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A global and high-resolution assessment of the green, blue and grey water footprint of wheat

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A GLOBAL AND HIGH-RESOLUTION ASSESSMENT OF THE GREEN, BLUE AND GREY WATER FOOTPRINT OF WHEAT

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Summary

The aim of this study is to estimate the green, blue and grey water footprint of wheat in a spatially-explicit way, both from a production and consumption perspective. The assessment is global and improves upon earlier research by taking a high-resolution approach, estimating the water footprint of the crop at a 5 by 5 arc minute grid. We have used a grid-based dynamic water balance model to calculate crop water use over time, with a time step of one day. The model takes into account the daily soil water balance and climatic conditions for each grid cell. In addition, the water pollution associated with the use of nitrogen fertilizer in wheat production is estimated for each grid cell. We have used the water footprint and virtual water flow assessment framework as in the guideline of the Water Footprint Network (Hoekstra et al., 2009).

The global wheat production in the period 1996-2005 required about 1088 billion cubic meters of water per year. The major portion of this water (70%) comes from green water, about 19% comes from blue water, and the remaining 11% is grey water. The global average water footprint of wheat per ton of crop was 1830 m^3/ton. About 18% of the water footprint related to the production of wheat is meant not for domestic consumption but for export. About 55% of the virtual water export comes from the USA, Canada and Australia alone. For the period 1996-2005, the global average water saving from international trade in wheat products was 65 Gm^3/yr.

A relatively large total blue water footprint as a result of wheat production is observed in the Ganges and Indus river basins, which are known for their water stress problems. The two basins alone account for about 47% of the blue water footprint related to global wheat production. About 93% of the water footprint of wheat consumption in Japan lies in other countries, particularly the USA, Australia and Canada. In Italy, with an average wheat consumption of 150 kg/yr per person, more than two times the word average, about 44% of the total water footprint related to this wheat consumption lies outside Italy. The major part of this external water footprint of Italy lies in France and the USA.

1. Introduction

Fresh water is a renewable but finite resource. Both freshwater availability and quality vary enormously in time and space. Growing populations coupled with continued socio-economic developments put pressure on the globe's scarce water resources. In many parts of the world, there are signs that water consumption and pollution exceed a sustainable level. The reported incidents of groundwater depletion, rivers running dry and worsening pollution levels form an indication of the growing water scarcity (Gleick, 1993; Postel, 2000; WWAP, 2009). Authors of the Comprehensive Assessment of Water Management in Agriculture (2007) argue that to meet the acute freshwater challenges facing humankind over the coming fifty years requires substantial reduction of water use in agriculture.

The concept of 'water footprint' introduced by Hoekstra (2003) and subsequently elaborated by Hoekstra and Chapagain (2008) provides a framework to analyse the link between human consumption and the appropriation of the globe's freshwater. The water footprint of a product is defined as the total volume of freshwater that is used to produce the product (Hoekstra et al., 2009). The *blue* water footprint refers to the volume of surface and groundwater consumed (evaporated) as a result of the production of a good; the *green* water footprint refers to the rainwater consumed. The *grey* water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards. The water footprint of national consumption is defined as the total amount of freshwater that is used to produce the goods consumed by the inhabitants of the nation. The water footprint of national consumption always has two components: the internal and the external footprint. The latter refers to the appropriation of water resources in other nations for the production of goods and services that are imported into and consumed within the nation considered. Externalising the water footprint reduces the pressure on domestic water resources, but increases the pressure on the water resources in other countries. Virtual water transfer in the form of international trade in agricultural goods is increasingly recognized as a mechanism to save domestic water resources and achieve national water security (Allan, 2003; Hoekstra, 2003; De Fraiture et al., 2004; Oki and Kanae, 2004; Chapagain et al., 2006a; Yang et al., 2006; Hoekstra and Chapagain, 2008). Virtual water import is an instrument that enables nations to save scarce domestic water resources by importing water-intensive products and exporting commodities that require less water. On the other hand, water-abundant countries can profit by exporting water-intensive commodities.

In this report, we focus on the water footprint of wheat, which is one of the most widely cultivated cereal grains globally. It is grown on more land area than any other commercial crop and is the second most produced cereal crop after maize and a little above rice. It is believed to originate in Southwest Asia and the most likely site of its first domestication is near Diyarbakir in Turkey (Dubcovsky and Dvorak, 2007). About 90 to 95 percent of the wheat produced is the common wheat or bread wheat followed by durum wheat which accounts less than 5% of world wheat production (Pena, 2002; Ekboir, 2002). For trading purposes, wheat is classified into distinct categories of grain hardness (soft, medium-hard and hard) and colour (red, white and amber). Based on the growing period, it may be further subdivided into spring and winter wheat.

A number of previous studies on global water use for wheat are already available. Hoekstra and Hung (2002, 2005) were the first to make a global estimate of the water use in wheat production. They analysed the period 1995-99 and looked at total evapotranspiration, not distinguishing between green and blue water consumption. Hoekstra and Chapagain (2007, 2008) improved this first study in a number of respects and studied the period 1997-2001. Still, no distinction between green and blue water consumption was made. Liu et al. (2007) made a global estimate of water consumption in wheat production for the period 1998-2002 without making the green-blue water distinction, but for the first time grid-based. Liu et al. (2009) and Liu and Yang (2010) present similar results, but now they show the green-blue water distinction. Siebert and Döll (2008, 2010) have estimated the global water consumption for wheat production for the same period as Liu et al. (2007, 2009), showing the green-blue water distinction and applying a grid-based approach as well. Gerbens et al. (2009) estimated the green and blue water footprint for wheat in the 25 largest producing countries. Aldaya et al. (2010) have calculated the green and blue water components for wheat in four major producing countries and also estimate international virtual water flows related to wheat trade. Aldaya and Hoekstra (2010) made an assessment of the water footprint of wheat in different regions of Italy, for the first time specifying not only the green and blue, but the grey water footprint as well.

The aim of this study is to estimate the green, blue and grey water footprint of wheat in a spatially-explicit way, both from a production and consumption perspective. We quantify the green, blue and grey water footprint of *wheat production* by using a grid-based dynamic water balance model that takes into account local climate and soil conditions and nitrogen fertilizer application rates and calculates the crop water requirements, actual crop water use and yields and finally the green, blue and grey water footprint at grid level. The model has been applied at a spatial resolution of 5 arc minutes by 5 arc minutes. The model's conceptual framework is based on the FAO CROPWAT approach (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979; Allen et al., 1998). The water footprint of *wheat consumption* per country is estimated by tracing the different sources of wheat consumed in a country and considering the specific water footprints of wheat production in the producing regions.

2. Method and data

2.1. Method

In this study the global green, blue and grey water footprint of wheat production and consumption and the international virtual water flows related to wheat trade were estimated following the calculation framework of Hoekstra and Chapagain (2008) and Hoekstra et al. (2009). The computations of crop evapotranspiration and yield, required for the estimation of the green and blue water footprint in wheat production, have been done following the method and assumptions provided by Allen et al. (1998) for the case of crop growth under non-optimal conditions (Chapter 8). The grid-based dynamic water balance model developed in this study for estimating the crop evapotranspiration and yield computes a daily soil water balance and calculates crop water requirements, actual crop water use (both green and blue) and actual yields. The model is applied at a global scale using a resolution level of 5 by 5 arc minute grid size (about 10 km by 10 km around the Equator). The water balance model is largely written in Python language and embedded in a computational framework where input and output data are in grid-format. The input data available in grid-format (like precipitation, reference evapotranspiration, soil, crop parameters) are converted to text-format to feed the Python code. Output data from the Python code are converted back to grid-format. The steps followed in the calculation framework are schematically shown in Figure 1.

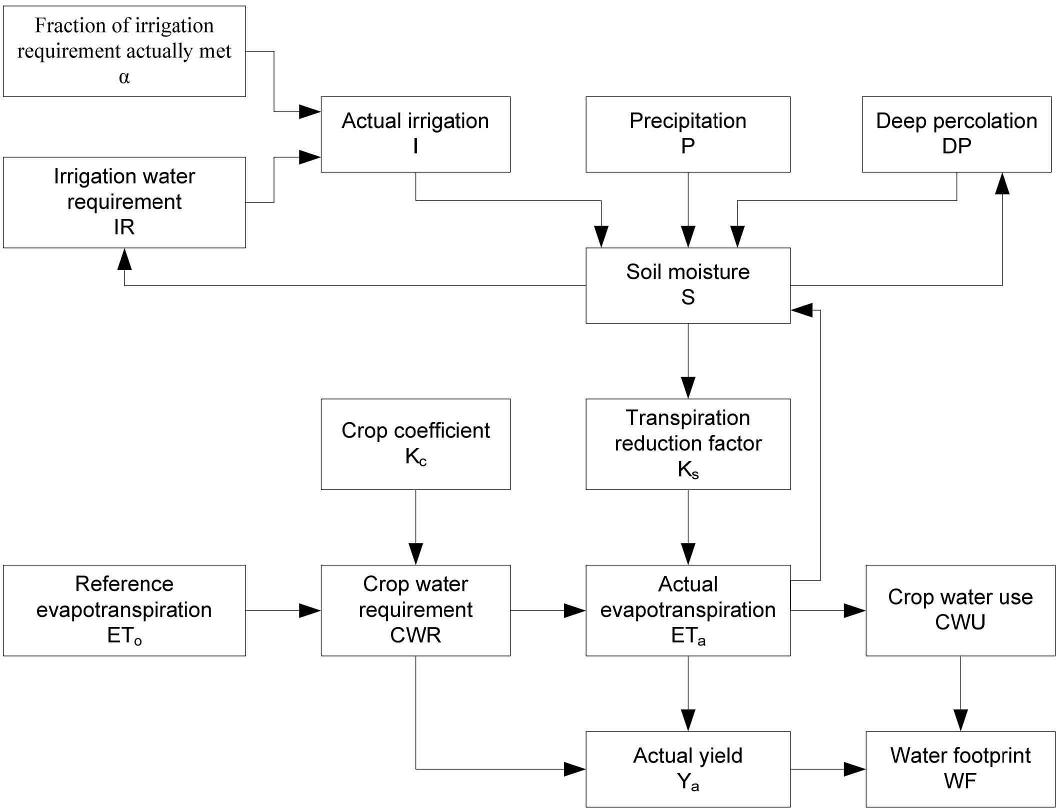

Figure 1. Simplified representation of the model to calculate the water footprint of a crop.

Under conditions in which water is not a limiting factor, the maximum crop evapotranspiration (the crop water requirement) is expressed as:

$$CWR[t] = K_c[t] \times ET_o[t] \tag{1}$$

where $CWR[t]$ is the crop water requirement, K_c the crop coefficient and $ET_o[t]$ the reference evapotranspiration (mm/day). The crop coefficient varies in time, as a function of the plant growth stage as shown in Figure 2. During the initial and mid-season stages of the crop development, K_c is a constant and equals $K_{c,ini}$ and $K_{c,mid}$ respectively. During the crop development and late season stages, K_c varies linearly and linear interpolation is applied for days within the development and late growing seasons.

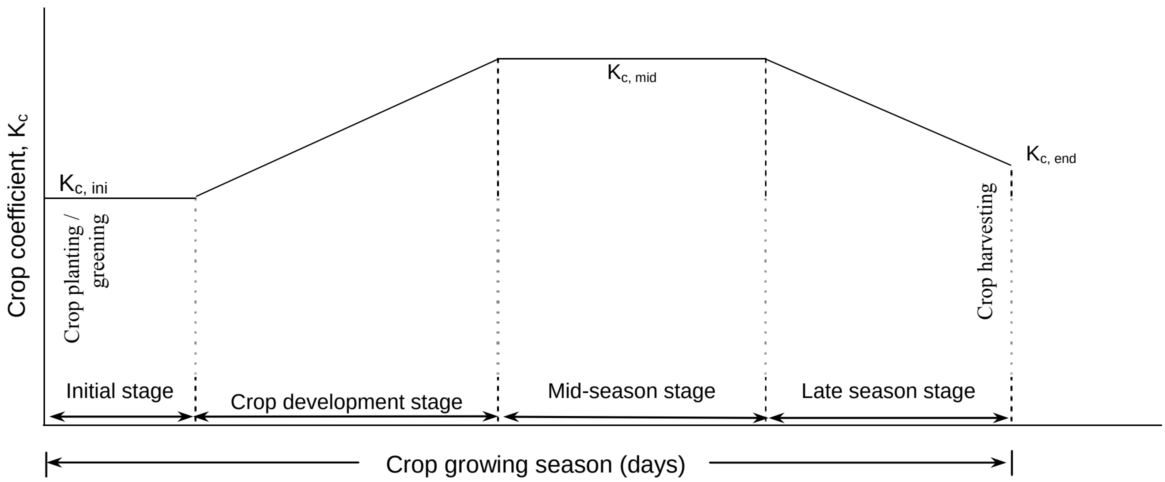

Figure 2. Development of K_c during the crop growing season (based on Allen et al., 1998).

For the development stage:

$$K_c[t] = K_{c,ini} + (K_{c,mid} - K_{c,ini}) \times (J[t] - J_{dev}) / L_{dev} \tag{2}$$

For the late stage:

$$K_c[t] = K_{c,mid} + (K_{c,end} - K_{c,nud}) \times (J[t] - J_{late}) / L_{late} \tag{3}$$

where J is the day number within the growing season, J_{dev} the day number at the beginning of the development period, J_{late} the day number at the beginning of the late season stage. L_{dev} and L_{late} represent the length of the development and late season stages respectively.

The actual crop evapotranspiration (ET_a, mm/day) depends on soil water availability. The effect of soil water stress on the crop evapotranspiration is expressed as (Allen et al, 1998):

$$ET_a[t] = K_s[t] \times CWR[t] \tag{4}$$

with:

$$K_s[t] = \begin{cases} \dfrac{S[t]}{(1-p)\times S_{\max}[t]} & if \quad S[t] < (1-p)\times S_{\max}[t] \\ 1 & Otherwise \end{cases} \tag{5}$$

where $K_s\,[t]$ is a dimensionless transpiration reduction factor dependent on available soil water [0-1]; $S[t]$ the actual available soil moisture at time t [mm]; $S_{max}[t]$ the maximum available soil water in the root zone, i.e., the available soil water in the root zone when soil water content is at field capacity [mm] (represented by the symbol TAW in Allen et al., 1998); and p the fraction of S_{max} that a crop can extract from the root zone without suffering water stress [-].

Following heavy rainfall and irrigation, all the pores of soil will be filled with water until the saturation point is reached. During dry days, water will drain out of the root zone until the field capacity is reached. Field capacity (θ_{FC}) refers to the amount of water that a well-drained soil can hold against the gravitational forces. Unless there is an additional water supply, the water content in the root zone will decrease due to water uptake by the crops. As evapotranspiration progresses the remaining water is held to the soil particles at increasingly greater suctions and it is more difficult for the plants to extract it. Eventually, the point is reached where water is tightly held in very fine pores and is no longer available to plants. This point is defined as the permanent wilting point (θ_{WP}). The maximum available soil water in the root zone (S_{max}) at a certain point in time is the amount of water held in a soil between the limits of field capacity and permanent wilting point (Figure 3). The maximum available water (S_{max}) is expressed as:

$$S_{\max}[t] = 1000 \times (\theta_{FC} - \theta_{WP}) \times Z_r[t] = TAWC \times Z_r[t] \tag{6}$$

in which θ_{FC} is the water content at field capacity [m^3/m^3]; θ_{WP} the water content at wilting point [m^3/m^3]; Z_r the time-dependent rooting depth [m]; and $TAWC$ the total available water capacity in 1 m soil, i.e. the available soil water in the root zone when soil water content is at field capacity [mm/m]. Not all S_{max} is available to plants. Under sufficient soil moisture, the soil will supply water at the rate the crop takes up water in order to meet its atmospheric demand, and water uptake equals the crop water requirement (*CWR*). As the soil moisture drops below the stress threshold value, the plant will come under water-stress and wilt. The fraction of S_{max} that a crop can extract from the root zone without suffering water stress is the readily available soil water (*RAW*, mm) and is expressed as:

$$RAW[t] = p[t] \times S_{\max}[t] \tag{7}$$

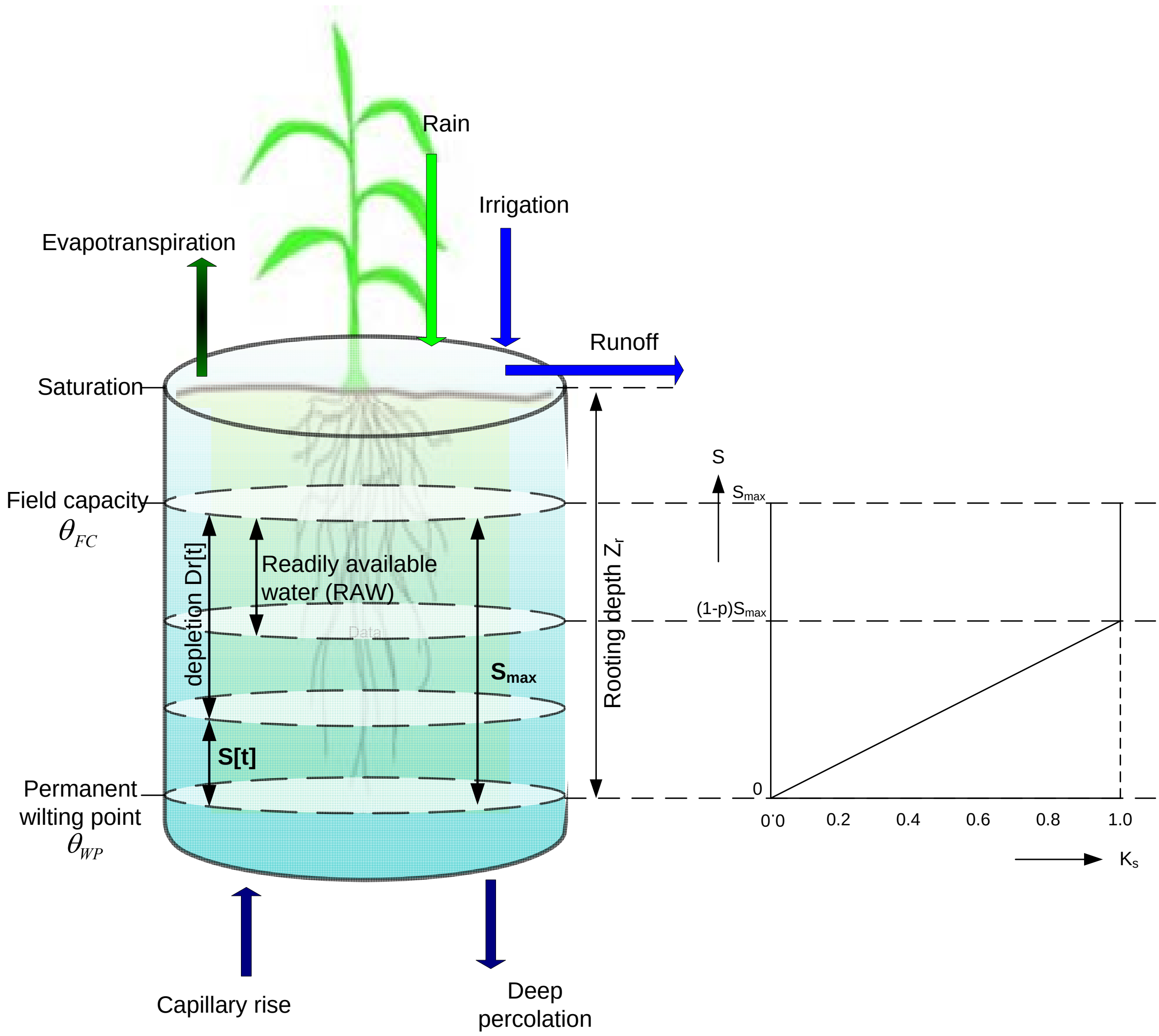

Figure 3. Water balance of the root zone and water stress coefficient (K_s) as a function of the actual available soil moisture (S) in case of a rooting depth Z_r (based on Allen et al., 1998).

The depletion fraction p depends on the crop type and the maximum crop evapotranspiration and is expressed as:

$$p[t] = p_{std} + 0.04 \times (5 - CWR[t]) \tag{8}$$

where p_{std} is the standard depletion fraction for crop water requirement $CWR[t] \approx 5$ mm/day and is obtained from Allen et al (1998). The adjusted p should be within the range $0.1 \leq p \leq 0.8$.

For annual crops the effective root depth varies in time, as a function of the plant growth stage as shown in Figure 4. During the initial stages of the crop development, Z_r is assumed to be constant and equals $Z_{r,min}$. During the crop development season stage, Z_r increases in proportion to the increase in K_c and reaches a maximum by the beginning of the midseason (Allen et al., 1998).

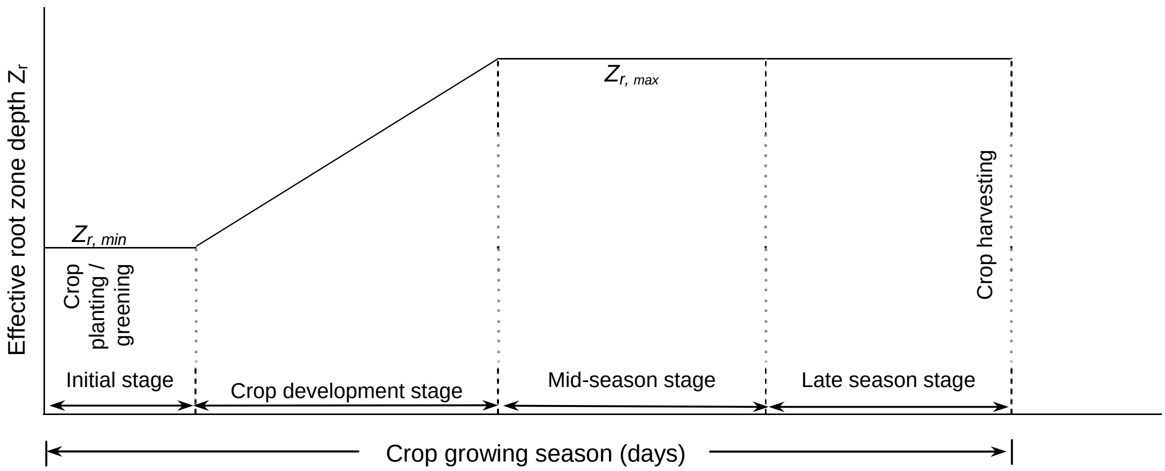

Figure 4. Development of effective root depth (Z_r) during the crop growing season.

The effective root zone depth on day *t* is calculated as follows:

$$Z_r[t] = \begin{cases} Z_{r,\min} + (Z_{r,\max} - Z_{r,\min}) \times \dfrac{(K_c - K_{c,ini})}{(K_{c,mid} - K_{c,ini})} & if \quad J < J_{mid} \\ Z_{r,\max} & if \quad J \geq J_{mid} \end{cases} \tag{9}$$

where $K_{c,ini}$ is the initial crop coefficient; $K_{c,mid}$ the mid-season crop coefficient; K_c the crop coefficient at Julian date *J*; J_{mid} the mid-season Julian date; $Z_{r,min}$ the initial effective depth of the root zone (at the beginning of the initial stage, i.e. planting date); and $Z_{r,max}$ the maximum effective depth of the root zone during the mid-season stage obtained from Allen et al. (1998). For many annual crops, $Z_{r,min}$ is assumed to be 0.15 to 0.20 (ibid.). For perennial crops, the effective root depth is kept constant at the maximum root depth.

A daily calculation of the root zone soil water balance is required in order to estimate K_s. The daily water balance, expressed in terms of depletion at the end of the day is:

$$D_r[t] = D_r[t-1] - P[t] - I[t] - CR[t] + RO[t] + ET_a[t] + DP[t] \tag{10}$$

where $D_r[t]$ is the root zone depletion at the end of day t [mm]; $D_r[t-1]$ the water content in the root zone at the end of the previous day *t-1* [mm]; *P[t]* precipitation on day *t* [mm]; *RO[t]* runoff on day *t* [mm]; *I[t]* the net irrigation depth on day *t* that infiltrates the soil [mm]; *CR[t]* the capillary rise from the groundwater table on day *t* [mm]; $ET_a[t]$ the actual evapotranspiration [mm]; and *DP[t]* the deep percolation [mm]. The calculated $D_r[t]$ should be within the range $0 \leq D_r[t] \leq S_{max}$.

During the planting stage, the root zone soil moisture is assumed to be near field capacity. Therefore, the initial depletion $D_r[t-1]$ is assumed to be equal to zero.

The daily water balance can also be expressed in terms of soil moisture at the end of the day:

$$S[t] = S[t-1] + P[t] + I[t] + CR[t] - RO[t] - ET_a[t] - DP[t] \tag{11}$$

Following the approach as in the HBV model (Bergström, 1995; Lidén and Harlin, 2000) the amount of rainfall lost through runoff is computed as:

$$RO[t] = (P[t] + IR[t]) \times \left(\frac{S[t-1]}{S_{\max}[t-1]} \right)^{\gamma} \tag{12}$$

The value of the parameter γ is adopted from Siebert and Döll (2008) and was set to 3 for irrigated land and to 2 for rain-fed areas.

