the 20th century: Extension of the WaterGAP Global Irrigation Model (GIM) with the spatially explicit Historical Irrigation Data set (HID)“

selbständig ohne fremde Hilfe angefertigt habe. Ich habe nur die in der Arbeit ausdrücklich benannten Quellen und Hilfsmittel benutzt. Wörtlich oder sinngemäß übernommenes Gedankengut habe ich als solches kenntlich gemacht.

Ort, Datum Unterschrift