The ground water table is assumed to be more than 1 meter below ground level, therefore, the water transported upward by capillary rise (*CR*) can be assumed to be nil (Allen et al. 1998).

The irrigation requirement is determined based on the root zone depletion. Irrigation requirement exists when the root zone depletion is greater than or equal to the readily available soil moisture (*RAW*) and the amount of irrigation is equal to the depletion level as expressed below:

$$IR[t] = \begin{cases} D_r[t-1] & if \quad D_r[t-1] \geq RAW \\ 0 & \quad otherwise \end{cases} \tag{13}$$

The actual irrigation *I[t]* depends on the extent to which the irrigation requirement is met:

$$I[t] = \alpha \times IR[t] \tag{14}$$

where α is the fraction of the irrigation requirement that is actually met. Following the method as proposed in Hoekstra et al. (2009) and also applied by Siebert and Döll (2010), we run two scenarios, one with $\alpha = 0$ (no application of irrigation, i.e. rain-fed conditions) and the other with $\alpha = 1$ (full irrigation). In the second scenario we have assumed that the amount of actual irrigation is sufficient to meet the irrigation requirement.

The water lost through deep percolation (*DP*) will be larger than zero if the soil water content is at field capacity. As long as the soil is under water stress ($S[t] < S_{max}[t]$) the soil will not drain and deep percolation is expressed as:

$$DP[t] = \begin{cases} \max(0, (P[t] + I[t] - RO[t] - ET_a[t] - (S_{\max}[t-1] - S[t-1]))) & if \quad S[t] = S_{\max}[t] \\ 0 & otherwise \end{cases} \tag{15}$$

The crop growth and yield are affected by the water stress. To account for the effect of water stress, a linear relationship between yield and crop evapotranspiration was proposed by Doorenbos and Kassam (1979):

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{\sum ET_a[t]}{\sum CWR[t]}\right) \tag{16}$$

where K_y is a yield response factor (water stress coefficient), Y_a the actual harvested yield [kg/ha], Y_m the maximum yield [kg/ha], ET_a the actual crop evapotranspiration in mm/period and CWR the crop water requirement in mm/period. K_y values for individual periods and the complete growing period are given in Doorenbos and Kassam (1979). The K_y values for the total growing period for winter wheat and spring wheat are 1.0 and 1.15 respectively. The maximum yield value for a number of countries is obtained from Ekboir (2002) and Pingali (1999). For countries with no such data the regional average value is taken.

The actual yields which are calculated per grid cell are averaged over the nation and compared with the national average yield data (for the period 1996-2005) obtained from FAO (2008a). The calculated yield values are scaled to fit the national average FAO yield data. The resulting yield map is shown in Appendix II.

The green and blue water use for irrigated crops is calculated by running two scenarios: one for rain-fed (α = 0) and the other for irrigated agriculture (α = 1). The green and blue crop water use are calculated following Hoekstra et al. (2009):

Rain-fed scenario (α = 0):

$$CWU(\alpha = 0) = CWU_g(\alpha = 0) \tag{17}$$

$$CWU_g(\alpha = 0) = 10 \times \sum ET_a(\alpha = 0) \tag{18}$$

$$CWU_b(\alpha = 0) = 0 \tag{19}$$

Irrigated scenario (α = 1):

$$CWU(\alpha = 1) = 10 \times \sum ET_a(\alpha = 1) \tag{20}$$

$$CWU_g(\alpha = 1) = CWU_g(\alpha = 0) \tag{21}$$

$$CWU_b(\alpha = 1) = CWU(\alpha = 1) - CWU_g(\alpha = 0) \tag{22}$$

where CWU_g is the green crop water use (m^3/ha) and CWU_b the blue crop water use (m^3/ha). For both cases (α = 0 and α = 1), the green and blue water footprints are calculated as:

$$WF_g = \frac{CWU_g}{Y_a} \quad (23)$$

$$WF_b = \frac{CWU_b}{Y_a} \quad (24)$$

where Y_a is the actual crop yield (ton/ha), WF_g the green water footprint and WF_b the blue water footprint (m^3/ton).

Both the total green and the total blue water footprint in each grid cell are calculated as the weighted average of the (green, respectively blue) water footprints under the two scenarios:

$$WF = \beta \times WF(\alpha = 1) + (1 - \beta) \times WF(\alpha = 0) \quad (25)$$

where β refers to the fraction of wheat area in the grid cell that is irrigated.

The grey water footprint of wheat production is calculated by quantifying the volume of water needed to assimilate the fertilisers that reach ground- or surface water. Nutrients leaching from agricultural fields are the main cause of non-point source pollution of surface and subsurface water bodies. Nitrate is essential for the growth of plants and high yields. But it is considered as a threat to both public health and natural waters once it leached to the water bodies (Addiscott, 1996). In this study we have quantified the grey water footprint related to nitrogen use only. The grey component of the water footprint of wheat (WF_{gy}, m^3/ton) is calculated by multiplying the fraction of nitrogen that leached (δ, %) by the nitrogen application rate (AR, kg/ha) and dividing this by the difference between the maximum acceptable concentration of nitrogen (c_{max}, kg/m^3) and the natural concentration of nitrogen in the receiving water body (c_{nat}, kg/m^3) and by the actual wheat yield (Y_a, ton/ha):

$$WF_{gy} = \left(\frac{\delta \times AR}{c_{\max} - c_{nat}} \right) \times \frac{1}{Y_a} \quad (26)$$

The average green, blue and grey water footprints of wheat in a whole nation or river basin were estimated by taking the area-weighted average of the water footprint (m^3/ton) over the relevant grid cells:

$$\overline{WF} = \frac{\sum WF[x,y] \times A[x,y]}{\sum A[x,y]} \quad (27)$$

where $\overline{WF}$ is the average water footprint in the country or river basin in m^3/ton, $WF[x,y]$ the water footprint in grid cell (x,y) in m^3/ton and $A[x,y]$ the wheat cultivation area in grid cell (x,y) in hectare.

The water footprints of wheat as harvested (unmilled wheat) have been used as a basis to calculate the water footprints of derived wheat products (wheat flour, wheat groats and meal, wheat starch and gluten) based on product and value fractions following the method as in Hoekstra et al. (2009).

International virtual water flows (m^3/yr) related to trade in wheat products were calculated by multiplying the trade volumes (tons/yr) by their respective water footprint (m^3/ton). The virtual water flow V (m^3/yr) from exporting country n_e to importing country n_i as a result of export of a wheat product p has been calculated as:

$$V[n_e, n_i, p] = T[n_e, n_i, p] \times WF[n_e, p] \tag{28}$$

in which T represents the international commodity trade (ton/yr) while WF is the exporting country's product water footprint (m^3/ton) of exported commodity p.

The national water saving S_n (m^3/yr) of a country n_i as a result of trade in product p is:

$$S_n[n_i, p] = (T_i[n_i, p] - T_e[n_i, p]) \times WF[n_i, p] \tag{29}$$

where WF is the water footprint (m^3/ton) of the product p in importing country n_i, T_i the volume of product p imported (ton/yr) and T_e the volume of the product exported (ton/yr). S_n can have a negative sign, which means a net water loss instead of a saving. The global water saving S_g (m^3/yr) through trade in wheat products from an exporting country n_e to an importing country n_i can be calculated as follows:

$$S_g[n_e, n_i, p] = T[n_e, n_i, p] \times \left(WF[n_i, p] - WF[n_e, p]\right) \tag{30}$$

where T is the volume of trade (ton/yr) between the two countries.

The virtual water budget (V_b) of a country is the sum of the water footprint related to production within the country (WF_p) and the virtual water import V_i (Hoekstra and Chapagain, 2008). Based on the water footprint accounting scheme as shown in Figure 5, one can calculate the water footprint related to consumption in the country (WF_c). The water footprint of national consumption can be distinguished into an internal (WF_i) and external component (WF_e). The internal water footprint (WF_i) is defined as the use of domestic water resources to produce goods and services consumed by inhabitants of the country. It is the water footprint related to production within the country minus the volume of virtual water export to other countries insofar as related to export of domestically produced products. The external water footprint can be estimated based on the relative share of virtual-water import to the total virtual water budget:

$$WF_e = \frac{V_i}{WF_p + V_i} \times WF_c \tag{31}$$

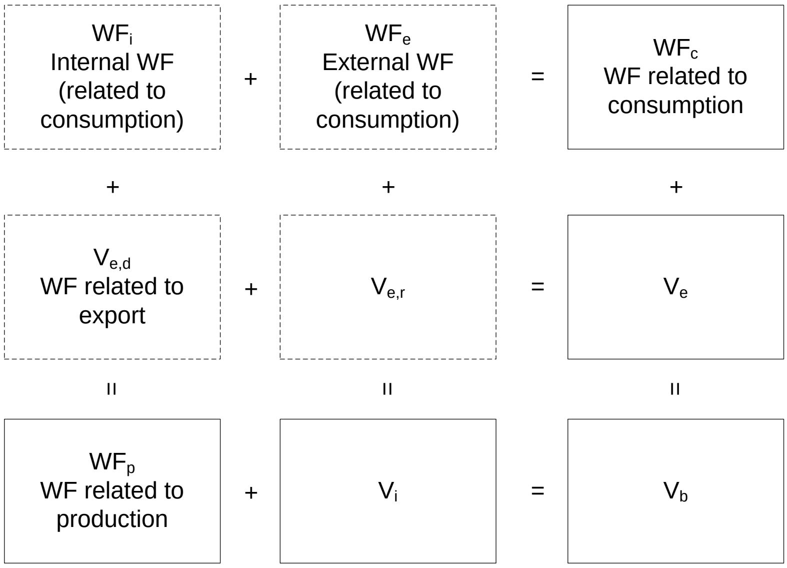

Figure 5. The water footprint and virtual water trade accounting framework as can be applied to a nation or river basin (Hoekstra et al., 2009).

2.2. Data

Average monthly reference evapotranspiration data at 10 arc minute resolution were obtained from FAO (2008b). The 10 minute data were converted to 5 arc minute resolution by assigning the 10 minute data to each of the four 5 minute grid cells. Following the CROPWAT approach, the monthly average data were converted to daily values by curve fitting to the monthly average through polynomial interpolation.

Monthly values for precipitation, wet days and minimum and maximum temperature with a spatial resolution of 30 arc minute were obtained from CRU-TS-2.1 (Mitchell and Jones, 2005). The 30 arc minute data were assigned to each of the thirty-six 5 arc minute grid cells contained in the 30 arc minute grid cell. Daily precipitation values were generated from these monthly average values using the CRU-dGen daily weather generator model (Schuol and Abbaspour, 2007).

Wheat growing areas on a 5 arc minute grid cell resolution were obtained from Monfreda et al. (2008). Countries such as Angola, Chad, Cyprus, Mauritania, Namibia, Qatar, Thailand, United Arab Emirates and Venezuela have wheat production according to FAOSTAT, but Monfreda et al. (2008) do not show data for these countries. For these countries, the MICRA grid database as described in Portmann et al. (2008) was used to fill the gap. The harvested wheat areas as available in grid format were aggregated to a national level and scaled to fit national average wheat harvest areas for the period 1996-2005 obtained from FAO (2008a). Grid data on irrigated wheat area per country were obtained from Portmann et al. (2008). The national averages of harvested wheat area, wheat production, wheat yield and irrigated wheat area as reckoned with in this study are provided in Appendix I.

Crop coefficients (K_c's) for wheat were obtained from Chapagain and Hoekstra (2004). Wheat planting dates and lengths of cropping seasons for most wheat producing countries and regions were obtained from Sacks et al. (2009) and Portmann et al. (2008). For some countries, values from Chapagain and Hoekstra (2004) were used. We have not considered multi-cropping practices.

Grid based data on total available water capacity of the soil (TAWC) at a 5 arc minute resolution were taken from ISRIC-WISE (Batjes, 2006). An average value of TAWC of the five soil layers was used in the model.

Country-specific nitrogen fertilizer application rates for wheat have been based on Heffer (2009), FAO (2006, 2009) and IFA (2009). National average data on fertilizer application rates are provided in Appendix I. Globally, wheat accounts for about 17% of total fertilizer use and 19% of the total nitrogen fertilizer consumption. A number of authors show that about 45-85% of the applied nitrogen fertilizer is recovered by the plant (Addiscot, 1996, King et al., 2001, Ma et al., 2009, Noulas et al., 2004). On average, about 16% of the applied nitrogen is presumed to be lost either by denitrification or leaching (Addiscot, 1996). The reported value of nitrogen leaching varies between 2-13% (Addiscot, 1996, Goulding et al., 2000, Riley et al., 2001, Webster et al., 1999). In this study we have assumed that on average 10% of the applied nitrogen fertilizer is lost through leaching, following Chapagain et al. (2006b). The recommended standard value of nitrate in surface and groundwater by the World Health Organization and the European Union is 50 mg nitrate (NO_3) per litre and the standard recommended by US-EPA is 10 mg per litre measured as nitrate-nitrogen (NO_3-N). In this study we have used the standard of 10 mg/litre of nitrate-nitrogen (NO_3-N), following again Chapagain et al. (2006b). Because of a lack of data, the natural nitrogen concentrations were assumed to be zero.

Data on international trade in wheat products have been taken from the SITA database (Statistics for International Trade Analysis) available from the International Trade Centre (ITC, 2007). This database covers trade data over ten years (1996-2005) from 230 reporting countries disaggregated by product and partner countries. We have taken the average for the period 1996-2005 in wheat products trade.

3. The global picture

3.1. The water footprint of wheat from the production perspective

The global water footprint of wheat production for the period 1996-2005 is 1088 Gm^3/year (70% green, 19% blue, and 11% grey). Data per country are shown in Table 1 for the largest producers. Appendices V and VII provide data for all countries in the world in global maps and in a table, respectively. The global green water footprint related to wheat production was 760 Gm^3/yr. At a country level, large green water footprints can be found in the USA (112 Gm^3/yr), China (83 Gm^3/yr), Russia (91 Gm^3/yr), Australia (44 Gm^3/yr), and India (44 Gm^3/yr). About 49% of the global green water footprint related to wheat production is in these five countries. At sub-national level (state or province level), the largest green water footprints can be found in Kansas in the USA (21 Gm^3/yr), Saskatchewan in Canada (18 Gm^3/yr), Western Australia (15 Gm^3/yr), and North Dakota in the USA (15 Gm^3/yr). The global blue water footprint was estimated to be 204 Gm^3/yr. The largest blue water footprints were calculated for India (81 Gm^3/yr), China (47 Gm^3/yr), Pakistan (28 Gm^3/yr), Iran (11 Gm^3/yr), Egypt (5.9 Gm^3/yr) and the USA (5.5 Gm^3/yr). These six countries together account for 88% of the total blue water footprint related to wheat production. At sub-national level, the largest blue water footprints can be found in Uttar Pradesh (24 Gm^3/yr) and Madhya Pradesh (21 Gm^3/yr) in the India and Punjab in Pakistan (20 Gm^3/yr). These three states in the two countries alone account about 32% of the global blue water footprint related to wheat production. The grey water footprint related to the use of nitrogen fertilizer in wheat cultivation was 124 Gm^3/yr. The largest grey water footprint was observed for China (32 Gm^3/yr), India (20 Gm^3/yr) the USA (14 Gm^3/yr) and Pakistan (8 Gm^3/yr).

The calculated global average water footprint per ton of wheat was 1830 m^3/ton. The results show a great variation, however, both within a country and among countries (Figure 6). Among the major wheat producers, the highest total water footprint per ton of wheat was found for Morroco, Iran and Kazakhstan. On the other side of the spectrum, there are countries like the UK and France with a wheat water footprint of around 560 - 600 m^3/ton.

The global average blue water footprint per ton of wheat amounts to 343 m^3/ton. For a few countries, including Pakistan, India, Iran and Egypt, the blue water footprint is much higher, up to 1478 m^3/ton in Pakistan. In Pakistan, the blue water component in the total water footprint is nearly 58%. The grey water footprint per ton of wheat is 208 m^3/ton as a global average, but in Poland it is 2.5 times higher than the global average.

Table 2 shows the water footprint related to production of wheat for some selected river basins. About 59% of the global water footprint related to wheat production is located in this limited number of basins. Large blue water footprints can be found in the Ganges-Brahmaputra-Meghna (53 Gm^3/yr), Indus (42 Gm^3/yr), Hwang Ho (13 Gm^3/yr), Tigris-Euphrates (10 Gm^3/yr), Amur (3.1 Gm^3/yr) and Yangtze river basins (2.7 Gm^3/yr). The Ganges-Brahmaputra-Meghna and Indus river basins together account for about 47% of the global blue and 21% of the global grey water footprint. Appendices VI and VIII provide data for the major river basins of the world in maps and a table, respectively.

Table 1. Water footprint of wheat production for the major wheat producing countries. Period: 1996-2005.

Country	Contribution to global wheat production (%)	Total water footprint of production (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
		Green	Blue	Grey	Total	Green	Blue	Grey	Total
Argentina	2.5	25905	162	1601	27668	1777	11	110	1898
Australia	3.6	44057	363	2246	46666	2130	18	109	2256
Canada	3.9	32320	114	4852	37286	1358	5	204	1567
China	17.4	83459	47370	31626	162455	820	466	311	1597
Czech Republic	0.6	2834	0	900	3734	726	0	231	957
Denmark	0.8	2486	30	533	3049	530	6	114	651
Egypt	1.1	1410	5930	2695	10034	216	907	412	1536
France	6.0	21014	48	199	21261	584	1	6	591
Germany	3.5	12717	0	3914	16631	602	0	185	787
Hungary	0.7	4078	8	1389	5476	973	2	331	1306
India	11.9	44025	81335	20491	145851	635	1173	296	2104
Iran	1.8	26699	10940	3208	40847	2412	988	290	3690
Italy	1.2	8890	120	1399	10409	1200	16	189	1405
Kazakhstan	1.7	33724	241	1	33966	3604	26	0	3629
Morocco	0.5	10081	894	387	11362	3291	292	126	3710
Pakistan	3.2	12083	27733	8000	47816	644	1478	426	2548
Poland	1.5	9922	4	4591	14517	1120	0	518	1639
Romania	0.9	9066	247	428	9741	1799	49	85	1933
Russian Fed.	6.5	91117	1207	3430	95754	2359	31	89	2479
Spain	1.0	8053	275	1615	9943	1441	49	289	1779
Syria	0.7	5913	1790	842	8544	1511	457	215	2184
Turkey	3.3	40898	2570	3857	47325	2081	131	196	2408
UK	2.5	6188	2	2292	8482	413	0	153	566
Ukraine	2.5	26288	287	1149	27724	1884	21	82	1987
USA	10.2	111926	5503	13723	131152	1879	92	230	2202
Uzbekistan	0.7	3713	399	0	4112	939	101	0	1039
World		760301	203744	123533	1087578	1279	343	208	1830

The global average water footprint of rain-fed wheat production is 1805 m^3/ton, while in irrigated wheat production it is 1868 m^3/ton (Table 3). Obviously, the blue water footprint in rain-fed wheat production is zero. In irrigated wheat production, the blue water footprint constitutes 50% of the total water footprint. Although, on average, wheat yields are 30% higher in irrigated fields, the water footprint of wheat from irrigated lands is higher than in the case of rain-fed lands. The reason is that under irrigation, yields are higher, but water consumption (evapotranspiration) as well.

Table 2. The water footprint of wheat production for some selected river basins (1996-2005).

River basin	Total water footprint of production (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Ganges-Brahmaputra-Meghna	30288	53009	12653	95950	665	1164	278	2107
Mississippi	79484	2339	9413	91236	1979	58	234	2271
Indus	22897	42145	13326	78368	604	1111	351	2066
Ob	51984	225	511	52721	2680	12	26	2718
Nelson-Saskatchewan	38486	118	5691	44294	1275	4	189	1468
Tigris-Euphrates	29219	10282	2670	42170	2893	1018	264	4175
Hwang Ho	17012	13127	7592	37731	695	536	310	1541
Danube	27884	273	3579	31735	1298	13	167	1477
Volga	25078	272	955	26305	2315	25	88	2429
Don	24834	384	927	26144	2658	41	99	2799
Yangtze	17436	2700	4855	24991	1112	172	310	1594
Murray-Darling	20673	343	987	22003	2061	34	98	2193
La Plata	17127	73	1070	18271	2039	9	127	2175
Amur	8726	3136	2355	14216	985	354	266	1604
Dnieper	13219	68	813	14100	1732	9	107	1847
Columbia	7238	1877	1122	10236	1852	480	287	2620
Oral	9338	94	192	9624	2542	26	52	2620
World	760301	203744	123533	1087578	1279	343	208	1830

Table 3. The global water footprint of wheat production in rain-fed and irrigated lands (1996-2005).

Farming system	Yield (ton/ha)	Total water footprint of production (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
		Green	Blue	Grey	Total	Green	Blue	Grey	Total
Rain-fed	2.5	611	0	66	676	1629	0	175	1805
Irrigated	3.3	150	204	58	411	679	926	263	1868
World average	2.7	760	204	124	1088	1279	343	208	1830

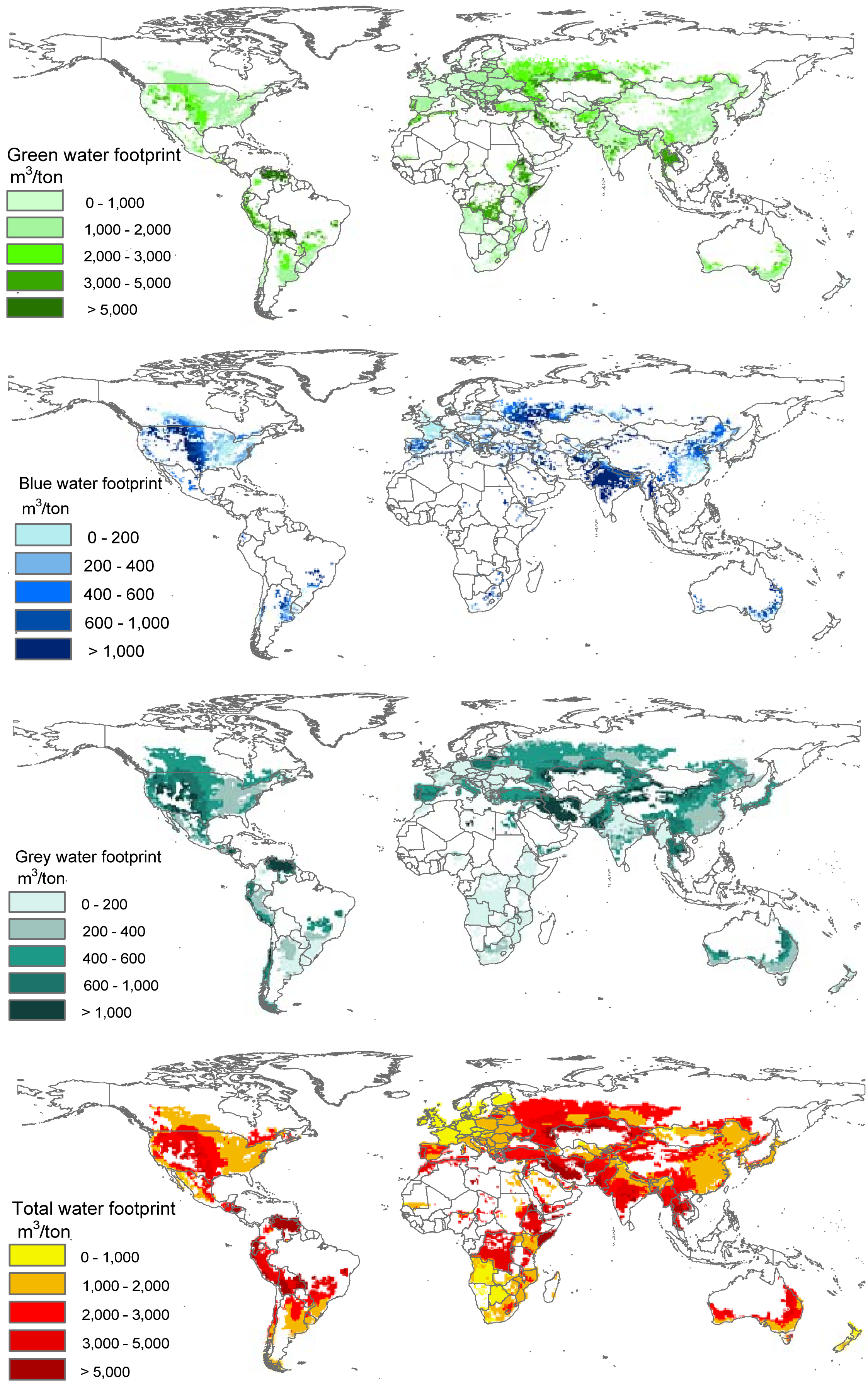

Figure 6. The green, blue, grey and total water footprint of wheat production per ton of wheat. Period: 1996-2005.

3.2. International virtual water flows related to trade in wheat products

The total global virtual water flow related to trade in wheat products averaged over the period 1996-2005 was 200 Gm^3/year. This means that an estimated 18% of the global water footprint was related to wheat production for export. About 87% of this amount comes from green water and only 4% from blue water and the remaining 9% is grey water. Wheat exports in the world are thus basically from rain-fed agriculture. The world's largest 26 wheat producers, which account for about 90% of global wheat production (Table 1), were responsible for about 94% of the global virtual water export. The USA, Canada and Australia alone were responsible for about 55% of the total virtual water export. China, which is the top wheat producer accounting for 17.4% of the global wheat production, was a net virtual water importer. India and the USA were the largest exporters of blue water, accounting for about 62% of the total blue water export. A very small fraction (4%) of the total blue water consumption in wheat production was traded internationally. Surprisingly, some water-scarce regions in the world, relying on irrigation, show a net export of blue water virtually embedded in wheat. Saudi Arabia had a net blue virtual water export of 21 Mm^3/yr and Iraq exported a net volume of blue water of 6 Mm^3/yr. The largest grey water exporters were the USA, Canada, Australia and Germany. Data per country are shown in Tables 4 and 5 for the largest virtual water exporters and importers, respectively, and in Appendix IX for all countries of the world. The largest net virtual water flows related to international wheat trade are shown in Figure 7.

Table 4. Gross virtual water export related to the export of wheat products in the period 1996-2005.

Country	Gross virtual water export (Mm^3/yr)				Contribution to the global export (%)
	Green	Blue	Grey	Total	
USA	48603	2389	5959	56952	28.4
Canada	24144	85	3625	27854	13.9
Australia	24396	201	1244	25841	12.9
Argentina	15973	100	987	17060	8.5
Kazakhstan	16490	118	0	16608	8.3
France	9347	21	89	9457	4.7
Russian Federation	7569	100	285	7954	4.0
Ukraine	4587	50	200	4837	2.4
Germany	3537	0	1090	4626	2.3
India	1266	2338	589	4193	2.1
Turkey	2208	139	208	2555	1.3
UK	1189	0	441	1630	0.8
Spain	1242	42	249	1534	0.8
Others	14142	2204	2840	19186	9.6
Global flow	174693	7789	17807	200289	100.0

Table 5. Gross virtual water import related to the import of wheat products in the period 1996-2005.

Country	Virtual water import (Mm^3/yr)				Contribution to the global import (%)
	Green	Blue	Grey	Total	
Brazil	11415	88	801	12304	6.1
Japan	10393	320	1147	11860	5.9
Italy	7345	174	760	8279	4.1
Egypt	6838	274	633	7745	3.9
Korea, Rep	6511	398	685	7594	3.8
Indonesia	6512	364	577	7453	3.7
Iran	6105	60	504	6670	3.3
Malaysia	5616	185	636	6437	3.2
Algeria	5330	323	696	6350	3.2
Mexico	5155	205	660	6020	3.0
Russian Federation	5334	69	92	5495	2.7
Philippines	3923	426	538	4887	2.4
Spain	4161	80	493	4734	2.4
China	4087	98	453	4638	2.3
Uzbekistan	3816	35	35	3886	1.9
Morocco	3281	69	310	3660	1.8
Nigeria	2872	152	346	3370	1.7
USA	2796	26	422	3244	1.6
Pakistan	2794	92	264	3150	1.6
Tajikistan	2885	26	11	2922	1.5
Others	67523	4324	7744	79592	39.7
Global flow	174693	7789	17807	200289	100.0

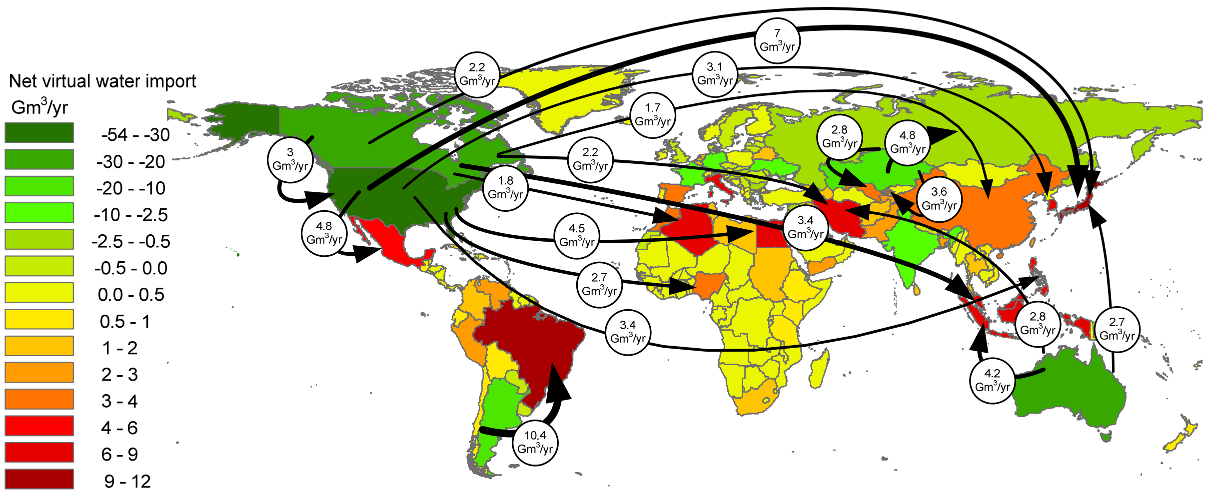

Figure 7. National virtual water balances and net virtual water flows related to trade in wheat products in the period 1996-2005. Only the largest net flows (> 2 Gm^3/yr) are shown.

The global water saving associated with the international trade in wheat products adds up to 65 Gm^3/yr (39% green, 48% blue, and 13% grey). Import of wheat and wheat products by Algeria, Iran, Morocco and Venezuela from Canada, France, the USA and Australia resulted in the largest global water savings. Figure 8 illustrates the concept of global water saving through an example of the trade in durum wheat from France to Morocco.

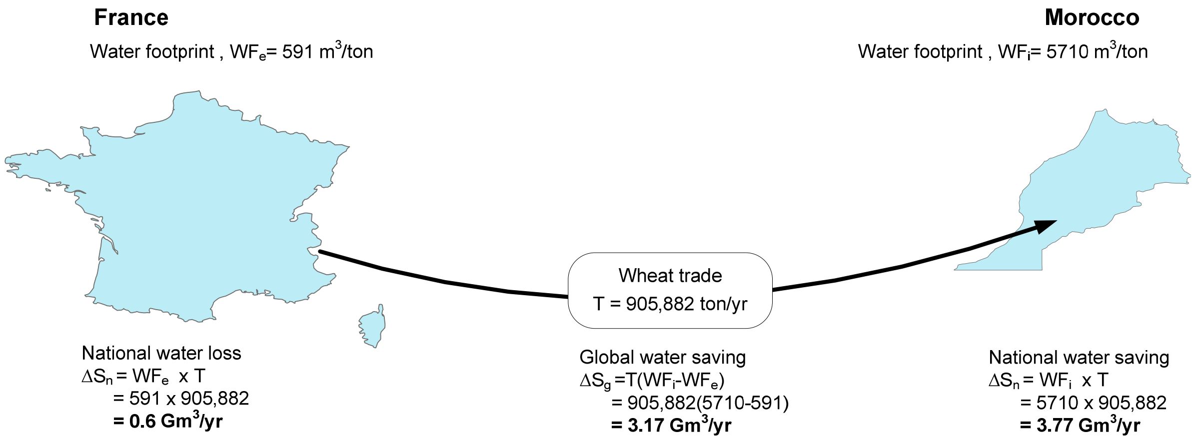

Figure 8. Global water saving through the trade in durum wheat from France to Morocco. Period: 1996-2005.

3.3. The water footprint of wheat from the consumption perspective

The global water footprint related to the consumption of wheat products was estimated at 1088 Gm^3/yr, which is 177 m^3/yr per person on average (70% green, 19% blue, and 11% grey). About 82% of the total water footprint related to consumption was from domestic production while the remaining 18% was external water footprint (Figure 9). In terms of water footprint per capita, Kazakhstan has the largest water footprint, with 1156 m^3/cap/yr, followed by Australia and Iran with 1082 and 716 m^3/cap/yr respectively. Data per country are shown in Table 6 for the major wheat consuming countries and in Figure 10 and Appendix X for all countries of the world. When the water footprint of wheat consumption per capita is relatively high in a country, this can be explained by either one or a combination of two factors: (i) the wheat consumption in the country is relatively high; (ii) the wheat consumed has a high water footprint per kg of wheat. As one can see in Table 6, in the case of Kazakhstan and Iran, both factors play a role. In the case of Australia, the relatively high water footprint related to wheat consumption can be mostly explained by the high wheat consumption per capita alone. Germany has a large wheat consumption per capita – more than twice the world average – so that one would expect that the associated water footprint would be high as well, but this is not the case because, on average, the wheat consumed in Germany has a low water footprint per kg (43% of the global average).

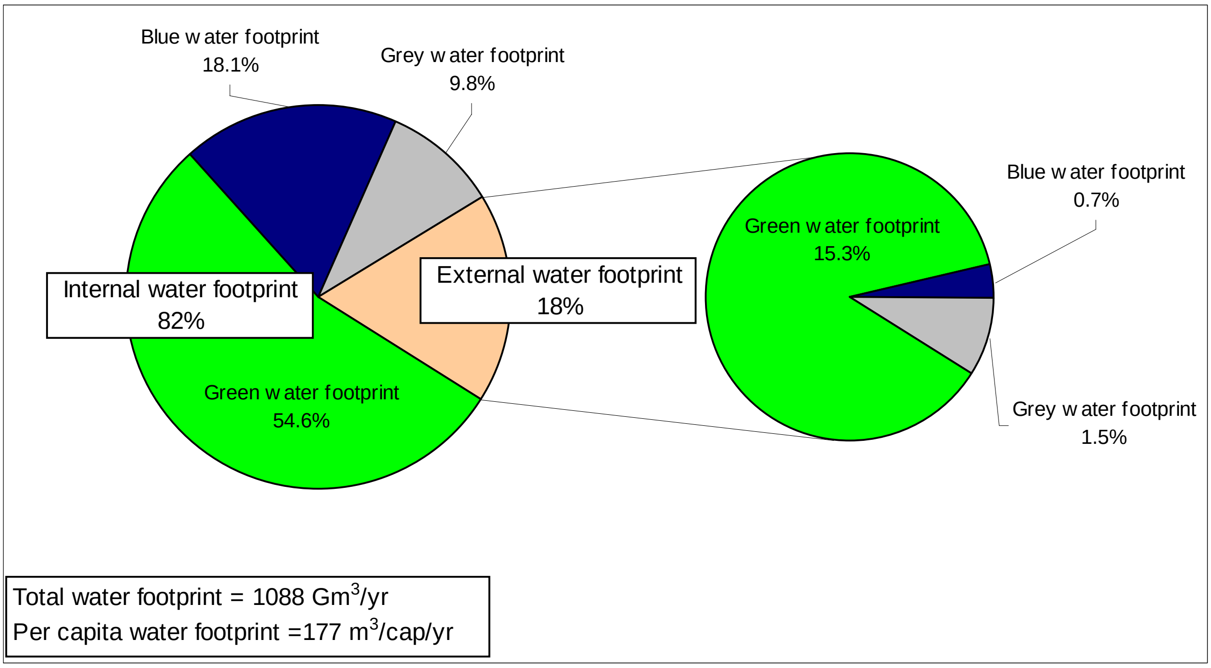

Figure 9. Global water footprint related the consumption of wheat products. Period: 1996-2005.

Table 6. Water footprint of wheat consumption for the major wheat consuming countries (1996-2005).

Countries	Internal water footprint (Mm^3/yr)			External water footprint (Mm^3/yr)			Water footprint		WF per capita	Wheat consump-tion per capita	WF of wheat products
	Green	Blue	Grey	Green	Blue	Grey	Total WF (Mm^3/yr)	WF per capita (m^3/yr)	Fraction of world average	Fraction of world average	Fraction of world average
China	82990	47091	31442	4064	97	450	166134	133	0.75	0.86	0.88
India	42786	78997	19903	931	17	64	142699	135	0.76	0.66	1.15
Russia	83967	1112	3152	4915	63	85	93295	635	3.59	2.67	1.33
USA	64508	3124	7941	1612	15	244	77444	270	1.53	1.32	1.17
Pakistan	11900	27218	7856	2752	90	259	50075	345	1.95	1.42	1.37
Iran	26693	10937	3208	6104	60	504	47505	716	4.04	2.32	1.74
Turkey	38810	2434	3659	2238	54	181	47376	691	3.90	2.98	1.30
Ukraine	21905	239	955	1021	12	30	24163	496	2.80	2.78	1.01
Australia	19671	162	1005	8	1	3	20851	1082	6.11	5.47	1.16
Brazil	6901	3	469	11224	88	788	19472	111	0.63	0.58	1.08
Egypt	1409	5924	2692	6837	274	633	17768	264	1.49	1.62	0.92
Kazakhstan	17312	124	1	83	1	7	17529	1156	6.53	3.92	1.85
Italy	8274	114	1284	6837	165	697	17372	300	1.69	2.35	0.70
Poland	9687	4	4478	572	7	94	14841	386	2.18	2.48	0.87
Morocco	9923	877	383	3230	68	306	14786	505	2.85	2.21	1.29
Germany	9459	0	2868	810	13	120	13270	161	0.91	2.07	0.43
World	593599	196690	106972	166703	7147	16586	1087696	177			

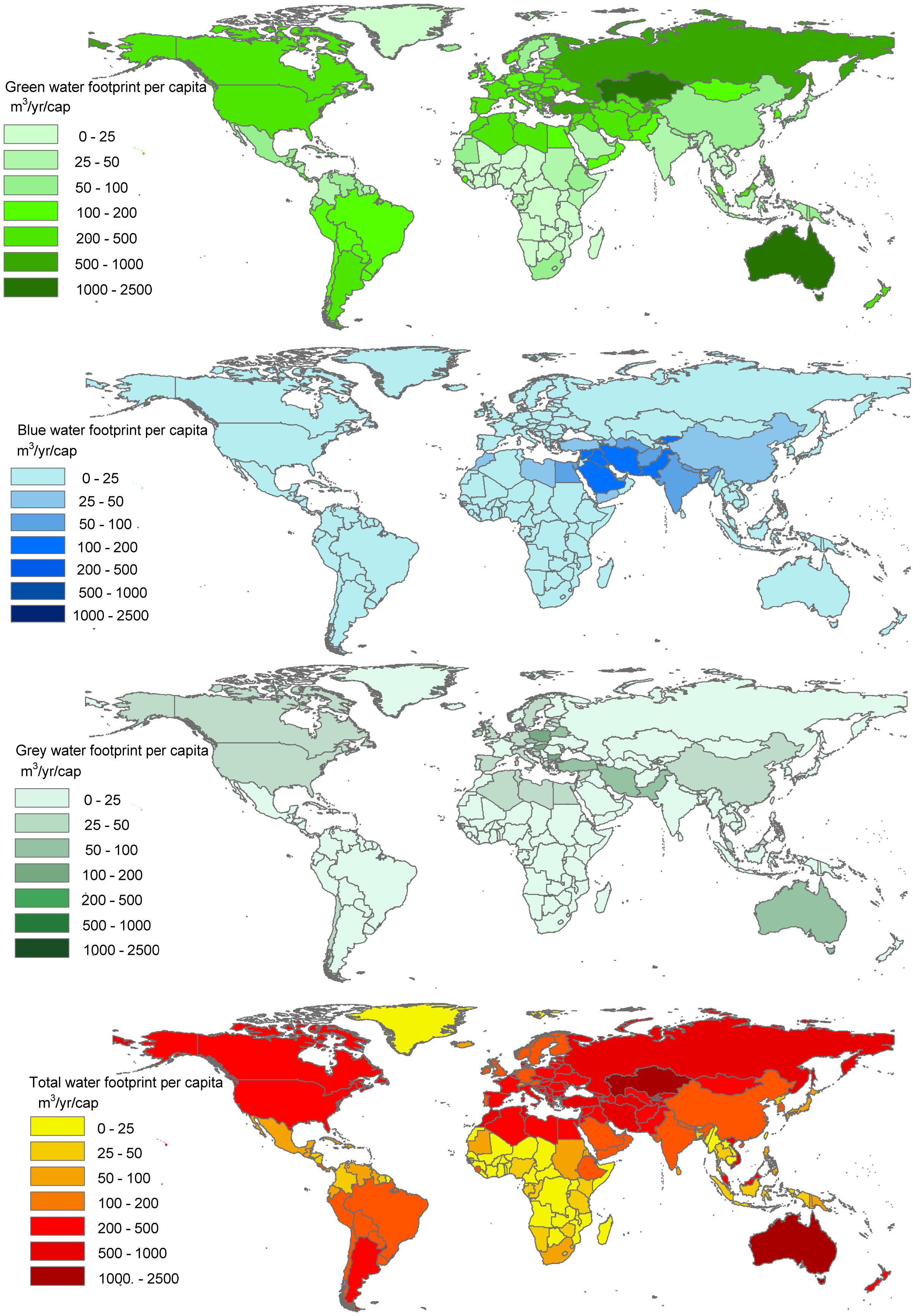

Figure 10. Water footprint per capita related to consumption of wheat products in the period 1996-2005.

The countries with the largest external water footprint related to wheat consumption were Brazil, Japan, Egypt, Italy, the Republic of Korea and Iran. Together, these countries account for about 28% of the total external water footprint. Japan's water footprint related to wheat consumption lies outside the country for about 93%. In Italy, with an average wheat consumption of 150 kg/yr per person, more than two times the word average, this was about 44%. Most African, South-East Asian, Caribbean and Central American countries strongly rely on external water resources for their wheat consumption as shown in Figure 11.

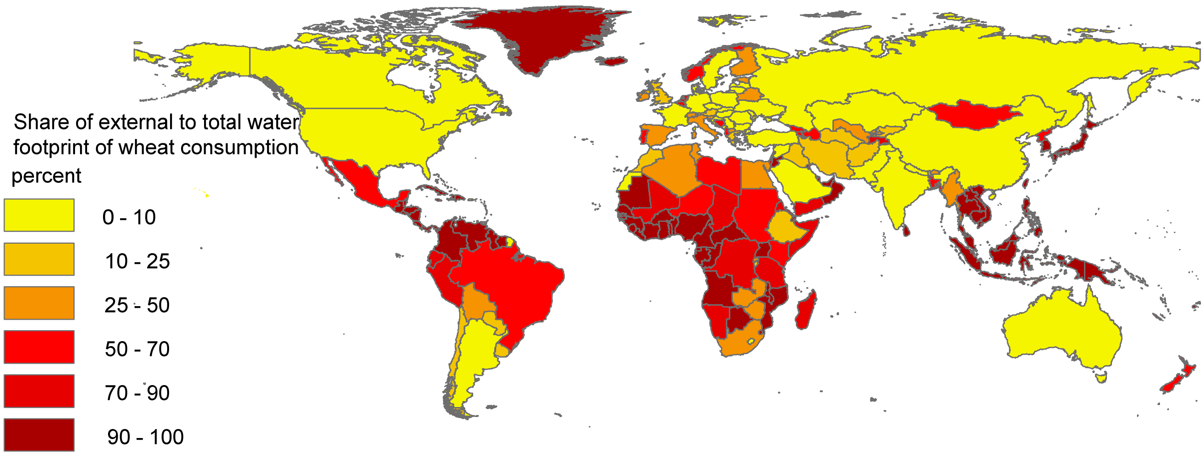

Figure 11. The extent to which countries rely on external water resources for their wheat consumption. Period: 1996-2005.

4. Case studies

4.1. *The water footprint of wheat production in the Ogallala area (USA)*

The Ogallala Aquifer, also known as the High Plains Aquifer, is a regional aquifer system located beneath the Great Plains in the United States in portions of the eight states of South Dakota, Nebraska, Wyoming, Colorado, Kansas, Oklahoma, New Mexico, and Texas (Figure 12). It covers an area of approximately 451,000 km², making it the largest area of irrigation-sustained cropland in the world (Peterson and Bernardo, 2003). Most of the aquifer underlies parts of three states: Nebraska has 65% of the aquifer's volume, Texas 12% and Kansas 10% (Peck, 2007). About 27 percent of the irrigated land in the United States overlies this aquifer system, which yields about 30 percent of the nation's ground water used for irrigation (Dennehy, 2000).

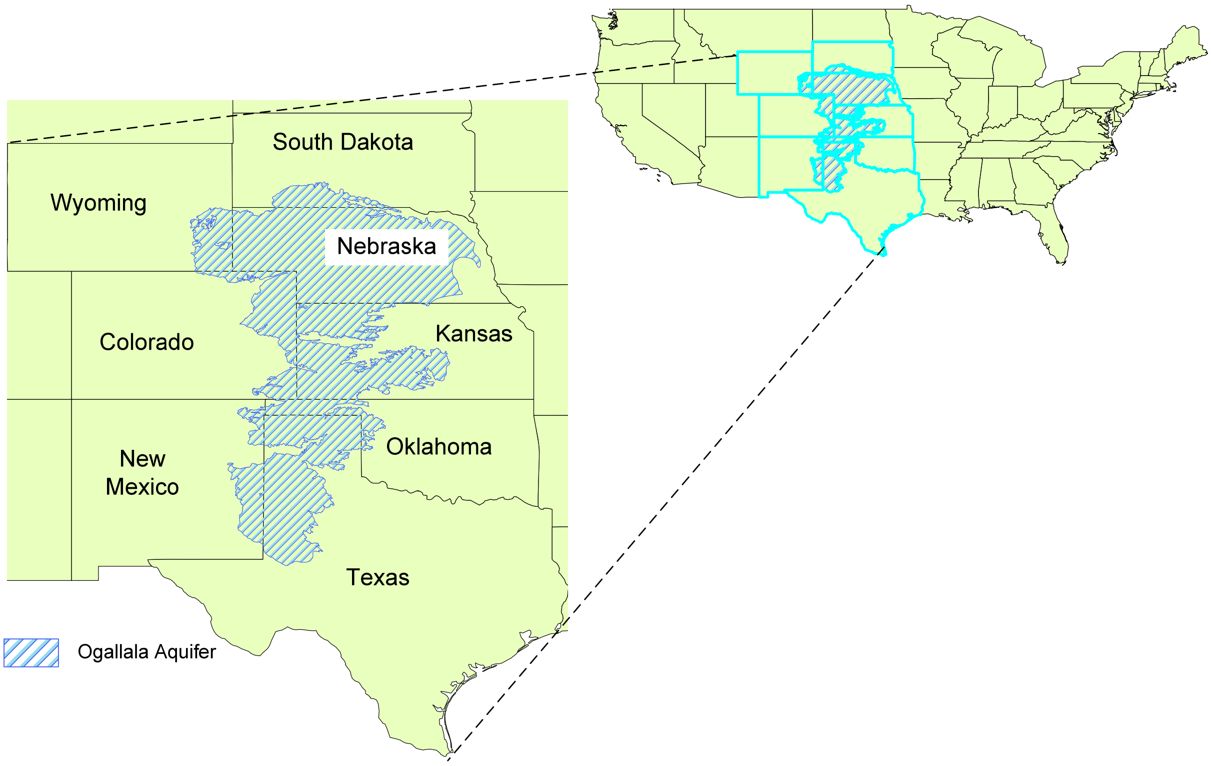

Figure 12. The area of the Ogallala (High Plains) Aquifer in the USA.

Water from the Ogallala Aquifer is the principal source of supply for irrigated agriculture. In 1995, the Ogallala Aquifer contributed about 81% of the water supply in the Ogallala area while the remainder was withdrawn from rivers and streams, most of it from the Platte River in Nebraska. Outside of the Platte River Valley, 92% of water used in the Ogallala area is supplied by ground water (Dennehy, 2000). Since the beginning of extensive irrigation using ground water, the water level of the aquifer has dropped by 3 to 15 meters in most part of the aquifer (McGuire, 2007).

Within the Ogallala area, Kansas takes the largest share in wheat production (51%), followed by Texas and Nebraska (16% and 15% respectively). In Kansas, 84% of the wheat production comes from rain-fed areas. In

Nebraska, this is 86% and in Texas 47%. The Ogallala area accounts for about 14% of the total wheat production in the USA. Our study shows that 16% of the total water footprint of wheat production in the country lies in the Ogallala area. About 19% of the *blue* water footprint of wheat production in the USA is in the Ogallala area (Table 7). The total water footprint in the Ogallala area was 21 Gm^3/yr (85% green, 5% blue, and 10% grey).

Table 7. Water footprint of wheat production and virtual water export from the Ogallala area (1996-2005).

States in the Ogallala area*	Water footprint related to wheat production (Mm^3/yr)				Virtual water export related to export of wheat products (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Kansas	9136	368	1077	10581	3872	156	456	4484
Texas	1981	417	301	2699	839	177	128	1144
Nebraska	2952	78	345	3375	1251	33	146	1430
Colorado	2108	67	281	2456	893	29	119	1041
Oklahoma	693	26	91	809	293	11	38	343
New Mexico	317	94	45	455	134	40	19	193
South Dakota	211	0	24	235	90	0	10	100
Wyoming	299	6	34	338	127	2	14	143
Ogallala area total	17696	1056	2196	20949	7499	448	931	8877
USA total	111926	5503	13723	131152	48603	2389	5959	56952

* Values in the table refer to the part of the states within the Ogallala area only.

Texas takes the largest share (39%) in the blue water footprint of wheat production in the Ogallala area, followed by Kansas (35%). There is a considerable variation in the blue water footprint per ton of wheat within the Ogallala area. Besides, the blue water footprint per ton of wheat in the Ogallala area is relatively high if compared to the average in the USA (Appendix XI).

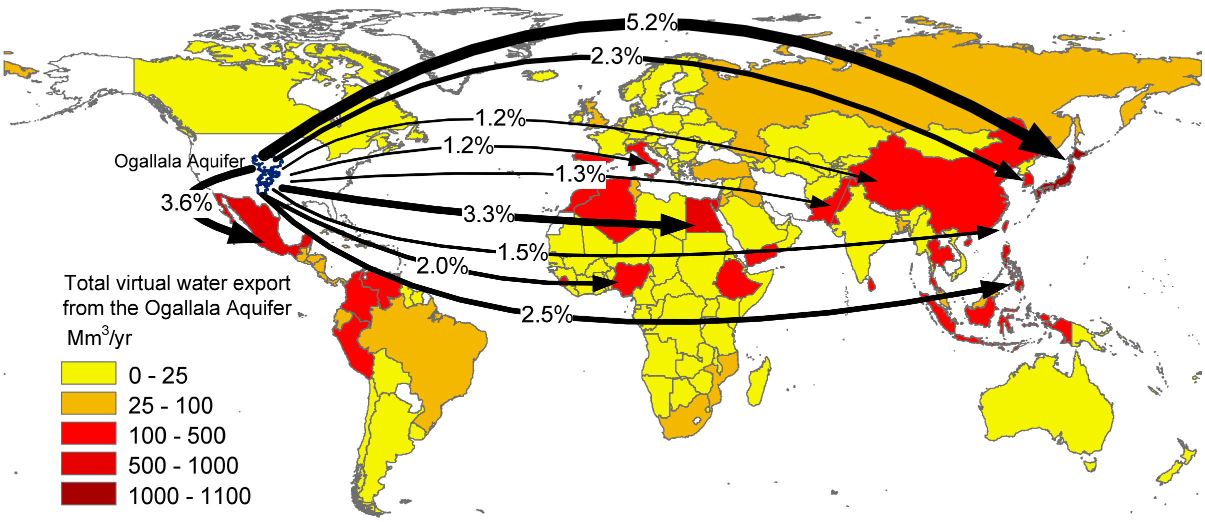

Figure 13. Major destinations of wheat-related virtual water exports from the Ogallala area in the USA (1996-2005). About 58% of the total water footprint of wheat production in the area is for wheat consumption in the USA and 42% is for export to other nations. Only the largest exports (> 1%) are shown.

In the period 1996-2005, the virtual water export related to export of wheat products from the USA was 57 Gm^3/yr. About 98% (55.6 Gm^3/yr) of the virtual water export comes from domestic water resources and the remaining 2% (1.4 Gm^3/yr) is from re-export of imported virtual water related to import of wheat products. If we assume that wheat export from the USA comes from the different states proportional to their production, the virtual water export for the period 1996-2005 from the Ogallala area was 8.9 Gm^3/yr, which is 42% of the total water footprint related to wheat production in the Ogallala area (Table 7). Figure 13 shows the major foreign destinations of wheat-related virtual water exports from the area of the Ogallala Aquifer.

4.2. The water footprint of wheat production in the Ganges and Indus river basins

The Ganges river basin, which is part of the composite Ganges-Brahmaputra-Meghna river basin, is one of most densely populated river basins in the world. It covers about 1 million km^2 (Gleick, 1993). The Indus river basin, which extends over four countries (China, India, Pakistan and Afghanistan), is also a highly populated river basin. The area of the Indus basin is a bit smaller than the Ganges basin but covers nearly 1 million km^2 as well (Gleick, 1993).

The two river basins together account for about 90 percent of the wheat production in India and Pakistan in the period 1996-2005. Almost all wheat production (98%) in Pakistan comes from the Indus river basin. About 89% of India's wheat is produced in the Ganges (62%) and the Indus basin (27%) (Figure 14). About 87% of the total water footprint related to wheat production in India and Pakistan lies in these two river basins. The total water footprint of wheat production in the Indian part of the Ganges basin is 92 Gm^3/yr (32% green, 54% blue, 14% grey). The total water footprint of wheat production in the Pakistani part of the Indus basin is 48 Gm^3/yr (25% green, 58% blue, 17% grey).

In the period 1996-2005, India and Pakistan together had a virtual water export related to wheat export of 5.1 Gm^3/yr (29% green water, 56% blue, 15% grey), which is a small fraction (3%) of the total water footprint of wheat production in these two countries. About 55% of this total virtual water export comes from the Ganges basin and 45% from the Indus basin. The blue water export to other countries from the Ganges and Indus river basins was 1304 Mm^3/yr and 1077 Mm^3/yr respectively.

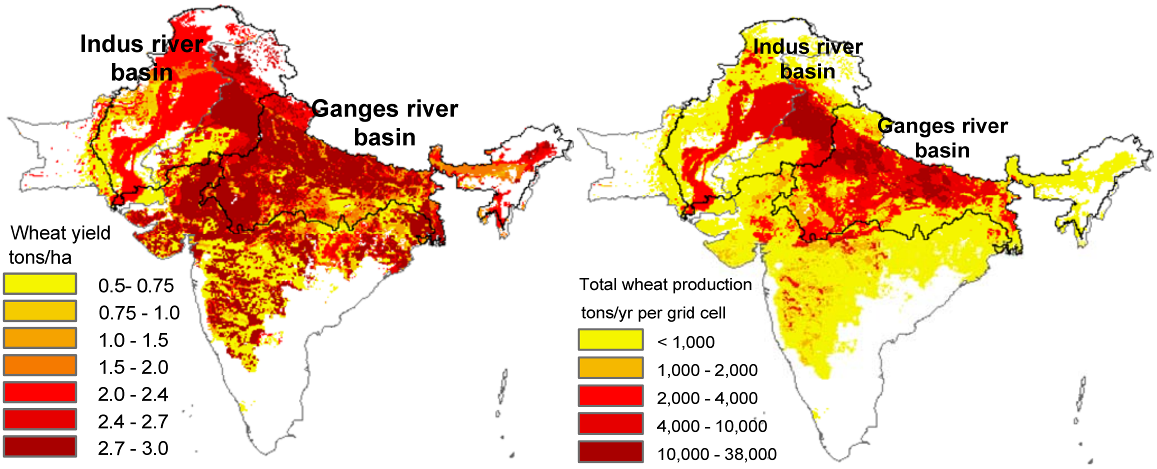

Figure 14. Total wheat production and average yield per grid cell in India and Pakistan. Period: 1996-2005.

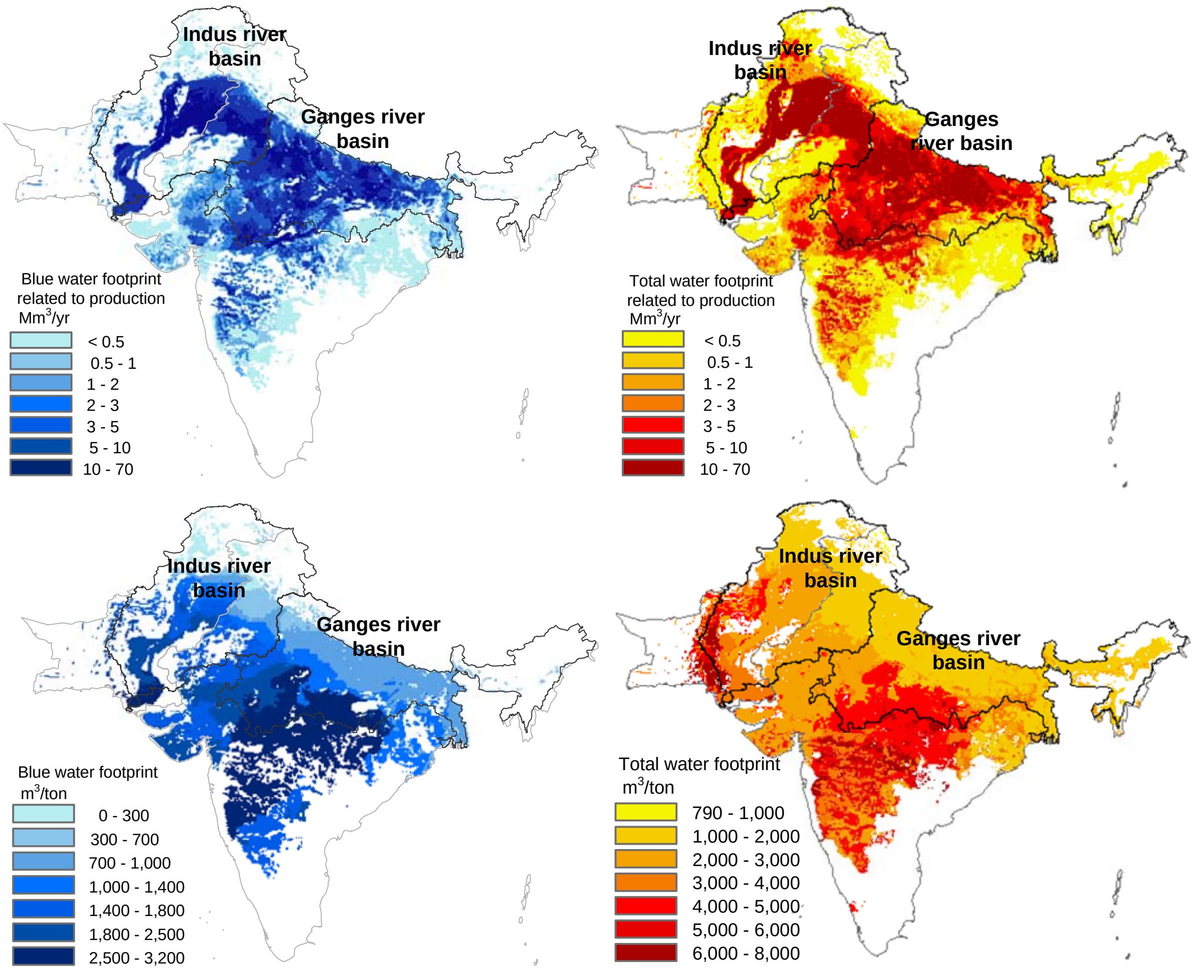

Figure 15. The total and blue water footprint related to wheat production in India and Pakistan, both expressed as a total (Mm^3/yr) and per ton of wheat (m^3/ton). Period: 1996-2005.

Based on the water withdrawal-to-availability ratio, which is an indicator of water stress (Alcamo *et al.*, 2003a; Alcamo *et al.*, 2007; Cosgrove and Rijsberman, 2000), most parts of Pakistan and India are highly water stressed (Alcamo et al., 2003b). Both the Ganges and Indus river basins are under severe water stress, in particular the Indus river basin. About 97% of the water footprint related to wheat production in the two basins is for domestic consumption within the two countries. Since the two basins are the wheat baskets of the two countries, there are substantial virtual water transfers from the Ganges and Indus basins to other areas within India and Pakistan. By looking at the virtual flows both within the country and to other countries, it is possible to link the impacts of wheat consumption in other places to the water stress in the Ganges and Indus basins. For the case of India, Kampman et al. (2008) have shown that the states which lie within the Indus and Ganges river basins, such as Punjab, Uttar Pradesh and Haryana are the largest inter-state virtual water exporters within India. The highly subsidized irrigation water in these regions has led to an intensive exploitation of the available water resources in these areas compared to other, more water-abundant regions of India. In order to provide incentives for water protection, negative externalities such as water overexploitation and pollution, and also scarcity rents should be included in the price of the crop. Both basins have a relatively high water productivity, which is shown by a smaller water footprint per ton of wheat, compared to other wheat producing areas in the two countries (Figure 15). Since wheat is a low-value crop, one may question whether water allocation to wheat production for export in states such as Punjab, Uttar Pradesh and Haryana is worth the cost. A major destination of wheat exports from India's parts of the Indus and Ganges basins is East India, to states like Bihar. Major foreign destinations of India's virtual water export related to export of wheat products are Bangladesh (22%), Indonesia (11%), Philippines (10%) and Yemen (10%). Pakistan's export mainly goes to Afghanistan (56%) and Kenya (11%).

4.3. The external water footprint of wheat consumption in Italy and Japan

In the previous two sections we have looked into the water footprint of wheat production in specific areas of the world and analysed how this water footprints could be linked to consumers elsewhere. In this section we will do the reverse: we will consider the wheat consumers in two selected countries – Italy and Japan – and trace where their water footprint lies.

Italy's water footprint related to the consumption of wheat products for the period 1996-2005 was 17.4 Gm^3/yr. More than half (56%) of Italy's water footprint is pressing on domestic water systems. The rest of the water footprint of Italian wheat consumption lies in other countries, mainly the USA (20%), France (19%), Canada (11%) and Russia (10%). The water footprint of Italy's wheat consumers in the USA lies in different regions of that country, among others in the Ogallala area as earlier shown in Figure 13. Italy also imports virtual water from the water-scarce countries of the Middle East, such as Syria (58 Mm^3/yr) and Iraq (36 Mm^3/yr). The global water footprint of Italian wheat consumption is shown in Figure 16.

About 93% of the water footprint of wheat consumption in Japan lies in other countries, mainly in the USA (59%), Australia (22%) and Canada (19%). About 87% of Japan's external water footprint is from green water. Japan's wheat-related water footprint in the USA partly presses on the water resources of the Ogallala area as shown in Figure 13. The water footprint in Australia largely lies in Southern Australia where most of the wheat is produced and water scarcity is high. Japan's global water footprint related to wheat consumption is mapped in Figure 17.

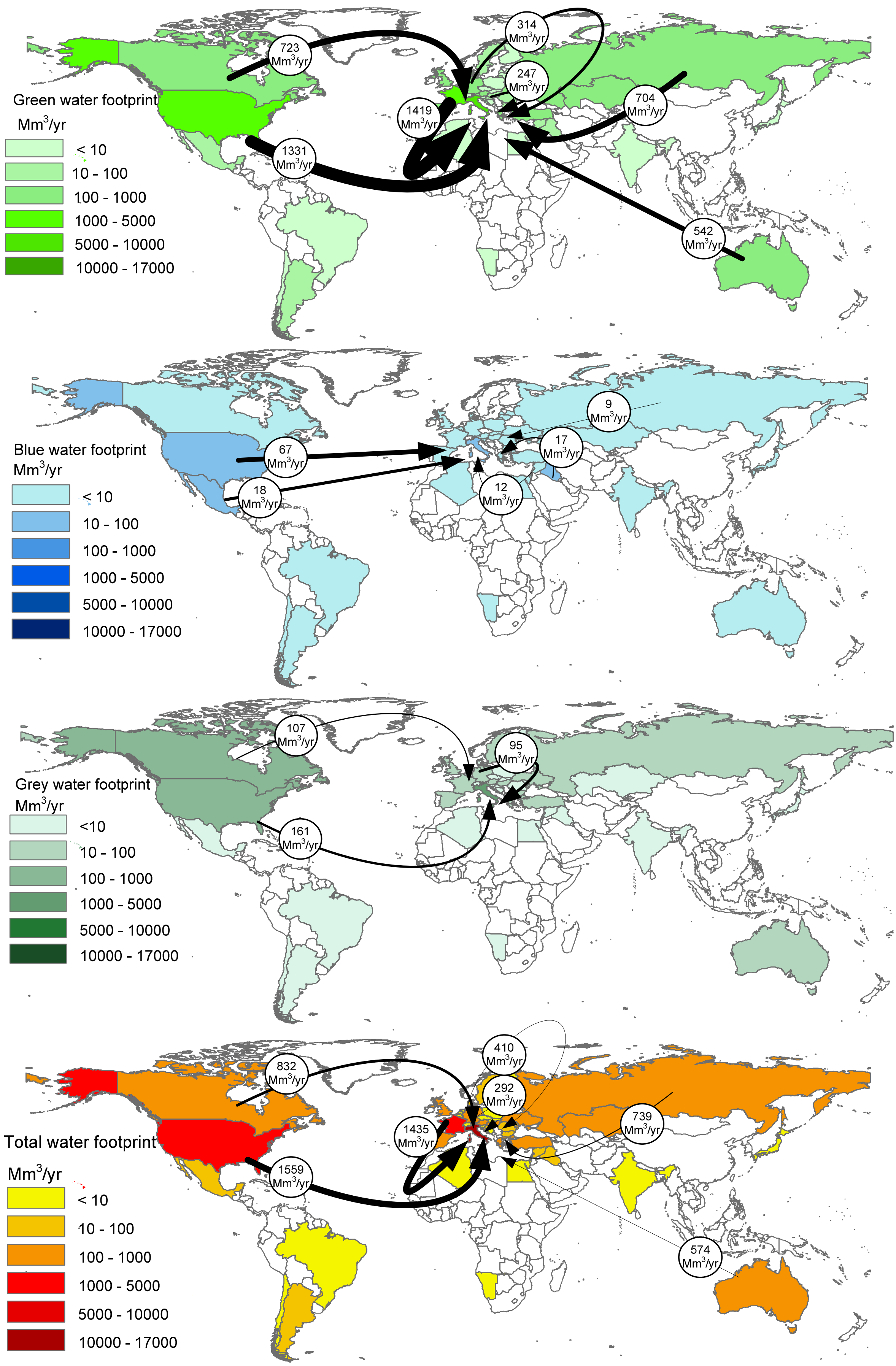

Figure 16. The global water footprint of wheat products consumed by Italy's citizens (Mm^3/yr). The arrows show the largest virtual water import flows to Italy. Period:1996-2005.

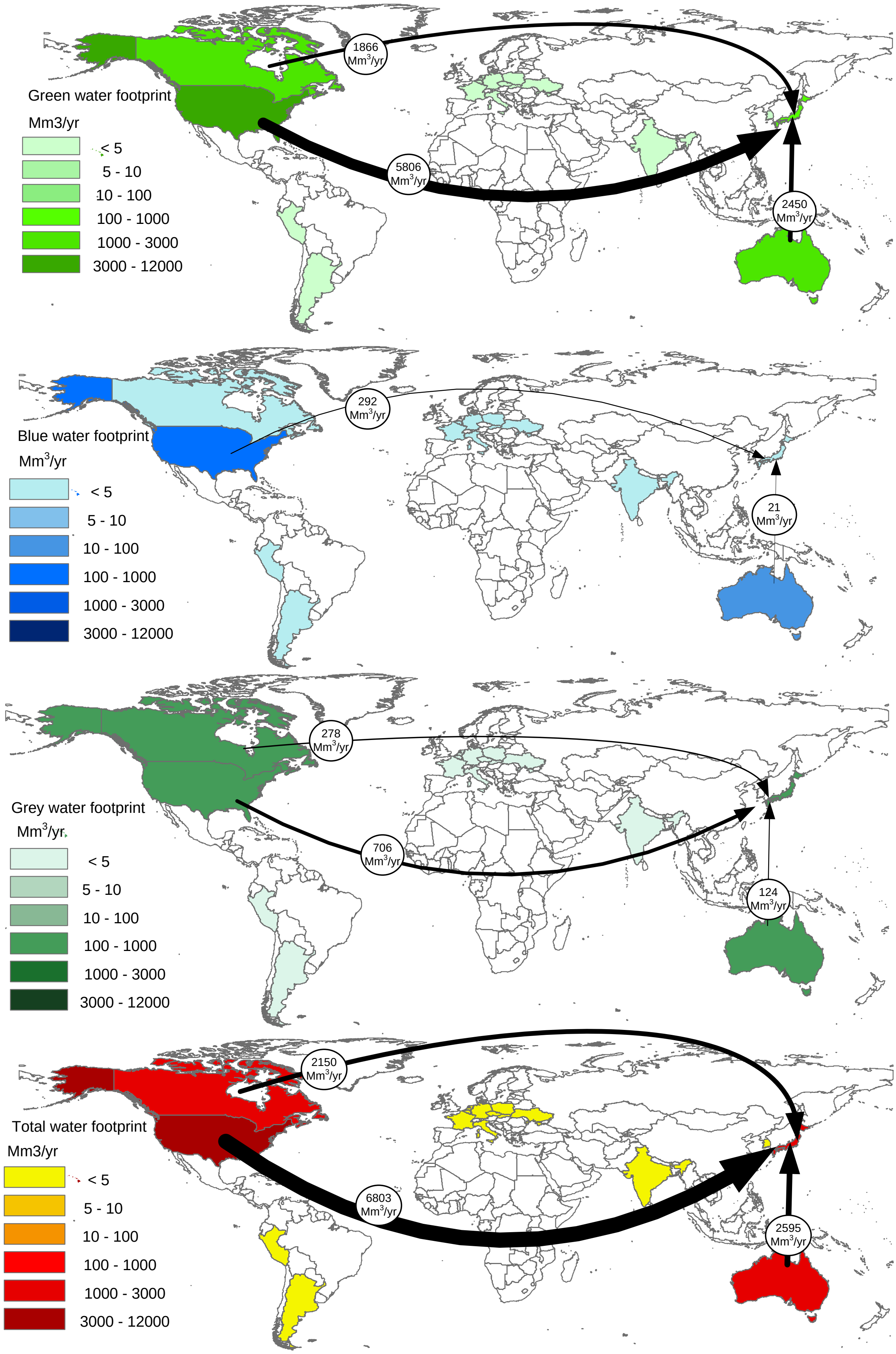

Figure 17. The global water footprint of wheat products consumed by Japan's citizens (Mm^3/yr). The arrows show the largest virtual water import flows to Japan. Period:1996-2005.

5. Discussion

The results of the current study can be compared to results from earlier studies as shown in Table 8. The global average water footprint of wheat in our study comes to 1622 m^3/ton (excluding grey water), while earlier studies gave estimates of 1334 m^3/ton (Chapagain and Hoekstra, 2004), 1253 m^3/ton (Liu et al., 2007) and 1469 m^3/ton (Siebert and Döll, 2010). A variety of factors differ in the various studies, so that it is difficult to identify the main reason for the different results. The model results with respect to the wheat water footprint per ton can also be compared for a number of specific locations to the inverse of the measured crop water productivity values as collected by Zwart and Bastiaanssen (2004). The comparison shows that out of 28 measured sites, for 17 sites (61% of the time) the simulated water footprint lies within the range of measured values (Appendix XII).

Table 8. Comparison between the results from the current study with the results from previous studies.

Study	Period	Global average water footprint of wheat	Global water footprint related to wheat production	International virtual water flows related to wheat trade	Global water saving due to wheat trade
		m^3/ton	Gm^3/yr	Gm^3/yr	Gm^3/yr
Hoekstra and Hung (2002, 2005)	1995-1999	-	-	210	-
Chapagain and Hoekstra (2004), Chapagain et al. (2006a), Hoekstra and Chapagain (2008)	1997-2001	1334	793	114	103
Oki and Kanae (2004)	2000	-	-	271	193
Yang et al. (2006)	1997-2001	-	-	188	130
Liu et al. (2007), Liu et al. (2009)	1998-2002	1253	688	159	77
Siebert and Döll (2010)	1998-2002	1469	858	-	-
Hanasaki et al. (2010)	2000	-	-	122	-
Current study, green & blue only	1996-2005	1622	964	182	57
Current study incl. grey water *	1996-2005	1830	1088	200	65

* None of the previous studies included grey water, so these figures are for information only, not for comparison.

The model results with respect to the total global water footprint of wheat production can be compared to three previous global wheat studies. The study by Chapagain and Hoekstra (2004) did not take a grid-based approach and also did not make the green-blue distinction, unlike the current study and the studies by Siebert and Döll (2010) and Liu et al. (2009), therefore we will compare here only with the latter two. When we compare the computed green and blue water footprints to the computation by Siebert and Döll (2010), we find that their estimate of the total water footprint of global wheat production is 11% lower, which is completely due to their lower estimate of the green water footprint component. The estimate of the total water footprint by Liu et al. (2009) is 29% lower than our estimate, again due to the difference in the estimate of the green component. The relatively low value presented by Liu et al. (2009) is not a surprise given the fact that their estimate is based on the GEPIC model, which has been shown to give low estimates of evapotranspiration compared to other models (Hoff et al., 2010). Our estimate of the total green water footprint in global wheat production is 760 Gm^3/yr (period 1996-2005), whereas Siebert and Döll (2010) give an estimation of 650 Gm^3/yr (period 1998-2002) and

Liu et al. (2009) 540 Gm^3/yr (1998-2002). Our estimate of the total blue water footprint in global wheat production is 204 Gm^3/yr, whereas Siebert and Döll (2010) give an estimation of 208 Gm^3/yr and Liu et al. (2009) 150 Gm^3/yr.

Liu et al. (2009) use another water balance model than applied in the current study. As a basis, they use the EPIC model (Williams et al., 1989), whereas we apply the model of Allen et al. (1998). Although both models compute the same variables, EPIC has been developed as a crop growth model, whereas the model of Allen et al. (1998) has been developed as a water balance model, which makes that the two models have a different structure and different parameters. One of the differences is the runoff model applied, which affects the soil water balance and thus soil water availability and finally the green water footprint. Besides, Liu et al. (2009) estimate water footprints (m^3/ton) based on computed yields, whereas we use computed yields, but scale them according to FAO statistics. Siebert and Döll (2010) basically apply the same modelling approach as in the current study. Both studies have the same spatial resolution, carry out a soil water balance with a daily time step, use the same CRU TS-2.1 climate data source to generate the daily precipitation and use the same crop, soil and irrigation maps. Although there are many similarities, the studies differ in some respects. For estimating daily reference evapotranspiration data, Siebert and Döll (2010) applied the cubic splin method to generate daily climate data from the monthly data as provided in the available database. In contrast, we have used long-term monthly average reference evapotranspiration global spatial data obtained from FAO (2008b) and converted these data to daily values by polynomial interpolation. Further, Siebert and Döll (2010) have considered multi-cropping based on a number of assumptions and generated their own cropping calendar based on climatic data, while in our study we have neglected multi-cropping and adopted cropping calendars as provided in literature at country level. Siebert and Döll (2010) compute local yields and scale them later on, like in the current study, but scaling is done a different manner. Finally, in our study we include the grey water footprint and study international virtual water flows, which is not done by Siebert and Döll (2010).

It is difficult to make a conclusion about the accuracy or reliability of our estimates vice versa the quality of the data presented in the other two modelling studies cited. All studies depend on a large set of assumptions with respect to modelling structure, parameter values and datasets used. For the time being, it is probably best to conclude that the divergence in outcomes is a reflection of the uncertainties involved. It implies that all estimates – both from the current and the previous studies – should be interpreted with care. Assuming that the different study periods are comparable, the three studies together give an estimation of the total water footprint of wheat production of about 830 $Gm^3/yr \pm 17\%$. This uncertainty range is probably still a conservative estimate, because it is based on the central estimates of three different modelling studies only. Furthermore, locally, differences and uncertainty ranges can be larger.

The green water footprint estimate is sensitive to a variety of assumptions, including: (a) the daily rain pattern (b) the modelling of runoff, (c) the rooting depth, (d) the soil type, which determines the soil water holding capacity, (e) the planting and harvesting dates and thus the length of the growing period, (f) the moisture content in the soil at the moment of planting, (g) the modelling of yield. The blue water footprint estimate depends on the same assumptions, plus it depends on data on actual irrigation. In a global study, given the limitations in global databases, it seems very difficult in this stage to reduce the uncertainties. Higher resolution maps of all input parameters and variables, based on either local measurements or remote sensing (Romaguera et al., 2010) may finally help to reduce the uncertainties in a global assessment like this one. In local studies, it will generally be less time-consuming to find better estimates for the various parameters and data involved and better be able to validate the model used for the specific local conditions, so that uncertainties can be reduced more easily.

6. Conclusion

Estimating water footprints of crops at national level and estimating international virtual water flows based on those national estimates – as done in all previous global water footprint studies until date – hides the existing variation at sub-national level in climatic conditions, water resources availability and crop yields. Therefore, the present study is an attempt to improve water footprint accounting through implementing the calculations at a grid basis, which takes into account the existing heterogeneity at grid level. Such approach has the advantage of being able to pinpoint precisely in space where the water footprint of wheat consumption is located. We have combined the water footprint assessment framework as provided in Hoekstra and Chapagain (2008) and Hoekstra et al. (2009) with a grid-based approach to estimating crop evapotranspiration as applied by for example Liu et al. (2009) and Siebert and Döll (2010).

The study showed that the global water footprint of wheat production for the period 1996-2005 was 1088 Gm^3/yr (70% green, 19% blue, 11% grey). Since about 18% of the global water footprint related to wheat production is for making products for export, the importance of mapping the impact of global wheat consumption on local water resources with the help of the water footprint and virtual water trade accounting framework (as shown in Figure 5) is quite clear. Quantifying the water footprint of wheat consumption and visualizing the hidden link between wheat consumers and their associated appropriation of water resources elsewhere (in the wheat producing areas) is quite relevant. The study shows that countries such as Italy and Japan, with high external water footprints related to wheat consumption, put pressure on the water resources of their trading partners. Including a water scarcity rent and the external costs of water depletion and pollution in the price of the wheat traded is crucial in order to provide an incentive within the global economy to enhance the efficiency and sustainability of water use and allocation.

The model result was compared with measured water productivity values found in the literature and outputs of previous studies. It appears very difficult to attribute differences in estimates from the various studies to specific factors; also it is difficult to assess the quality of our new estimates relative to the quality of earlier estimates. Our grid-based estimates of the water footprint of wheat production are better than the earlier national estimates as provided by Chapagain and Hoekstra (2004), but it is not possible to claim that they are better than the results from similar grid-based estimates as presented by Liu et al. (2009) and Siebert and Döll (2010). The quality of input data used defines the accuracy of the model output; all studies suffer the same sorts of limitations in terms of data availability and quality and deal with that in different ways. It has been observed that the model output is sensitive for example to the soil data and crop calendar, which are parameters about which no accurate data are available. A slight change in the planting date and length of cropping has a significant impact on the crop water footprint. In future studies it would be useful to spend more effort in structurally studying the sensitivity of the model outcomes to assumptions and parameters and assessing the uncertainties in the final outcome.

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Appendix I: Wheat cultivated area, yield and production average for the period 1996-2005 and fertilizer application rate and maximum yield.

Country	Area [ha][1]	Yield [ton/ha][1]	Production [ton/yr][1]	Irrigated area [ha][2]	Fertilizer application [kg/ha][3]	Maximum yield [ton/ha][4]
Afghanistan	2048700	1.27	2623200	856607	1	4.14
Albania	107074	2.85	301851	11200	73	4.30
Algeria	1677707	1.15	1980578	32802	7	1.84
Angola	2610	1.69	4400		192	5.01
Argentina	6084370	2.41	14624395	68921	25	3.96
Armenia	113391	2.08	235149	30168	15	4.30
Australia	11954440	1.83	21945711	97747	17	6.10
Austria	275390	5.07	1396875	2	64	9.00
Azerbaijan	544666	2.22	1228477	345494	12	5.68
Bangladesh	734976	2.08	1538912	342508	17	3.67
Belarus	360098	2.46	878427		136	4.30
Belgium	205590	8.35	1690342		151	9.00
Bhutan	7885	1.34	11059	1756	4	3.66
Bolivia	133583	0.94	124319		3	2.12
Bosnia and Herzegovina	89039	2.96	264341		31	4.30
Botswana	365	1.65	605			7.77
Brazil	1860247	1.85	3527680	1383	24	4.19
Bulgaria	1096256	2.86	3164797	49	107	3.63
Burundi	10450	0.81	8428		7	1.87
Cameroon	300	1.33	400	3	147	1.90
Canada	10390440	2.33	24182400	87591	46	5.54
Chad	1738	1.66	3057	1738		4.00
Chile	399580	4.10	1644663	111645	94	7.05
China	25993934	3.92	101715075	21749800	120	5.96
Colombia	20943	2.08	43630			2.40
Congo, DR	7289	1.28	9328		10	1.87
Croatia	209650	3.88	818983		72	4.30
Cyprus	5874	2.06	11686	567	96	2.24
Czech Republic	847678	4.65	3949259		105	7.30
Denmark	653259	7.18	4688225	43249	81	9.00
Ecuador	21776	0.72	15620	18997	6	3.34
Egypt	1052896	6.23	6563131	1029060	255	6.77
Eritrea	21355	0.51	12344		8	3.10
Estonia	65474	2.19	145202		80	4.30
Ethiopia	1113428	1.33	1492800	23162	8	3.05
Finland	159210	3.38	543280		9	5.33

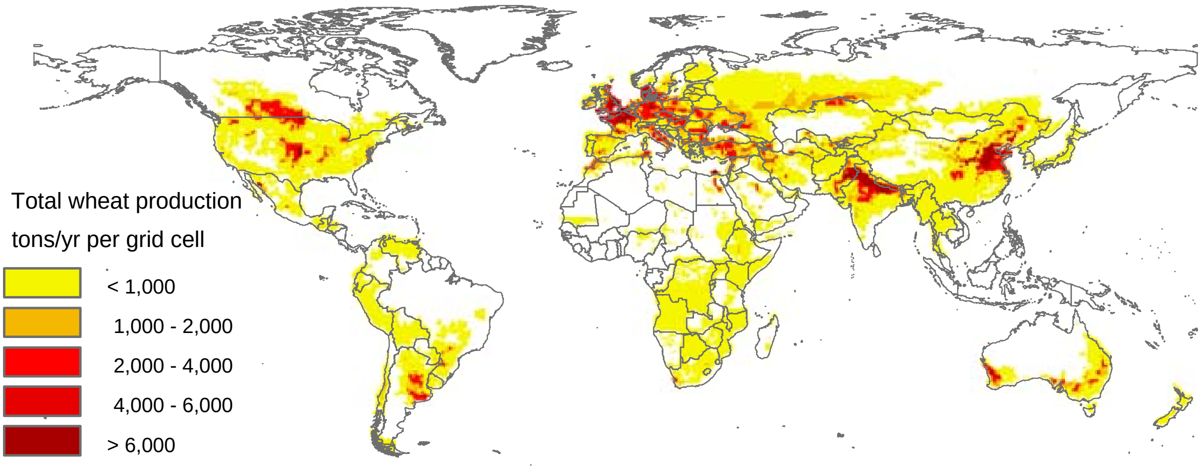
Country	Area [ha][1]	Yield [ton/ha][1]	Production [ton/yr][1]	Irrigated area [ha][2]	Fertilizer application [kg/ha][3]	Maximum yield [ton/ha][4]
France	5113580	7.06	36154101	32537	4	7.10
Georgia	112297	1.74	196675	17705	28	4.30
Germany	2885584	7.35	21220818		135	9.00
Greece	853316	2.41	2060055	32397	32	3.38
Guatemala	6331	1.98	12673		129	5.30
Honduras	1890	0.53	990		14	4.93
Hungary	1111733	3.89	4354400	6979	124	4.30
India	26285210	2.64	69445010	22832800	75	4.18
Iran	6040603	1.86	11300057	2227920	47	5.52
Iraq	1547700	0.91	1455840	717000	19	6.84
Ireland	89070	8.71	775580		70	9.00
Israel	75718	1.90	145365	1670	76	5.33
Italy	2326070	3.22	7483703	103759	59	6.83
Japan	187210	3.71	701060	57359	60	3.50
Jordan	23339	1.41	30824	7524	25	2.30
Kazakhstan	10707750	0.93	9977423	78601		4.30
Kenya	145311	2.01	294501		10	3.59
Korea, DPR	69127	1.97	138387	36049		5.77
Korea, Rep	2064	3.36	7009			4.74
Kuwait	201	2.27	410	173	237	5.33
Kyrgyzstan	468421	2.33	1090486	321672	4	4.30
Latvia	160187	2.81	453270		46	4.30
Lebanon	40633	2.51	103374	2042	1	4.63
Lesotho	20561	1.45	29560	2		4.20
Libya	164000	0.79	130040	45765	27	9.40
Lithuania	353540	3.25	1151070		14	4.30
Luxembourg	11273	6.00	67872		151	9.00
Madagascar	3700	2.37	8800		3	6.80
Malawi	2345	0.75	1763	1		0.87
Mali	2553	2.38	6160	2553	1	4.00
Malta	2208	4.01	8879		95	4.30
Mauritania	400	1.03	410			4.00
Mexico	678882	4.63	3134460	670092	85	5.30
Moldova	367155	2.34	893195	21977	32	4.30
Mongolia	231546	0.68	158141		8	5.77
Morocco	2872890	1.25	3654982	370931	13	4.94
Mozambique	1770	1.05	1870	39		2.20
Myanmar	92746	1.15	106882	25002		2.40
Namibia	1431	4.85	6994	1302	152	7.77
Nepal	658607	1.81	1194545	616490	9	2.60

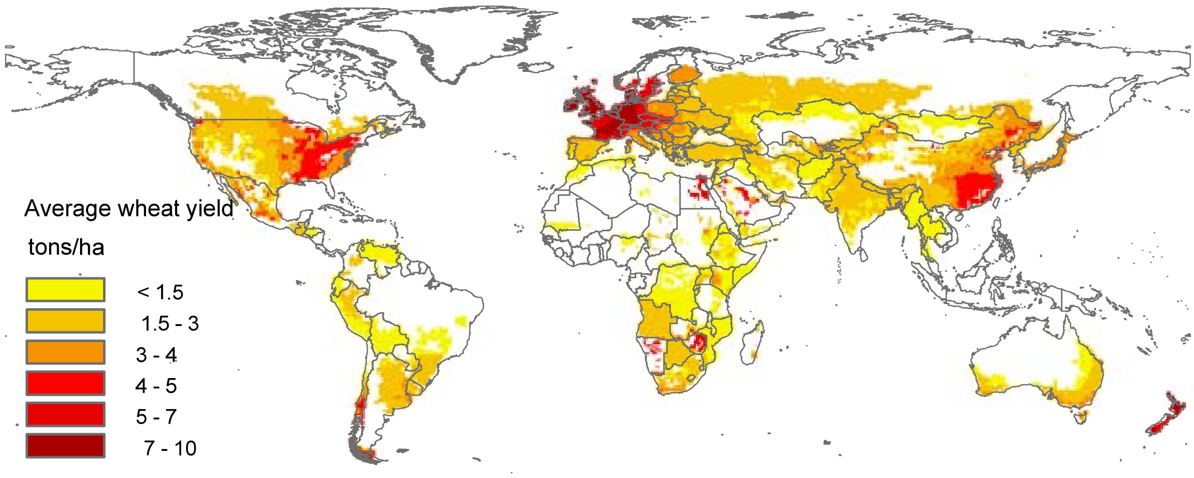
Country	Area [ha][1]	Yield [ton/ha][1]	Production [ton/yr][1]	Irrigated area [ha][2]	Fertilizer application [kg/ha][3]	Maximum yield [ton/ha][4]
Netherlands	132044	8.31	1097403		151	9.00
New Caledonia	18	1.86	34		136	4.00
New Zealand	47046	6.82	316604		117	6.10
Niger	4520	1.82	7886	3008	100	4.00
Nigeria	48020	1.53	67600	18940		4.00
Norway	67588	4.50	306063		15	5.33
Occ. Palestinian Territory	20034	1.83	37548	507		4.63
Oman	410	2.95	1199	331	191	4.63
Pakistan	8237950	2.29	18873370	7877620	95	3.17
Paraguay	229549	1.56	373088		28	2.29
Peru	131074	1.28	168182	3	166	1.80
Poland	2476301	3.60	8896854	4163	184	4.67
Portugal	200800	1.29	270544	25090	62	4.65
Qatar	31	2.32	72	24	195	6.20
Romania	2057399	2.58	5441640	114983	20	2.40
Russian Fed.	22244230	1.77	39644266	478602	14	3.74
Rwanda	12114	0.80	9672		5	1.87
Saudi Arabia	441425	4.73	2102918	440818	88	8.56
Serbia and Montenegro	665359	3.34	2240433		35	4.30
Slovakia	385590	4.02	1558150	6000	63	4.30
Slovenia	34658	4.30	149195	171	332	4.30
Somalia	2630	0.37	975	2000		3.10
South Africa	937380	2.30	2127458	216621	19	4.20
Spain	2196322	2.64	5777389	159164	71	5.55
Sudan	186966	2.10	387200	102690	26	3.00
Swaziland	202	1.51	305			9.90
Sweden	366246	5.95	2174060		81	9.00
Switzerland	93144	5.90	551510		125	9.00
Syria	1727742	2.35	4065933	686585	47	3.58
Tajikistan	324713	1.50	484441	62426	9	4.30
Tanzania, United Republic of	67779	1.31	87553			2.20
Thailand	1080	0.72	776			0.72
Macedonia, The fmr Yug Rep	111121	2.66	294742		14	4.30
Tunisia	847804	1.56	1336097	48894	17	2.36
Turkey	9317000	2.12	19723000	1004490	40	5.72
Turkmenistan	688000	2.46	1760800	288530		4.30
Uganda	7100	1.74	12300		66	3.60

Country	Area [ha][1]	Yield [ton/ha][1]	Production [ton/yr][1]	Irrigated area [ha][2]	Fertilizer application [kg/ha][3]	Maximum yield [ton/ha][4]
Ukraine	5732710	2.57	15239260	146119	20	3.50
United Arab Emirates	83	3.76	217	47	139	5.33
UK	1931500	7.77	15031500	3745	118	7.40
USA	21814022	2.75	59870774	1198520	55	5.54
Uruguay	173660	2.29	401750	400	37	3.70
Uzbekistan	1390439	3.02	4203371	458194		4.30
Venezuela	1018	0.37	381		48	2.18
Yemen	93246	1.42	132710	41030	15	1.50
Zambia	13487	6.27	84625	12199		6.93
Zimbabwe	42078	5.24	224800	42078	90	7.77

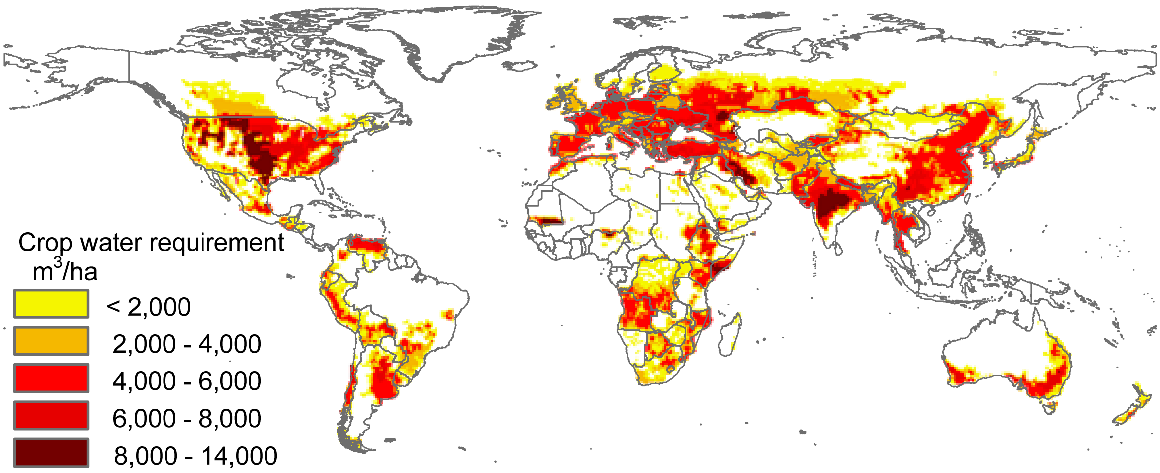
[1] Source: FAO (2008a).
[2] Source : Portman et al. (2008) with adjustment to the period of study.
[3] Based on Heffer (2009), FAO (2006, 200), IFA (2009).
[4] Source: Ekboir (2002) and Pingali (1999).

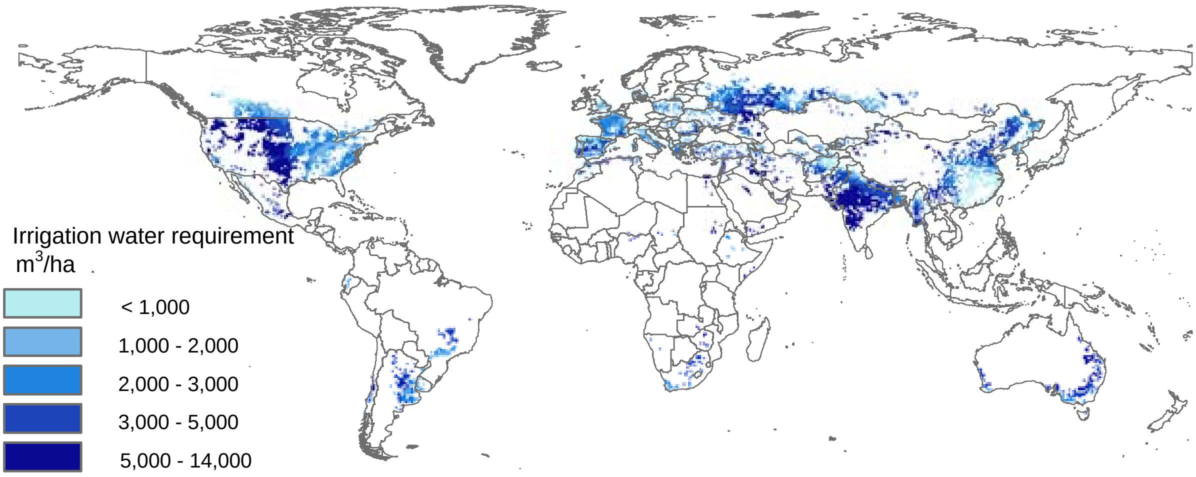
Appendix II: World wheat production and average yield (1996-2005).



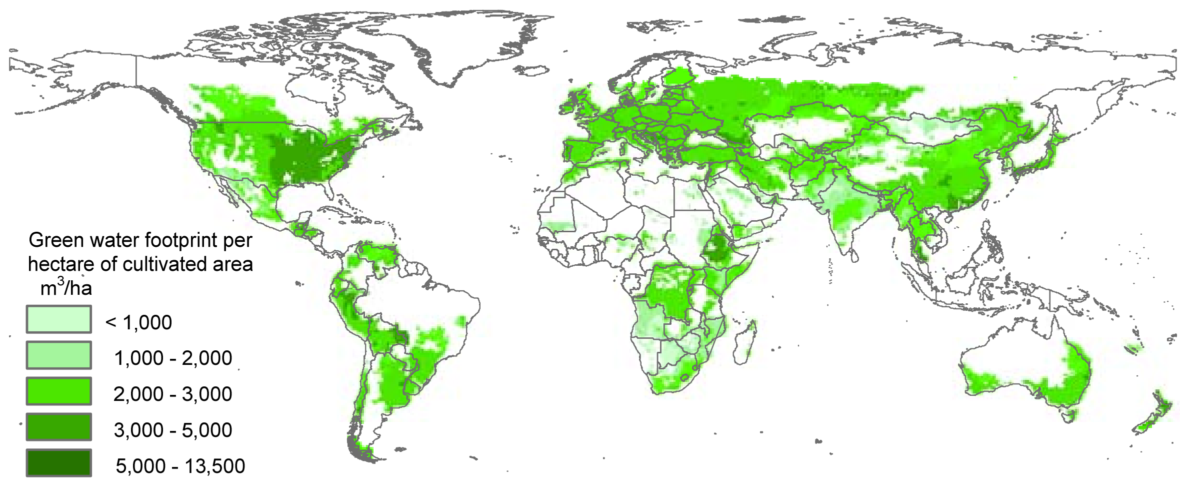


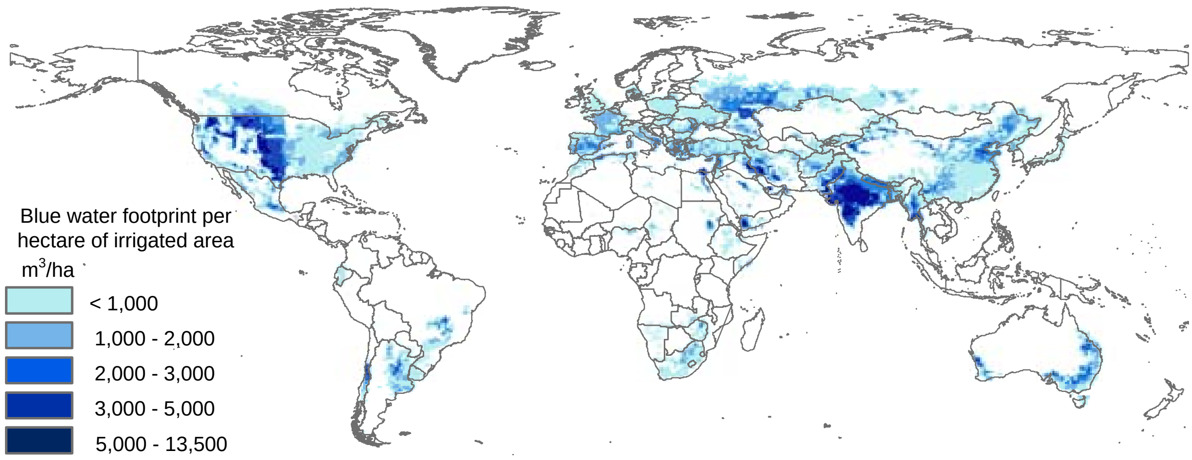
Appendix III: Crop and irrigation water requirements for wheat production in the world (1996-2005).



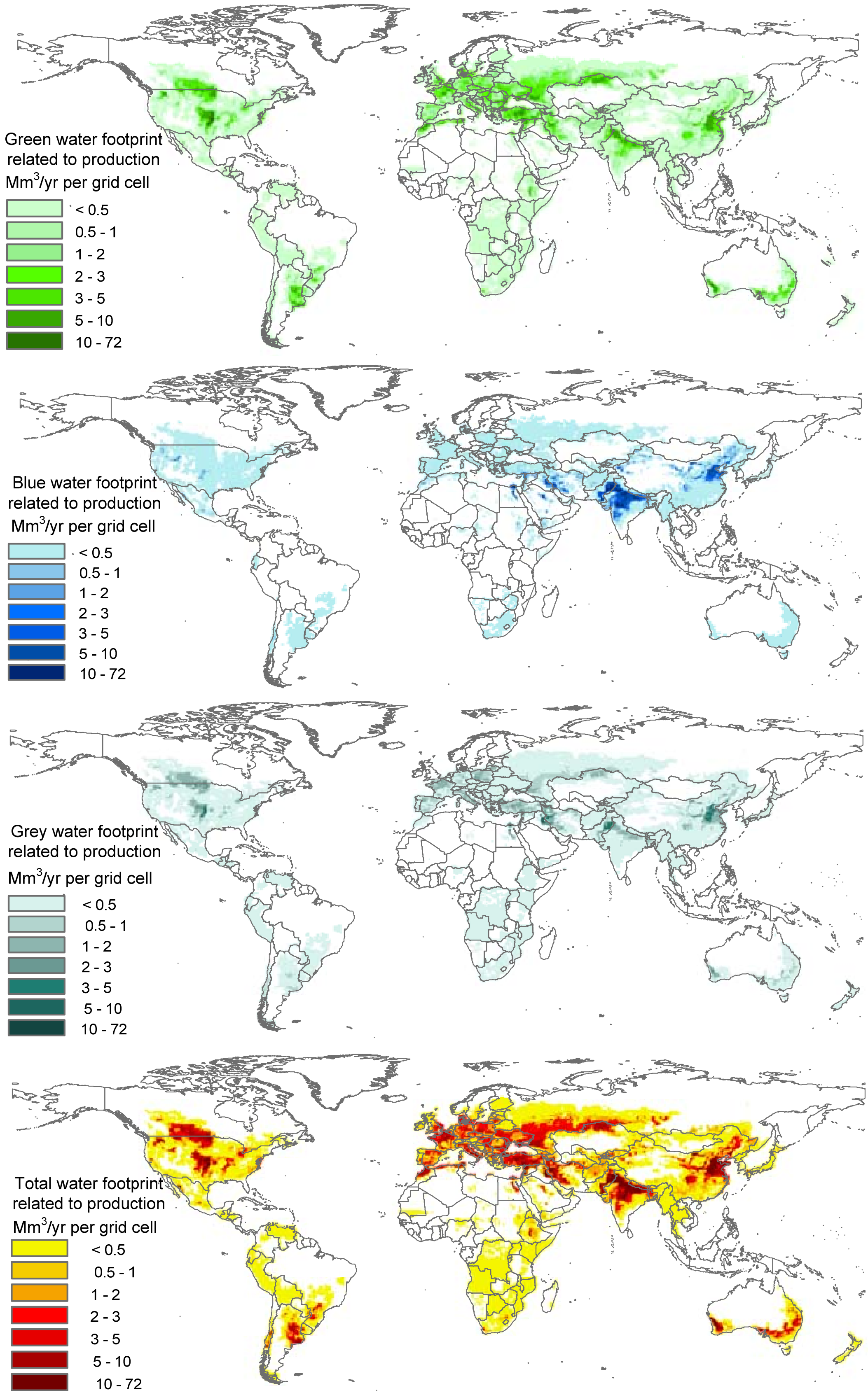


Appendix IV: Green and blue water footprint per hectare for wheat production in the world (1996-2005).

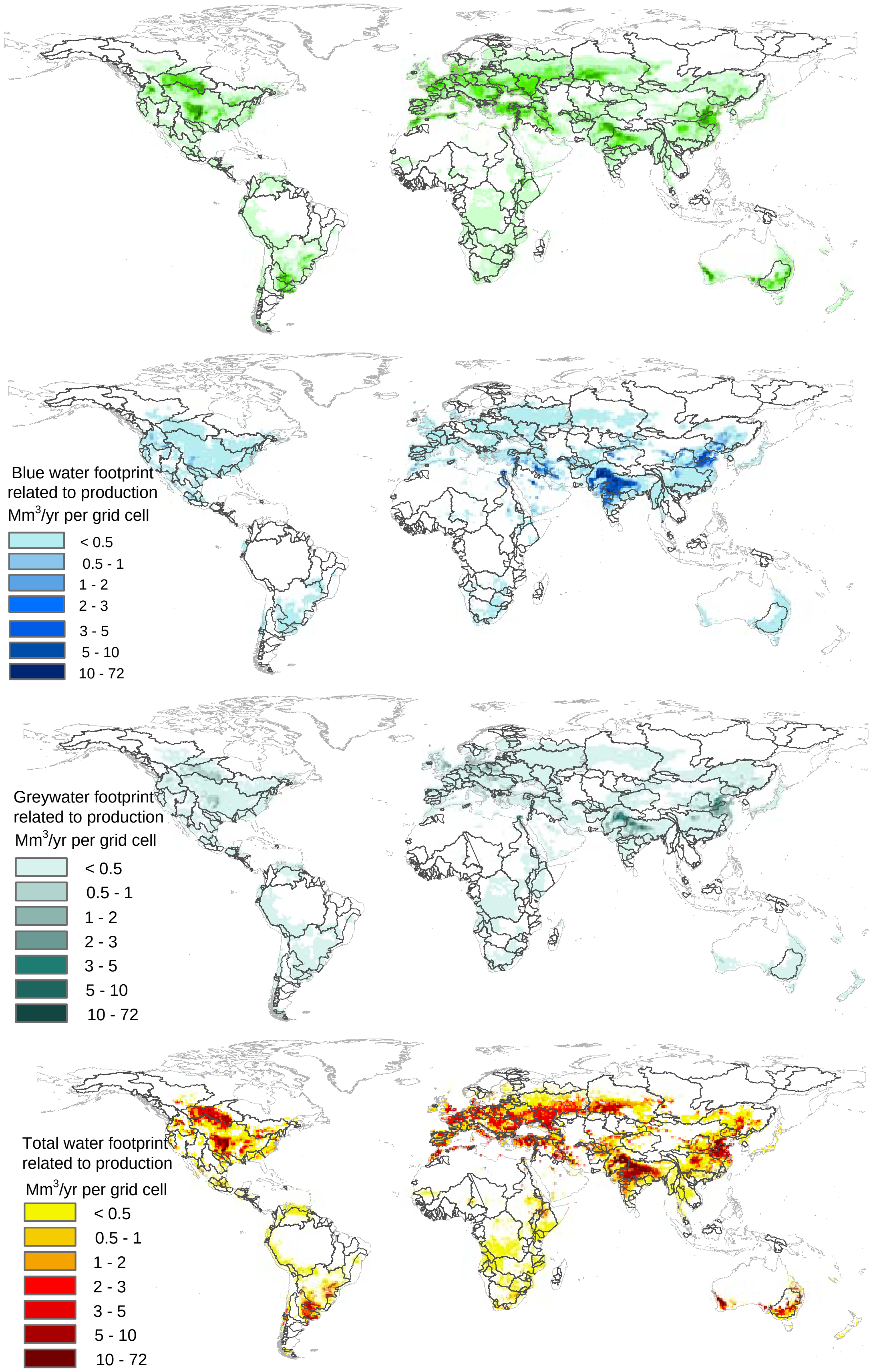




Appendix V: The water footprint of wheat production on a 5 by 5 arc minute grid in a global map showing country borders (1996-2005).



Appendix VI: The water footprint of wheat production on a 5 by 5 arc minute grid in a global map showing major river basins (1996-2005).



Appendix VII: The water footprint of wheat production per country (1996-2005).

Country	Contribution to global wheat production (%)	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
		Green	Blue	Grey	Total	Green	Blue	Grey	Total
Afghanistan	0.4	6060	1117	20	7197	2487	458	8	2953
Albania	0.1	335	4	79	418	1112	14	261	1388
Algeria	0.3	6516	129	115	6761	3529	70	62	3661
Angola	0.0	4	0	5	9	909	0	1182	2091
Argentina	2.5	25905	162	1601	27668	1777	11	110	1898
Armenia	0.0	241	8	17	266	1042	36	75	1152
Australia	3.7	44057	363	2246	46666	2130	18	109	2256
Austria	0.2	958	0	179	1137	691	0	129	820
Azerbaijan	0.2	1189	186	67	1442	1024	160	58	1242
Bangladesh	0.3	1573	521	125	2219	1036	343	82	1461
Belarus	0.1	1069	0	491	1559	1251	0	574	1825
Belgium	0.3	691	0	310	1001	404	0	182	586
Bhutan	0.0	24	3	0	28	2384	302	29	2715
Bolivia	0.0	689	0	4	693	5538	0	33	5571
Bosnia and Herzegovina	0.0	451	0	28	479	1741	0	109	1849
Botswana	0.0	0	0	0	0	671	0	0	671
Brazil	0.6	7018	3	476	7498	2084	1	141	2226
Bulgaria	0.5	4657	0	1180	5837	1532	0	388	1921
Burundi	0.0	43	0	1	44	5127	0	91	5218
Cameroon	0.0	1	0	0	1	2603	63	738	3404
Canada	4.1	32320	114	4852	37286	1358	5	204	1567
Chad	0.0	3	10	0	13	891	3144	19	4054
Chile	0.3	1677	350	431	2459	1035	216	266	1517
China	17.1	83459	47370	31626	162455	820	466	311	1597
Colombia	0.0	91	0	0	91	2088	0	0	2088
Congo, DR	0.0	32	0	1	33	3415	0	78	3493
Croatia	0.1	1039	0	152	1191	1294	0	189	1483
Cyprus	0.0	19	2	6	27	1679	143	496	2318
Czech Republic	0.7	2834	0	900	3734	726	0	231	957
Denmark	0.8	2486	30	533	3049	530	6	114	651
Ecuador	0.0	85	14	1	101	5521	935	87	6543
Egypt	1.1	1410	5930	2695	10034	216	907	412	1536
Eritrea	0.0	73	0	2	75	16285	0	404	16689
Estonia	0.0	250	0	52	302	1820	0	381	2201
Ethiopia	0.3	6282	28	90	6400	4290	19	61	4371
Finland	0.1	393	0	14	407	750	0	27	777

Country	Contribution to global wheat production (%)	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
		Green	Blue	Grey	Total	Green	Blue	Grey	Total
France	6.1	21014	48	199	21261	584	1	6	591
Georgia	0.0	610	20	31	662	3369	111	174	3654
Germany	3.6	12717	0	3914	16631	602	0	185	787
Greece	0.3	3062	59	277	3399	1494	29	135	1659
Guatemala	0.0	32	0	8	40	2559	0	651	3209
Honduras	0.0	7	0	0	7	7279	0	261	7540
Hungary	0.7	4078	8	1389	5476	973	2	331	1306
India	11.7	44025	81335	20491	145851	635	1173	296	2104
Iran	1.9	26699	10940	3208	40847	2412	988	290	3690
Iraq	0.2	4468	4103	315	8887	3803	3492	268	7563
Ireland	0.1	320	0	62	382	414	0	81	494
Israel	0.0	301	3	59	363	2690	30	530	3250
Italy	1.3	8890	120	1399	10409	1200	16	189	1405
Japan	0.1	756	3	112	871	1097	5	162	1264
Jordan	0.0	70	30	6	106	2199	959	185	3343
Kazakhstan	1.7	33724	241	1	33966	3604	26	0	3629
Kenya	0.0	439	0	20	460	1543	0	72	1615
Korea, DPR	0.0	256	41	0	297	2119	341	0	2460
Korea, Rep	0.0	10	0	0	10	1431	0	0	1431
Kuwait	0.0	0	1	0	2	928	2222	1124	4274
Kyrgyzstan	0.2	1628	683	18	2329	1495	627	17	2140
Latvia	0.1	626	0	73	699	1413	0	166	1579
Lebanon	0.0	161	10	0	171	1648	103	2	1753
Lesotho	0.0	67	0	0	67	2644	0	0	2645
Libya	0.0	567	201	45	813	4389	1553	351	6293
Lithuania	0.2	1447	0	49	1497	1283	0	44	1327
Luxembourg	0.0	30	0	10	41	971	141	240	1353
Madagascar	0.0	15	0	0	15	1695	0	13	1708
Malawi	0.0	6	0	0	6	3700	1	0	3701
Mali	0.0	6	10	0	16	1026	1787	5	2818
Malta	0.0	8	0	0	8	911	0	0	911
Mauritania	0.0	1	0	0	1	1409	0	0	1409
Mexico	0.5	1043	1750	579	3372	333	559	185	1077
Moldova	0.2	1638	50	117	1805	2514	77	179	2769
Mongolia	0.0	206	0	18	224	1335	0	115	1450
Morocco	0.6	10081	894	387	11362	3291	292	126	3710
Mozambique	0.0	3	0	0	3	1474	81	0	1556
Myanmar	0.0	211	76	0	287	2019	732	2	2753
Namibia	0.0	2	4	2	8	258	538	336	1132

Country	Contribution to global wheat production (%)	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
		Green	Blue	Grey	Total	Green	Blue	Grey	Total
Nepal	0.2	1547	2227	58	3832	1313	1891	50	3253
Netherlands	0.2	561	0	200	761	513	0	183	696
New Caledonia	0.0	0	0	0	0	1446	0	1280	2726
New Zealand	0.1	228	0	57	285	722	0	180	902
Niger	0.0	17	5	5	26	2567	698	685	3949
Nigeria	0.0	46	140	0	186	712	2169	0	2882
Norway	0.1	212	0	10	222	699	0	34	732
Occ. Palestinian Terr.	0.0	78	1	0	79	2396	28	0	2424
Oman	0.0	1	2	1	4	845	1944	665	3454
Pakistan	3.2	12083	27733	8000	47816	644	1478	426	2548
Paraguay	0.1	828	0	65	893	2452	0	194	2646
Peru	0.0	589	0	252	841	3526	0	1510	5036
Poland	1.5	9922	4	4591	14517	1120	0	518	1639
Portugal	0.0	921	49	128	1097	3989	212	553	4754
Qatar	0.0	0	0	0	0	674	1616	828	3118
Romania	0.9	9066	247	428	9741	1799	49	85	1933
Russian Federation	6.7	91117	1207	3430	95754	2359	31	89	2479
Rwanda	0.0	51	0	1	52	5433	0	67	5500
Saudi Arabia	0.4	501	2299	389	3189	242	1110	188	1539
Serbia and Montenegro	0.4	3309	0	0	3309	1538	0	0	1538
Slovakia	0.3	1452	6	247	1705	956	4	162	1123
Slovenia	0.0	168	0	116	284	1142	1	786	1928
Somalia	0.0	8	10	0	18	8365	10365	0	18730
South Africa	0.4	2213	488	209	2910	1042	230	98	1370
Spain	1.0	8053	275	1615	9943	1441	49	289	1779
Sudan	0.1	255	445	50	750	678	1181	132	1991
Swaziland	0.0	1	0	0	1	2161	1	0	2162
Sweden	0.4	1016	0	296	1312	467	0	136	603
Switzerland	0.1	383	0	117	500	701	0	214	915
Syria	0.7	5913	1790	842	8544	1511	457	215	2184
Tajikistan	0.1	780	30	29	839	1693	66	62	1820
Tanzania	0.0	282	0	0	282	3215	0	0	3215
Thailand	0.0	3	0	0	3	4189	0	0	4189
Macedonia,The Fmr Yug Rp	0.0	414	0	16	430	1433	0	55	1488
Tunisia	0.2	3173	96	146	3415	2489	75	115	2679

Country	Contribution to global wheat production (%)	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
		Green	Blue	Grey	Total	Green	Blue	Grey	Total
Turkey	3.3	40898	2570	3857	47325	2081	131	196	2408
Turkmenistan	0.3	1841	393	0	2234	1309	279	0	1588
Uganda	0.0	19	0	6	25	1525	0	470	1995
Ukraine	2.6	26288	287	1149	27724	1884	21	82	1987
United Arab Emirates	0.0	0	0	0	1	1456	473	641	2569
UK	2.5	6188	2	2292	8482	413	0	153	566
USA	10.1	111926	5503	13723	131152	1879	92	230	2202
Uruguay	0.1	775	0	64	839	2130	1	176	2307
Uzbekistan	0.7	3713	399	0	4112	939	101	0	1039
Venezuela	0.0	3	0	1	4	8189	0	1494	9682
Yemen	0.0	239	313	14	566	1829	2388	107	4324
Zambia	0.0	16	59	0	75	184	706	0	891
Zimbabwe	0.0	45	186	38	270	211	864	177	1252
World	100.0	760301	203744	123533	1087578	1279	343	208	1830

Appendix VIII: The water footprint of wheat production for the world's major river basins (1996-2005).

River basins	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Ganges-Brahmaputra-Meghna	40983	42315	12653	95950	900	929	278	2107
Mississippi	79783	2041	9413	91236	1986	51	234	2271
Indus	30327	34715	13326	78368	799	915	351	2066
Ob	52045	165	511	52721	2683	9	26	2718
Nelson-Saskatchewan	38535	68	5691	44294	1277	2	189	1468
Tigris-Euphrates	30374	9127	2670	42170	3007	904	264	4175
Hwang Ho	20794	9346	7592	37731	849	382	310	1541
Danube	27945	212	3579	31735	1301	10	167	1477
Volga	25134.4	215.7	955.0	26305.1	2321	20	88	2429
Don	24916.2	301.7	926.6	26144.5	2667	32	99	2799
Yangtze	18324.7	1811.5	4854.7	24991.0	1169	116	310	1594
Murray-Darling	20718	298	987	22003	2065	30	98	2193
La Plata	17142	59	1070	18271	2040	7	127	2175
Amur	9720	2141	2355	14216	1097	242	266	1604
Dnieper	13235.1	51.7	813.5	14100.3	1734	7	107	1847
Columbia	7439	1676	1122	10236	1904	429	287	2620
Oral	9363.5	68.2	191.8	9623.6	2549	19	52	2620
Liao	5232.5	2471.0	1785.9	9489.4	869	410	296	1575
Narmada	2583.5	5057.3	657.7	8298.5	1298	2541	330	4170
Nile	3337	3466	1425	8229	778	808	332	1918
Aral Sea (internal drainage)	7595.1	546.8	62.5	8204.5	1292	93	11	1396
Vistula	5850.6	0.8	2248.6	8100.0	1163	0	447	1610
Elbe	5869	0	1868	7737	667	0	212	879
Oder (Odra)	5290.0	1.0	2390.2	7681.2	1081	0	489	1570
Seine	6286.2	8.1	66.9	6361.1	548	1	6	555
Godavari	1854	3567	488	5910	1303	2507	343	4152
Loire	5179	8	49	5236	592	1	6	599
Kura-Araks	4529.9	232.4	428.6	5190.9	1447	74	137	1658
Rhine	3965.5	0.1	1037.7	5003.2	587	0	154	740
Kizil	4330	118	421	4869	1972	54	192	2218
St. Lawrence	4404.9	9.0	455.2	4869.1	1597	3	165	1766
Tarim	1522	2436	616	4574	691	1107	280	2078
Yenisey (Jenisej)	4134.5	28.6	154.4	4317.5	2183	15	82	2280
Dniester	4045.0	31.7	195.8	4272.4	1712	13	83	1808
Asi	3088	404	323	3815	1894	248	198	2340

River basins	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Rio Salado	3345.2	2.5	195.2	3542.9	1572	1	92	1665
Maritsa	2996.5	54.8	444.6	3495.9	1785	33	265	2082
Krishna	1100	2040	336	3477	1109	2057	339	3505
Helmand	2230	617	18	2864	2604	721	21	3345
Hari (Harirud)	2178	567	95	2839	1761	458	76	2296
Medjerda	2590	40	98	2728	2471	38	93	2603
Douro (Duero)	2240	31	436	2707	1412	20	275	1706
Brazos	2021	289	234	2545	2228	319	258	2805
Kel kit	2166	64	204	2434	1855	55	175	2085
Ebro	1985	58	363	2406	1491	44	273	1807
Weser	1809	0	569	2377	574	0	181	755
Hsi	1368	331	370	2069	1259	305	340	1904
Ili (Kunes He)	1195	646	206	2047	1176	635	203	2014
Po	1614	12	261	1888	969	7	157	1134
Rhone	1737	3	45	1785	648	1	17	666
Guadiana	1427	58	245	1730	2240	91	384	2715
Neman	1481	0	212	1693	1294	0	186	1480
Awash	1647	9	24	1680	3902	22	56	3981
Juba-Shibeli	1621	28	29	1678	3871	66	70	4007
Murgab	1576	86	4	1665	1955	107	4	2066
Garonne	1624	6	14	1644	702	3	6	711
Lake Turkana	1577	4	21	1602	4075	11	55	4141
Terek	1393	114	38	1545	2815	231	76	3122
Mackenzie	1303	0	223	1526	1052	0	180	1232
Guadalquivir	1212	28	273	1513	1129	26	254	1409
Tapti	458	772	126	1356	1380	2328	380	4089
Schelde	1153	0	191	1345	468	0	77	545
Atrek	728	433	110	1270	1624	965	244	2833
Orange	957	203	93	1253	1349	287	131	1767
Jordan	789	156	95	1040	2085	411	250	2746
Tagus (Tejo)	856	20	145	1020	2047	47	346	2440
Vardar	880	4	48	932	1461	7	80	1547
Colorado River	722	100	92	915	2636	366	338	3339
Amazon	764	0	111	875	4084	1	593	4678
Santiago-Lerma-Chapala	424	223	110	757	705	371	183	1259
Amu Darya	693	47	2	743	2276	155	7	2438
Mahanadi	226	396	75	697	1271	2227	422	3920
Red	352	188	111	651	1166	621	367	2154
Sacramento	330	194	54	579	951	559	157	1667

River basins	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Colorado	298	196	75	570	808	532	204	1544
Atrak	408	29	49	486	2442	173	295	2910
Struma	402	6	55	463	1482	20	204	1706
Daugava	347	0	96	444	1288	0	357	1645
Rio Colorado	396	7	28	431	1672	29	117	1817
Mekong	226	112	63	402	1314	651	367	2332
Lielupe	363	0	26	388	1325	0	94	1418
Rio Grande	146	175	37	358	798	961	205	1964
Negro-Argentina	331	2	24	357	1727	8	125	1861
Irrawaddy	236	91	14	341	1654	636	97	2386
Coruh	294	3	27	323	1601	16	146	1763
Kogilnik	299	0	17	316	1981	1	112	2094
Drin	295	0	11	307	1357	0	52	1409
Yaqui	131	105	64	299	379	303	184	866
Zambezi	122	148	22	291	558	675	98	1332
Narva	254	0	35	289	1732	0	239	1971
Balsas	129	119	30	278	793	734	186	1712
Sasquehanna	252	0	22	273	1577	0	136	1713
Si	192	21	46	259	1312	146	312	1770
Kowl-E-Namaksar	130	106	18	254	1698	1388	233	3318
Salween	154	57	36	248	1412	525	333	2269
Pu-Lun-T'o	107	89	48	244	729	611	329	1669
Tumen	167	15	47	229	969	87	275	1331
Sulak	213	3	6	222	2855	42	77	2974
Lava (Pregel)	195	0	23	218	1844	1	218	2063
Limpopo	95	104	10	209	639	703	71	1412
Valdivia	144	22	35	201	861	131	209	1201
Lake Chad	59	136	1	196	862	2001	15	2878
Nahr El Kebir	159	6	18	182	1623	57	186	1867
Mius	167	0	7	174	2201	4	89	2294
L-Prespa	142	1	29	172	1126	4	228	1358
Bio Bio	121	15	28	164	872	107	202	1181
Gash	144	9	3	157	4750	310	104	5164
An Nahr Al Kabir	128	11	12	152	1620	140	155	1916
Venta	139	0	10	149	1274	0	93	1366
Nestos	125	1	12	139	1427	16	142	1585
Panuco	45	70	14	128	612	962	188	1761
Sabi	41	63	18	122	384	601	167	1152
N. Dvina	110	0	4	114	1986	0	71	2057
Olifants	93	12	7	112	819	106	60	985

River basins	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Glama	99	0	5	104	646	0	33	679
Wiedau	82	1	19	102	516	3	120	639
Alabama	91	0	9	101	1269	0	128	1397
Vijose	82	0	17	100	1151	3	243	1398
Min	81	1	15	96	1624	20	292	1936
Gauja	85	0	11	96	1375	0	175	1550
Sujfun	72	5	16	93	1137	81	254	1471
Sarata	83	1	5	89	1941	18	111	2070
Dasht	22.1	48.0	10.4	80.5	864	1878	408	3150
Lake Natron	80	0	0	80	2650	0	12	2662
Ting	63	1	13	77	1441	26	293	1761
Lake Titicaca-Poopo System	58	0	12	70	4248	0	857	5105
Samur	66	1	2	69	2740	26	81	2847
Congo	64	0	3	67	3970	0	156	4126
Savannah	56	0	6	62	1307	5	143	1456
Yalu	49.9	5.9	5.2	61.0	1377	164	142	1683
Oued Bon Naima	51	8	2	61	2355	359	87	2801
Vuoksa	58	0	2	60	709	0	26	735
Dra	39.2	17.6	2.1	58.8	2410	1081	127	3618
Elancik	56	0	2	58	2238	4	91	2332
Magdalena	58	0	0	58	2125	0	0	2125
Lake Ubsa-Nur	52	0	3	55	1794	5	95	1895
Song Hong	28	17	9	54	1112	679	353	2144
Neretva	49.8	0.0	3.1	52.9	1760	0	111	1871
Yser	42	0	7	50	438	0	78	516
Rufiji	47	0	0	47	3247	0	0	3247
Niger	28.4	14.6	3.6	46.6	1687	869	212	2767
Parnu	37	0	8	45	1727	0	361	2089
Mino	37	0	6	44	1193	0	206	1399
Tana-Kenya	41	0	2	43	1733	0	97	1830
Lotagipi Swamp	33	0	3	36	1416	0	112	1528
Klamath	22.5	5.1	3.3	31.0	1167	267	173	1606
Barta	27.4	0.0	2.1	29.5	1328	0	104	1432
Krka	26	0	4	29	1406	0	193	1600
Karnaphuli	24.0	0.3	3.3	27.5	1467	16	199	1682
Daoura	19	2	1	22	2781	358	123	3261
Isonzo	13	0	8	21	1049	0	607	1657
Han	20	1	0	21	1921	68	0	1989
Orinoco	19	0	2	21	3069	0	273	3342

River basins	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Sittang	15	5	0	21	2069	722	0	2792
Sao Francisco	17.6	0.8	2.1	20.5	3420	157	407	3984
Prohladnaja	18.4	0.0	1.1	19.6	2019	1	125	2145
Grijalva	11.3	5.2	3.0	19.5	1345	614	360	2320
Saint John	18	0	2	19	1652	0	169	1821
Wadi Al Izziyah	17	0	2	19	1967	10	192	2169
Mira	14.2	0.4	0.2	14.8	4220	130	45	4395
Bann	9.7	0.0	3.8	13.5	361	0	141	502
Patia	13.1	0.1	0.0	13.2	2070	19	2	2091
Oulu	12.5	0.0	0.5	13.0	681	0	26	706
Meuse	9	0	3	13	534	0	188	722
Baraka	12.0	0.4	0.3	12.7	4914	174	130	5218
Motaqua	10.0	0.0	2.3	12.3	2707	0	631	3338
Dalalven	9	0	3	12	426	0	130	556
Ural	11	0	0	11	4803	0	0	4803
Chira	7	0	3	10	3232	33	1300	4565
Groot	9.0	0.3	0.5	9.9	1001	39	56	1096
Salaca	8.5	0.0	1.0	9.6	1355	0	165	1520
Astara Chay	8.3	0.1	1.1	9.4	1698	11	222	1931
Gallegos-chico	7.1	0.0	1.5	8.6	876	0	190	1066
Pearl	7.6	0.0	0.7	8.3	1495	0	132	1628
Kaladan	7.3	0.3	0.0	7.7	2575	122	17	2715
Lima	6.0	0.0	0.9	6.9	1452	0	221	1672
Tocantins	5.9	0.3	0.7	6.8	3539	151	402	4092
Tijuana	5	0	1	7	672	31	190	893
Hudson	6	0	1	7	1422	0	132	1554
Lagoon Mirim	6	0	0	6	1464	1	120	1584
Lempa	6	0	1	6	4803	0	451	5255
Skagit	5	0	1	6	1258	4	127	1389
Fraser	5	0	1	6	1798	16	221	2035
Har Us Nur	5	0	0	6	1375	0	104	1480
Muga	5	0	1	6	1408	49	258	1715
Fenney	4	1	0	5	1213	304	158	1675
Velaka	4	0	1	5	1592	0	386	1978
Papaloapan	2	2	0	5	673	883	185	1741
Yelcho	3	0	1	3	969	0	194	1163
Palena	3	0	1	3	992	0	188	1180
Umba	3	0	0	3	2757	0	44	2801
Maputo	3	0	0	3	1705	51	86	1841
Erne	2	0	1	3	368	0	100	467

River basins	Production water footprint (Mm^3/yr)				Water footprint per ton of wheat (m^3/ton)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Okavango	1	1	1	3	315	676	470	1461
Seno Union (Serrano)	2	0	1	3	1004	0	289	1293
Foyle	2	0	1	2	347	0	133	480
Incomati	1	1	0	2	860	565	55	1480
Tumbes	1	0	0	2	3234	159	954	4347
Rio Grande-Argentina-Chile	1	0	0	2	622	0	195	817
Puelo	2	0	0	2	920	1	210	1130
W. Dvina	2	0	0	2	1461	0	174	1635
Klaralven	1	0	0	2	468	0	116	584
Zarumilla	1	0	0	2	3345	434	842	4622
Rezvaya	1	0	0	2	1855	0	200	2054
Bidasoa	1	0	0	2	1123	0	186	1310
Kwanza	1	0	1	1	954	0	1209	2163
Syr Darya	1	0	0	1	1829	0	20	1849
Paz	1	0	0	1	2465	0	643	3108
Buzi	0	0	0	1	537	455	157	1149
Lena	1	0	0	1	2285	0	105	2390
Roia	1	0	0	1	660	0	30	690
Pakchan	1	0	0	1	3300	400	0	3700
Kunene	0	0	0	1	851	0	1124	1976
San Martin	1	0	0	1	639	0	183	822
Chao Phraya	1	0	0	1	4294	0	0	4294
Castletown	1	0	0	1	382	0	123	505
Cullen	0	0	0	1	732	0	204	936
Fane	0	0	0	1	407	0	92	499
Choluteca	1	0	0	1	7626	0	277	7903
Coatan Achute	0	0	0	1	925	675	251	1851
Cancoso (Lauca)	1	0	0	1	8371	0	78	8449

Appendix IX: Virtual water import and export per country related to trade in wheat products (1996-2005).

Countries	Virtual water import (Mm^3/yr)				Virtual water export (Mm^3/yr)				Net virtual water import (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Afghanistan	719.6	297.5	91.2	1108	0.0	0.0	0.0	0	719.6	297.5	91.2	1108
Albania	470.0	11.6	48.0	530	0.1	0.0	0.0	0	469.9	11.6	48.0	530
Algeria	5330.5	323.0	696.4	6350	106.6	2.1	1.9	111	5223.9	320.9	694.6	6239
Andorra	3.5	0.1	0.6	4	0.0	0.0	0.0	0	3.5	0.1	0.6	4
Angola	183.5	10.2	32.6	226	0.9	0.0	1.2	2	182.6	10.2	31.4	224
Antigua and Barbuda	4.4	1.2	0.7	6	2.2	0.6	0.3	3	2.2	0.6	0.4	3
Argentina	8.3	0.2	1.7	10	15973	99.7	987.3	17060	-15965	-99.5	-985.6	-17050
Armenia	477.8	20.5	54.5	553	0.1	0.0	0.0	0	477.7	20.5	54.5	553
Aruba	14.1	1.9	2.1	18	0.0	0.0	0.0	0	14.1	1.9	2.1	18
Australia	18.9	1.2	6.2	26	24397	200.8	1244.1	25841	-24378	-199.5	-1237.9	-25815
Austria	141.4	0.5	41.3	183	394.2	0.0	73.7	468	-252.8	0.5	-32.4	-285
Azerbaijan	1811.3	24.9	37.6	1874	1.0	0.2	0.1	1	1810.3	24.7	37.6	1873
Bahamas	10.4	0.4	1.3	12	0.6	0.2	0.1	1	9.8	0.2	1.2	11
Bahrain	65.7	18.2	9.5	93	3.6	1.0	0.6	5	62.1	17.2	8.9	88
Bangladesh	1627.5	545.9	271.7	2445	0.1	0.0	0.0	0	1627.4	545.9	271.7	2445
Barbados	39.7	2.3	5.0	47	4.2	1.1	0.7	6	35.5	1.2	4.3	41
Belarus	1072.2	9.6	53.6	1135	0.9	0.0	0.4	1	1071.2	9.6	53.2	1134
Belgium	2471.0	20.5	294.3	2786	749.7	111.9	219.2	1081	1721.3	-91.4	75.1	1705
Belize	29.8	1.7	3.8	35	0.0	0.0	0.0	0	29.8	1.7	3.8	35
Benin	27.9	1.2	1.9	31	1.8	0.5	0.3	3	26.1	0.7	1.6	28
Bermuda	113.1	2.1	5.2	120	4.0	1.1	0.7	6	109.0	1.0	4.5	115
Bhutan	4.0	7.0	1.8	13	2.5	0.3	0.0	3	1.5	6.7	1.8	10
Bolivia	510.8	9.1	43.1	563	0.0	0.0	0.0	0	510.7	9.1	43.1	563
Bosnia and Herzegovina	416.4	7.2	80.4	504	11.6	0.0	0.7	12	404.8	7.2	79.7	492
Botswana	25.0	2.6	2.4	30	0.3	0.0	0.0	0	24.7	2.6	2.4	30
British Virgin Islands	58.0	1.2	2.8	62	8.1	2.1	1.3	12	49.9	-0.9	1.5	50
Brazil	11415	88.0	801.2	12304	309.0	0.1	21.0	330	11106	87.9	780.2	11974
Brunei Darussalam	23.6	6.0	3.7	33	0.0	0.0	0.0	0	23.6	6.0	3.7	33
Bulgaria	145.3	3.0	16.6	165	746.7	0.0	189.3	936	-601.4	3.0	-172.7	-771
Burkina Faso	32.2	2.6	2.7	37	2.0	0.5	0.3	3	30.3	2.0	2.3	35
Burundi	7.7	0.8	0.7	9	0.2	0.0	0.0	0	7.5	0.8	0.7	9
Cambodia	18.3	1.0	1.1	20	0.2	0.0	0.0	0	18.1	1.0	1.1	20
Cameroon	204.1	2.3	19.1	225	3.4	0.1	1.0	4	200.7	2.3	18.2	221
Canada	172.0	6.6	17.0	196	24144	85.4	3624.5	27854	-23972	-78.8	-3607.5	-27658

Countries	Virtual water import (Mm³/yr)				Virtual water export (Mm³/yr)				Net virtual water import (Mm³/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Cape Verde	14.2	0.9	1.9	17	0.0	0.0	0.0	0	14.2	0.9	1.9	17
Cayman Islands	34.2	0.1	2.3	37	0.0	0.0	0.0	0	34.2	0.1	2.3	37
Central African Rep.	10.6	0.3	0.7	12	0.0	0.0	0.0	0	10.6	0.3	0.7	12
Chad	28.1	0.9	2.2	31	0.0	0.0	0.0	0	28.1	0.9	2.2	31
Chile	471.2	7.4	54.6	533	2.4	0.5	0.6	4	468.8	6.9	54.0	530
China	4087.5	97.6	453.0	4638	492.4	279.5	186.8	959	3595.0	-181.9	266.2	3679
Colombia	1587.7	52.9	199.1	1840	14.4	0.0	0.0	14	1573.3	52.9	199.1	1825
Comoros	4.5	0.5	0.5	6	0.0	0.0	0.0	0	4.5	0.5	0.5	6
Congo, Rep	143.1	6.0	13.5	163	1.3	0.3	0.2	2	141.8	5.7	13.3	161
Congo, DR	213.3	15.4	24.8	254	0.0	0.0	0.0	0	213.3	15.4	24.8	254
Costa Rica	540.7	26.1	68.6	635	15.7	4.2	2.5	22	525.0	21.9	66.1	613
Côte d'Ivoire	199.2	2.1	13.3	215	3.9	1.0	0.6	6	195.3	1.1	12.7	209
Croatia	57.3	0.5	10.7	68	144.4	0.0	21.1	166	-87.2	0.5	-10.4	-97
Cuba	864.8	20.7	83.9	969	0.3	0.1	0.0	0	864.5	20.6	83.9	969
Cyprus	152.4	3.9	17.0	173	10.5	0.9	3.1	15	141.9	3.0	13.9	159
Czech Republic	47.3	0.1	10.6	58	261.6	0.0	83.1	345	-214.3	0.1	-72.5	-287
Denmark	268.8	1.3	62.2	332	358.0	4.3	76.8	439	-89.2	-2.9	-14.6	-107
Djibouti	143.4	11.3	18.8	173	5.4	1.5	0.9	8	137.9	9.9	17.9	166
Dominica	5.7	1.5	0.9	8	0.5	0.1	0.1	1	5.2	1.4	0.8	7
Dominican Republic	561.3	28.1	70.2	660	0.8	0.2	0.1	1	560.5	27.9	70.1	658
Ecuador	708.4	19.8	90.4	819	22.9	3.9	0.4	27	685.5	15.9	90.1	792
Egypt	6837.9	273.9	633.4	7745	1.5	6.5	2.9	11	6836.3	267.4	630.4	7734
El Salvador	409.5	18.7	51.7	480	21.2	5.7	3.4	30	388.3	13.1	48.3	450
Equatorial Guinea	9.2	0.1	0.5	10	0.0	0.0	0.0	0	9.2	0.1	0.5	10
Eritrea	239.9	19.0	27.3	286	6.2	0.0	0.2	6	233.7	19.0	27.1	280
Estonia	98.4	0.9	9.0	108	24.1	0.0	5.0	29	74.4	0.9	3.9	79
Ethiopia	761.7	45.9	99.7	907	2.2	0.0	0.0	2	759.4	45.9	99.7	905
Faeroe Islands	1.8	0.0	0.5	2	0.1	0.0	0.0	0	1.6	0.0	0.4	2
Fiji Islands	161.2	1.7	8.9	172	4.7	1.2	0.7	7	156.5	0.4	8.2	165
Finland	118.3	1.0	24.2	144	28.9	0.0	1.0	30	89.5	1.0	23.2	114
French Polynesia	18.4	0.2	1.2	20	0.1	0.0	0.0	0	18.4	0.2	1.2	20
France	585.3	21.7	139.0	746	9347.0	21.4	88.5	9457	-8761.7	0.3	50.5	-8711
Gabon	40.5	0.5	1.7	43	0.0	0.0	0.0	0	40.5	0.5	1.7	43
Gambia	19.0	1.6	3.4	24	0.1	0.0	0.0	0	19.0	1.6	3.4	24
Georgia	1034.3	27.6	56.6	1118	102.8	3.4	5.3	111	931.5	24.2	51.3	1007

Countries	Virtual water import (Mm^3/yr)				Virtual water export (Mm^3/yr)				Net virtual water import (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Germany	1089.4	12.8	163.4	1266	3536.5	0.0	1089.9	4626	-2447.1	12.8	-926.5	-3361
Ghana	421.6	15.7	47.1	484	2.5	0.7	0.4	4	419.1	15.0	46.7	481
Gibraltar	12.2	0.2	0.5	13	0.0	0.0	0.0	0	12.2	0.2	0.5	13
Greece	999.2	16.3	108.0	1123	578.4	11.2	52.4	642	420.8	5.0	55.6	481
Greenland	0.7	0.0	0.2	1	0.0	0.0	0.0	0	0.7	0.0	0.2	1
Grenada	19.4	1.2	2.4	23	7.9	2.1	1.3	11	11.6	-0.9	1.1	12
Guatemala	593.7	26.2	79.6	700	15.6	0.0	4.0	20	578.1	26.2	75.6	680
Guinea	83.1	2.2	4.3	90	2.5	0.6	0.4	4	80.7	1.6	3.9	86
Guinea-Bissau	7.3	0.3	0.6	8	0.0	0.0	0.0	0	7.3	0.3	0.6	8
Guyana	66.6	3.2	8.3	78	3.4	0.9	0.5	5	63.2	2.3	7.7	73
Haiti	358.0	17.7	44.7	420	0.0	0.0	0.0	0	358.0	17.7	44.7	420
Honduras	221.1	11.9	27.4	260	28.5	0.0	1.0	30	192.6	11.9	26.4	231
Hungary	13.0	0.1	2.3	15	1034.6	2.0	352.4	1389	-1021.6	-2.0	-350.1	-1374
Iceland	21.1	0.5	3.9	25	0.4	0.1	0.1	1	20.6	0.4	3.8	25
India	957.8	17.3	66.0	1041	1265.8	2338.5	589.1	4193	-308.0	-2321	-523.2	-3152
Indonesia	6511.7	363.9	577.0	7453	21.8	5.7	3.5	31	6489.8	358.1	573.5	7422
Iran	6105.2	60.1	504.3	6670	7.4	3.0	0.9	11	6097.9	57.1	503.4	6658
Iraq	1620.3	119.4	147.7	1887	136.7	125.6	9.6	272	1483.5	-6.2	138.0	1615
Ireland	274.1	1.0	67.1	342	44.5	0.0	8.7	53	229.6	1.0	58.4	289
Israel	1378.2	43.6	149.1	1571	0.8	0.0	0.1	1	1377.5	43.6	149.0	1570
Italy	7345.1	174.2	759.7	8279	1123.8	15.2	177.0	1316	6221.3	159.0	582.6	6963
Jamaica	336.5	15.0	43.2	395	1.1	0.3	0.2	2	335.4	14.7	43.0	393
Japan	10393	320.5	1146.5	11860	285.1	1.2	42.7	329	10108	319.3	1103.9	11531
Jordan	937.6	63.1	101.7	1102	11.4	5.0	1.0	17	926.2	58.1	100.7	1085
Kazakhstan	161.3	2.0	7.8	171	16490	118.0	0.3	16608	-16329	-116.0	7.5	-16437
Kenya	794.4	96.8	83.4	975	22.1	0.0	1.0	23	772.3	96.8	82.4	951
Kiribati	24.2	0.3	1.3	26	0.0	0.0	0.0	0	24.2	0.3	1.3	26
Korea, DPR	212.0	70.9	53.9	337	3.2	0.5	0.0	4	208.8	70.4	53.9	333
Korea, Rep	6510.9	398.0	684.9	7594	32.9	0.0	0.0	33	6478.0	398.0	684.9	7561
Kuwait	206.6	13.0	14.5	234	11.1	26.6	13.4	51	195.5	-13.6	1.0	183
Kyrgyzstan	400.8	5.2	5.8	412	26.7	11.2	0.3	38	374.1	-6.0	5.5	374
Laos	12.7	0.1	0.1	13	0.0	0.0	0.0	0	12.7	0.1	0.1	13
Latvia	43.6	0.2	3.4	47	108.0	0.0	12.7	121	-64.4	0.2	-9.3	-73
Lebanon	803.1	32.2	63.3	899	11.5	0.7	0.0	12	791.6	31.5	63.3	886
Lesotho	0.4	0.5	0.2	1	0.1	0.0	0.0	0	0.4	0.5	0.2	1
Liberia	50.9	2.0	3.8	57	1.5	0.4	0.2	2	49.5	1.6	3.6	55
Libya	1375.2	51.0	172.9	1599	1.0	0.4	0.1	1	1374.2	50.7	172.8	1598
Lithuania	65.1	0.6	2.8	69	347.6	0.0	11.9	359	-282.5	0.6	-9.1	-291
Luxembourg	21.6	0.1	2.4	24	21.0	1.1	6.5	29	0.7	-1.0	-4.1	-4

Countries	Virtual water import (Mm^3/yr)				Virtual water export (Mm^3/yr)				Net virtual water import (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Macedonia, The Fmr Yug Rp	155.0	1.1	17.1	173	11.3	0.0	0.4	12	143.7	1.1	16.7	162
Madagascar	59.5	7.4	8.6	75	3.6	0.0	0.0	4	55.8	7.4	8.6	72
Malawi	136.8	35.0	33.8	206	0.9	0.0	0.0	1	135.9	35.0	33.8	205
Malaysia	5616.1	184.6	636.2	6437	104.3	28.0	17.0	149	5511.9	156.5	619.2	6288
Maldives	16.5	6.2	3.9	27	4.4	1.2	0.7	6	12.1	5.0	3.2	20
Mali	48.7	1.7	3.1	54	2.0	3.5	0.0	5	46.7	-1.8	3.1	48
Malta	73.8	2.7	8.7	85	4.1	0.0	0.0	4	69.7	2.7	8.7	81
Marshall Islands	2.1	0.1	0.2	2	0.0	0.0	0.0	0	2.1	0.1	0.2	2
Mauritania	235.0	3.1	20.2	258	0.2	0.0	0.0	0	234.7	3.1	20.2	258
Mauritius	194.9	2.0	9.2	206	27.0	7.2	4.4	39	167.9	-5.2	4.9	168
Mexico	5155.3	204.5	659.8	6020	119.7	200.8	66.4	387	5035.6	3.7	593.3	5633
Micronesia, Fed States of	2.3	0.2	0.3	3	0.0	0.0	0.0	0	2.3	0.2	0.3	3
Moldova, Rep. of	103.1	2.3	5.2	111	122.7	3.7	8.7	135	-19.6	-1.5	-3.6	-25
Mongolia	272.1	21.5	20.2	314	0.0	0.0	0.0	0	272.1	21.5	20.2	314
Morocco	3281.0	69.4	309.6	3660	209.2	18.6	8.0	236	3071.8	50.8	301.6	3424
Mozambique	384.0	15.6	43.1	443	34.2	1.9	0.0	36	349.8	13.7	43.1	407
Myanmar	71.2	26.0	12.8	110	2.7	1.0	0.0	4	68.5	25.0	12.8	106
New Caledonia	40.8	0.3	2.1	43	0.0	0.0	0.0	0	40.7	0.3	2.1	43
Namibia	34.7	1.8	3.7	40	0.1	0.2	0.1	0	34.6	1.6	3.6	40
Nepal	2.4	3.6	0.9	7	12.8	18.5	0.5	32	-10.4	-14.9	0.4	-25
Netherlands Antiles	19.3	0.8	2.3	22	0.3	0.1	0.0	0	19.0	0.7	2.2	22
Netherlands	2016.2	36.4	327.0	2380	389.8	0.0	141.4	531	1626.4	36.4	185.6	1848
New Zealand	568.2	4.8	35.2	608	9.4	0.0	2.4	12	558.8	4.8	32.8	596
Nicaragua	202.7	12.6	25.7	241	13.7	3.6	2.2	19	189.1	9.0	23.5	222
Niger	35.7	4.3	3.4	44	9.9	2.7	2.6	15	25.9	1.7	0.8	28
Nigeria	2872.1	152.1	345.8	3370	2.1	6.4	0.0	8	2870.0	145.7	345.8	3362
Norway	265.8	4.5	39.8	310	2.2	0.0	0.1	2	263.6	4.5	39.7	308
Occ. Palestinian Terr.	4.5	0.4	0.6	6	0.0	0.0	0.0	0	4.5	0.4	0.6	6
Oman	424.5	81.0	56.0	562	63.0	144.9	49.6	257	361.6	-63.9	6.4	304
Pakistan	2794.3	91.9	264.1	3150	225.1	516.7	149.1	891	2569.1	-424.9	115.0	2259
Panama	199.2	11.0	24.9	235	6.1	1.7	1.0	9	193.1	9.3	23.9	226
Papua New Guinea	382.0	3.5	20.2	406	0.2	0.0	0.0	0	381.8	3.5	20.1	405
Paraguay	98.9	0.6	6.3	106	351.5	0.0	27.8	379	-252.6	0.6	-21.5	-274

Countries	Virtual water import (Mm^3/yr)				Virtual water export (Mm^3/yr)				Net virtual water import (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Peru	2239.1	71.2	247.6	2558	9.1	0.0	3.9	13	2229.9	71.2	243.7	2545
Philippines	3923.0	426.4	537.8	4887	1.7	0.4	0.3	2	3921.3	425.9	537.5	4885
Poland	586.0	6.6	96.0	689	249.3	0.1	115.4	365	336.7	6.5	-19.4	324
Portugal	1051.2	13.3	134.4	1199	526.0	27.9	72.9	627	525.1	-14.6	61.5	572
Qatar	72.9	23.3	16.6	113	0.9	2.1	1.1	4	72.1	21.3	15.5	109
Romania	566.2	10.8	99.0	676	949.4	25.9	44.8	1020	-383.2	-15.1	54.1	-344
Russian Federation	5333.9	68.8	92.4	5495	7568.5	100.3	284.9	7954	-2234.6	-31.5	-192.5	-2459
Rwanda	21.7	1.0	1.3	24	0.0	0.0	0.0	0	21.7	1.0	1.3	24
Saint Vincent/ Grenadines	41.1	2.1	5.1	48	18.8	5.0	3.0	27	22.4	-3.0	2.0	21
Samoa	4.0	0.2	0.3	4	0.0	0.0	0.0	0	4.0	0.2	0.3	4
Sao Tome and Principe	3.7	0.4	0.7	5	0.0	0.0	0.0	0	3.7	0.4	0.7	5
Saudi Arabia	52.6	20.9	13.2	87	9.2	42.2	7.1	59	43.4	-21.4	6.1	28
Senegal	179.4	1.4	11.3	192	1.0	0.3	0.2	1	178.4	1.1	11.2	191
Seychelles	2.3	0.7	0.4	3	0.0	0.0	0.0	0	2.3	0.7	0.4	3
Sierra Leone	711.4	35.3	87.2	834	0.1	0.0	0.0	0	711.4	35.3	87.2	834
Singapore	446.8	35.5	52.5	535	105.1	28.3	17.2	151	341.7	7.2	35.3	384
Slovakia	62.9	0.4	12.9	76	80.9	0.3	13.8	95	-18.0	0.0	-0.9	-19
Slovenia	119.8	1.1	26.9	148	15.8	0.0	10.9	27	104.0	1.1	16.0	121
Somalia	34.2	48.5	15.3	98	24.4	30.3	0.0	55	9.8	18.2	15.3	43
South Africa	1300.4	27.0	119.0	1446	93.5	20.6	8.8	123	1206.9	6.4	110.2	1323
Spain	4160.5	80.5	493.3	4734	1242.2	42.4	249.1	1534	2918.3	38.0	244.2	3201
Sri Lanka	1292.8	160.5	156.3	1610	12.3	3.3	1.9	17	1280.5	157.3	154.4	1592
Saint Kitts and Nevis	2.2	0.5	0.4	3	0.0	0.0	0.0	0	2.2	0.5	0.4	3
Saint Lucia	17.6	4.4	2.8	25	0.1	0.0	0.0	0	17.5	4.4	2.8	25
Sudan	1092.5	113.2	116.9	1323	1.8	3.2	0.4	5	1090.7	110.1	116.5	1317
Suriname	18.6	1.3	2.4	22	2.1	0.6	0.3	3	16.5	0.8	2.1	19
Swaziland	11.3	2.2	1.1	15	13.0	0.0	0.0	13	-1.7	2.2	1.1	2
Sweden	92.9	3.7	14.6	111	223.1	0.0	64.9	288	-130.2	3.7	-50.3	-177
Switzerland	312.9	5.6	47.3	366	133.8	0.0	40.8	175	179.1	5.6	6.5	191
Syria	142.4	54.8	9.0	206	531.3	160.8	75.7	768	-388.9	-106.0	-66.7	-562
Tajikistan	2884.6	26.3	10.9	2922	0.5	0.0	0.0	1	2884.1	26.3	10.9	2921
Tanzania	510.1	104.3	55.6	670	64.2	0.0	0.0	64	446.0	104.3	55.6	606
Thailand	1576.3	49.8	155.8	1782	61.1	0.0	0.0	61	1515.2	49.8	155.8	1721
Togo	103.2	0.9	13.4	118	8.4	2.3	1.3	12	94.7	-1.3	12.1	105
Tonga	10.2	0.7	0.8	12	0.0	0.0	0.0	0	10.2	0.7	0.8	12
Trinidad and Tobago	148.6	7.9	19.0	175	8.2	2.2	1.3	12	140.3	5.7	17.6	164

Countries	Virtual water import (Mm^3/yr)				Virtual water export (Mm^3/yr)				Net virtual water import (Mm^3/yr)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Tunisia	1646.3	57.4	150.8	1855	171.4	5.2	7.9	185	1474.9	52.3	142.9	1670
Turkey	2358.2	57.4	190.6	2606	2208.2	138.8	208.3	2555	149.9	-81.4	-17.7	51
Turkmenistan	419.0	4.3	2.7	426	0.0	0.0	0.0	0	419.0	4.3	2.7	426
Uganda	234.7	14.7	20.3	270	1.2	0.0	0.4	2	233.5	14.7	19.9	268
Ukraine	1225.6	14.7	35.9	1276	4586.9	50.1	200.5	4837	-3361.3	-35.4	-164.5	-3561
United Arab Emirates	730.9	308.8	151.2	1191	398.9	129.5	175.7	704	331.9	179.3	-24.5	487
UK	1173.7	16.6	178.2	1369	1188.9	0.4	440.7	1630	-15.2	16.3	-262.5	-261
Uruguay	127.9	1.2	11.9	141	513.6	0.1	42.5	556	-385.8	1.1	-30.7	-415
USA	2796.1	26.0	421.8	3244	48603	2389.5	5959.4	56952	-45807	-2363	-5537.5	-53708
Uzbekistan	3816.1	35.1	34.6	3886	30.8	3.3	0.0	34	3785.3	31.7	34.6	3852
Vanuatu	23.9	0.5	1.3	26	0.0	0.0	0.0	0	23.9	0.5	1.3	26
Venezuela	1906.4	69.3	255.5	2231	21.5	0.0	3.9	25	1884.9	69.3	251.6	2206
Viet Nam	417.1	128.4	76.4	622	8.8	2.4	1.4	13	408.3	126.1	75.0	609
Wallis and Futuna Is	1.3	0.0	0.1	1	0.0	0.0	0.0	0	1.3	0.0	0.1	1
Yemen	2016.6	392.2	310.0	2719	22.4	29.2	1.3	53	1994.2	363.0	308.7	2666
Serbia and Montenegro	99.7	1.5	15.7	117	238.0	0.0	0.0	238	-138.3	1.5	15.7	-121
Zambia	46.1	19.1	7.4	73	1.0	3.9	0.0	5	45.1	15.2	7.4	68
Zimbabwe	122.6	9.3	12.1	144	7.3	30.0	6.1	43	115.3	-20.6	6.0	101
Others	2031.5	126.1	247.4	2405	75.6	34.1	22.3	132	1955.8	92.0	225.1	2273
World	174693	7789	17807	200289	174693	7789	17807	200289	0	0	0	0

Appendix X: The water footprint of wheat consumption per country (1996-2005).

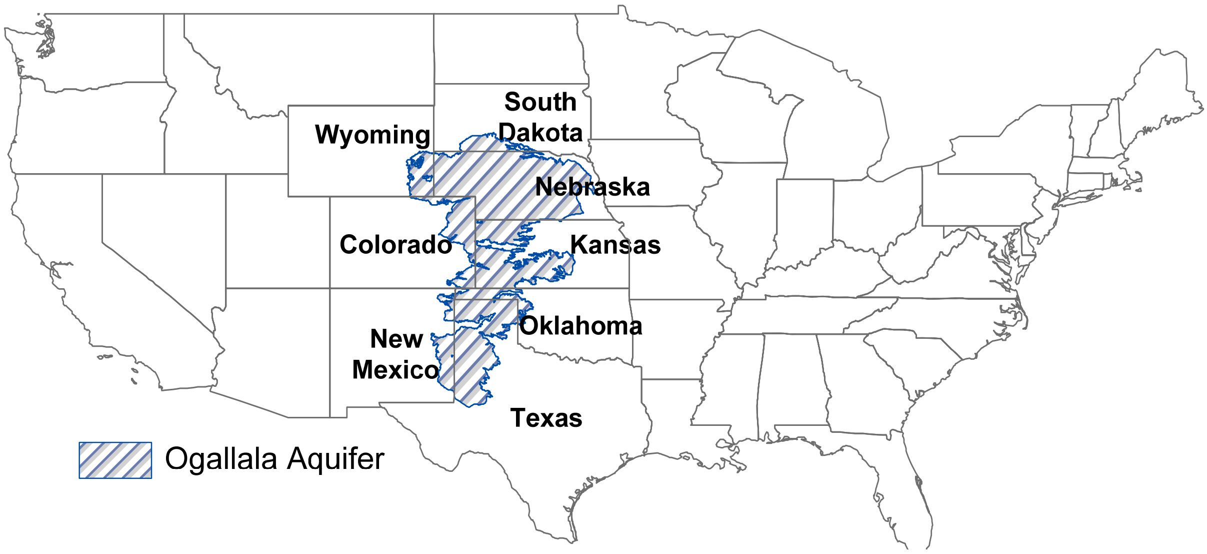
Countries	Internal water footprint (Mm^3/yr)				External water footprint (Mm^3/yr)				Total (Mm^3/yr)	Per capita ($m^3/cap/yr$)
	Green	Blue	Grey	Total	Green	Blue	Grey	Total		
Afghanistan	6060	1117	20	7197	720	297	91	1108	8305	386
Albania	335	4.3	79	418	470	11.6	48	530	948	305
Algeria	6458	128.6	115	6701	5283	322	695	6299	13000	423
Angola	4.0	0.0	5.0	9.0	183	10.2	32	224	233	16
Argentina	9937	62.1	615	10614	3.2	0.1	0.7	3.9	10618	287
Armenia	241	8.3	17	266	478	20.5	54	553	819	266
Australia	19671	162.5	1005	20839	8	0.6	3	12	20851	1082
Austria	615	0.0	119	734	91	0.5	27	119	853	105
Azerbaijan	1189	185	67	1441	1811	24.9	38	1873	3314	407
Bangladesh	1573	521	125	2219	1627	546	272	2445	4664	33
Belarus	1068	0.0	490	1559	1072	9.6	54	1135	2693	269
Belgium	527	0	198	725	1885	0.0	188	2073	2797	273
Bhutan	22	3.0	0.3	26	3.6	6.8	1.8	12	38	66
Bolivia	689	0.0	4	693	511	9.1	43	563	1256	149
Bosnia and Herzegovina	445	0.0	28	473	411	7.2	80	498	971	260
Botswana	0.4	0.0	0.0	0.4	25	2.6	2	30	30	17
Brazil	6901	3.1	469	7372	11224	87.9	788	12100	19472	111
Bulgaria	3933	0.1	994	4926	123	3.0	14	140	5066	634
Burundi	43	0.0	0.8	43	7.7	0.8	0.7	9.2	53	8
Cameroon	1.0	0.0	0.3	1.3	201	2.3	18	221	222	14
Canada	8304	34	1240	9577	44	1.9	4.4	50	9628	312
Chad	2.6	10.4	0.0	13.0	28	0.9	2.2	31	44	5
Chile	1675	350	431	2456	471	7.4	55	533	2988	193
China	82990	47091	31442	161522	4064	97	450	4612	166134	133
Colombia	90	0.0	0	90	1574	53	199	1826	1916	46
Congo, DR	32	0.0	1	33	213	15.4	25	254	286	6
Croatia	902	0.0	132	1034	50	0.5	9	59	1094	240
Cyprus	18	1.4	5	24	143	3.2	15	161	185	264
Czech Republic	2577	0.0	818	3395	43	0.1	10	53	3447	337
Denmark	2163	25.7	465	2653	234	1.2	54	289	2942	551
Ecuador	83	12.8	1	97	688	17.6	90	796	892	72
Egypt	1409	5924	2692	10025	6837	274	633	7743	17768	264
Eritrea	71	0.0	2	73	235	19.0	27	281	355	93
Estonia	232	0.0	48	280	92	0.9	8	101	381	278
Ethiopia	6280	28.3	90	6398	761	46	100	907	7305	104
Finland	371	0.0	14	384	112	1.0	24	136	521	100

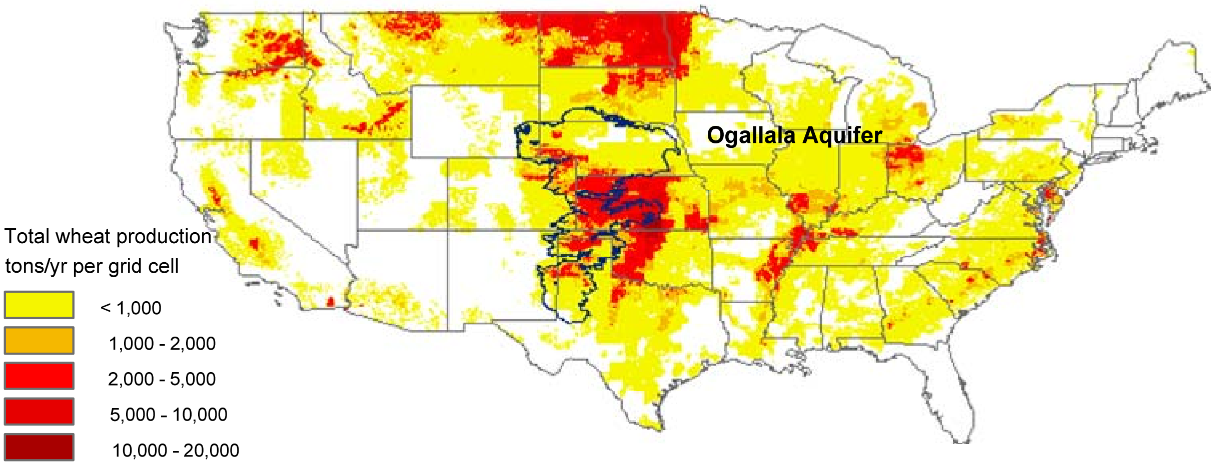
Countries	Internal water footprint (Mm^3/yr)				External water footprint (Mm^3/yr)				Total (Mm^3/yr)	Per capita ($m^3/cap/yr$)
	Green	Blue	Grey	Total	Green	Blue	Grey	Total		
France	11920	33	147	12101	332	15.1	103	450	12550	205
Georgia	572	18.7	30	621	970	25.6	53	1048	1669	355
Germany	9459	0.0	2868	12327	810	12.8	120	943	13270	161
Greece	2626	50.6	240	2916	857	13.8	93	964	3880	354
Guatemala	31	0.0	7.8	39	579	26.2	76	681	720	63
Honduras	6.3	0.0	0.2	6.6	193	11.9	26	232	238	38
Hungary	3047	6.0	1037	4090	10	0.0	1.7	12	4102	402
India	42786	78997	19903	141687	931	16.8	64	1012	142699	135
Iran	26693	10937	3208	40837	6104	60	504	6668	47505	716
Iraq	4368	3981	308	8658	1584	116	145	1844	10502	415
Ireland	296	0.0	58	354	254	1.0	63	317	671	174
Israel	301	3.4	59	363	1378	44	149	1570	1933	315
Italy	8274	114	1284	9673	6837	165	697	7699	17372	300
Japan	736	3.2	108	848	10127	319	1108	11554	12401	98
Jordan	69	28.9	6	104	927	60	101	1087	1191	242
Kazakhstan	17312	124.3	1	17437	83	1.0	7.5	91	17529	1156
Kenya	432	0.0	20	452	780	97	83	960	1411	44
Korea, DPR	254	41.1	0	296	211	70.6	54	335	631	27
Korea, Rep.	10	0.0	0	9.7	6478	398	685	7561	7571	162
Kyrgyzstan	1607	672	18	2297	396	5.1	6	406	2703	546
Latvia	525	0.0	61	586	37	0.2	3	40	625	263
Lebanon	159	9.9	0	169	794	31.7	63	889	1058	279
Lesotho	67	0.0	0	67	0	0.5	0	1	68	36
Libyan	567	200	45	812	1374	51	173	1598	2411	446
Lithuania	1115	0.0	38	1153	50	0.6	2.1	53	1206	344
Luxembourg	18	0.0	5.1	23	13	0.0	1.2	14	37	85
Macedonia,The Fmr Yug Rp	406	0.0	16	422	152	1.1	17	170	592	295
Madagascar	14	0.0	0.1	14	57	7.4	9	72	87	5
Malawi	6.4	0.0	0.0	6.4	136	35.0	34	205	211	18
Mali	5.7	7.2	0.0	13	47	1.2	3	51	64	6
Malta	7.7	0.0	0.0	8	70	2.7	9	82	89	228
Mauritania	0.6	0.0	0.0	0.6	235	3.1	20	258	259	99
Mexico	1023	1570	548	3141	5056	184	624	5864	9005	90
Moldovaublic of	1523	46.4	108	1677	96	2.1	5	103	1780	433
Mongolia	206	0.0	18	224	272	21.5	20	314	538	216
Morocco	9923	877	383	11183	3230	68	306	3604	14786	505
Mozambique	2.5	0.1	0.0	2.6	350	13.7	43	407	409	22
Myanmar	209	75.7	0	285	71	26	13	109	394	9

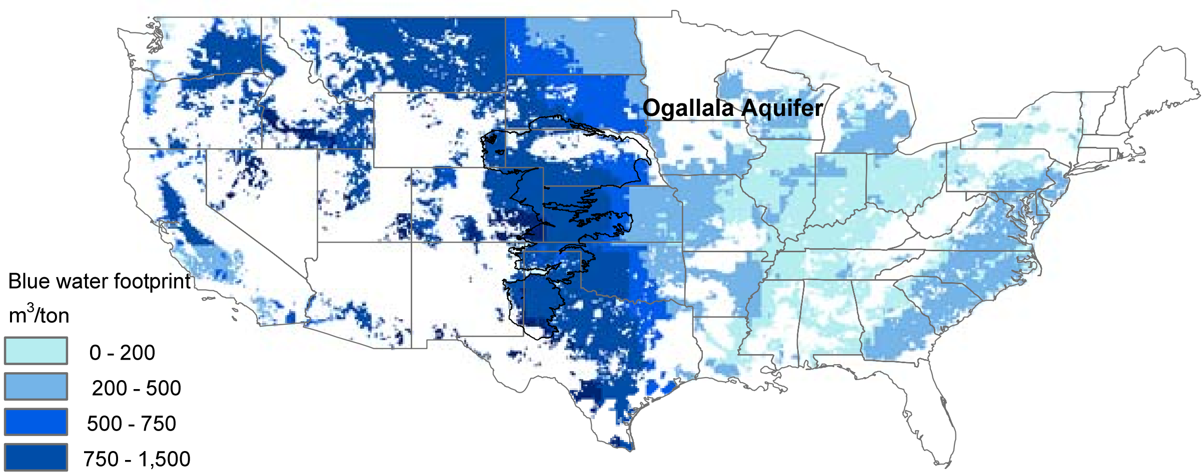
Countries	Internal water footprint (Mm^3/yr)				External water footprint (Mm^3/yr)				Total (Mm^3/yr)	Per capita ($m^3/cap/yr$)
	Green	Blue	Grey	Total	Green	Blue	Grey	Total		
New Caledonia	0.0	0.0	0.0	0.1	41	0.3	2.1	43	43	200
Namibia	1.7	3.5	2.2	7.3	35	1.7	3.7	40	47	25
Nepal	1534	2209	58	3800	2.4	3.5	0.9	6.8	3807	154
Netherlands	476	0.0	147	622	1711	36	239	1987	2609	163
New Zealand	225	0.0	55	281	562	4.8	34	601	881	226
Niger	14	3.3	3	20	29	3.1	2.3	34	55	5
Nigeria	46	137	0	183	2870	149	346	3365	3548	28
Norway	211	0.0	10	221	265	4	40	309	530	118
Occ. Palestinian Terr.	78	0.9	0	79	4.5	0.4	0.6	5.5	85	26
Pakistan	11900	27218	7856	46973	2752	90	259	3101	50075	345
Paraguay	514	0.0	40	554	61	0.6	3.8	66	619	115
Peru	587	0	250	837	2232	71	246	2549	3386	131
Poland	9687	3.5	4478	14169	572	6.5	94	672	14841	386
Portugal	675	26.9	92	794	771	7.3	97	875	1669	163
Qatar	0.0	0.1	0.1	0.2	72	21.3	16	109	109	168
Romania	8172	222.5	392	8786	510	9.7	91	611	9397	425
Russian Fed	83967	1112	3152	88232	4915	63	85	5064	93295	635
Rwanda	51	0.0	0.6	52	22	1.0	1.3	24	76	10
Saudi Arabia	493	2257	382	3132	52	20	13	85	3217	152
Slovakia	1375	5.6	234	1614	60	0.3	12	72	1686	313
Slovenia	159	0.1	107	266	113	1.1	25	139	405	204
Somalia	3.5	4.9	0.0	8.3	15	23	15	53	62	9
South Africa	2154	469	203	2826	1266	25.9	116	1408	4234	93
Spain	7234	242	1424	8900	3737	71	435	4243	13143	321
Sudan	255	442	49.6	747	1091	113	117	1320	2067	61
Swaziland	0.0	0.0	0.0	0.0	0.0	2.2	1.1	3.4	3.4	3
Sweden	812	0.0	234	1046	74	3.7	12	89	1135	127
Switzerland	309	0.0	88	397	253	5.6	36	294	691	95
Syria	5394	1634	767	7795	130	50	8	188	7983	475
Tajikistan	780	30.3	29	839	2884	26.3	11	2921	3760	606
Tanzania	259	0.0	0	259	469	104	56	629	888	27
Thailand	3.1	0.0	0.0	3.1	1515	50	156	1721	1724	28
Tunisia	3060	93	142	3295	1588	55	147	1790	5085	529
Turkey	38810	2434	3659	44903	2238	54	181	2473	47376	691
Turkmenistan	1841	393	0	2234	419	4.3	3	426	2660	586
Uganda	19	0.0	5.7	25	234	14.7	20	268	293	12
Ukraine	21905	239.3	955	23099	1021	12.3	30	1063	24163	496
United Arab Emirates	0.2	0.1	0.0	0.2	332	179	0	511	512	153

Countries	Internal water footprint (Mm^3/yr)				External water footprint (Mm^3/yr)				Total (Mm^3/yr)	Per capita ($m^3/cap/yr$)
	Green	Blue	Grey	Total	Green	Blue	Grey	Total		
UK	5188	1.8	1883	7074	984	16.3	146	1147	8221	139
Uruguay	334	0.2	28	362	55	1.1	5.2	61	424	128
USA	64508	3124	7941	75573	1612	14.8	244	1870	77444	270
Uzbekistan	3698	396	0	4094	3800	34.8	35	3870	7964	319
Venezuela	3.0	0.0	0.5	3.5	1885	69	252	2206	2209	90
Yemen	237	300	14	551	1997	376	309	2681	3232	175
Serbia and Montenegro	3078	0.0	0	3078	93	1.5	16	110	3188	297
Zambia	15	57	0	72	45	18.2	7	71	143	14
Zimbabwe	43	158	33	235	117	7.9	11	136	370	29
World	593599	196690	106972	897260	166703	7147	16586	190436	1087696	177

Appendix XI: Wheat production and associated blue water footprint in the USA, showing the Ogallala Aquifer (1996-2005).







Appendix XII: Comparison of computed water footprint values with measured values from the literature.

Location	Water footprint (m^3/ton)[a]			Simulated water footprint (m^3/ton)	Is simulated WF with in the range?[b]
	Minimum	Maximum	Median		
Parana, Argentina	671	1818	962	1807	Y
Merredin, Australia	877	1786	1053	1654	Y
Merredin & Mullewa, Australia	606	1818	1136	1805	Y
Benerpota, Bangladesh	746	1923	1099	1434	Y
Quzhou, China	513	725	633	1177	N
Xifeng, China	826	1538	1190	1494	Y
Wangtong, China	375	671	448	1240	N
Gansu, China	690	1724	1000	1603	Y
Luancheng, China	775	935	794	1342	N
Yucheng, China	862	1136	962	1129	Y
Beijing, China	645	1087	840	1014	Y
various locations, China	538	1176	855	1070	Y
Luancheng, China	775	935	794	1342	N
West Bengal, India	775	901	840	1485	N
Pantnagar, India	763	1163	901	1159	Y
Baruat, Uttar Pradesh, India	1408	2083	1563	1559	Y
Karnal, India	1220	3704	1493	1435	Y
Pantnagar, India	763	1163	901	1159	Y
Gilat, Israel	625	1667	1176	4189	N
Meknes, Morocco	870	9091	1724	3790	Y
Sidi El Aydi, Morocco	943	3125	1639	3110	Y
Konni, Niger	1075	2381	1639	3182	N
Faisalabad, Pakistan	457	1429	781	1395	Y
Tel Hadya, Syria	909	2083	1282	1639	Y
Cukurova, Turkey	690	752	719	3513	N
Yellow Jacket (CO), USA	926	2128	1299	3379	N
Grand Valley (CO), USA	413	654	581	3413	N
Tashkent, Uzbekistan	980	2273	1370	998	Y

[a] Measured water productivity values from Zwart and Bastiaanssen (2004). Estimated water footprint values as inverse of measured water productivity values from literature

[b] Y indicate the simulated water footprint lies in between the minimum and maximum measured values from litruature, while N indicates the simulated value outside these ranges.

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