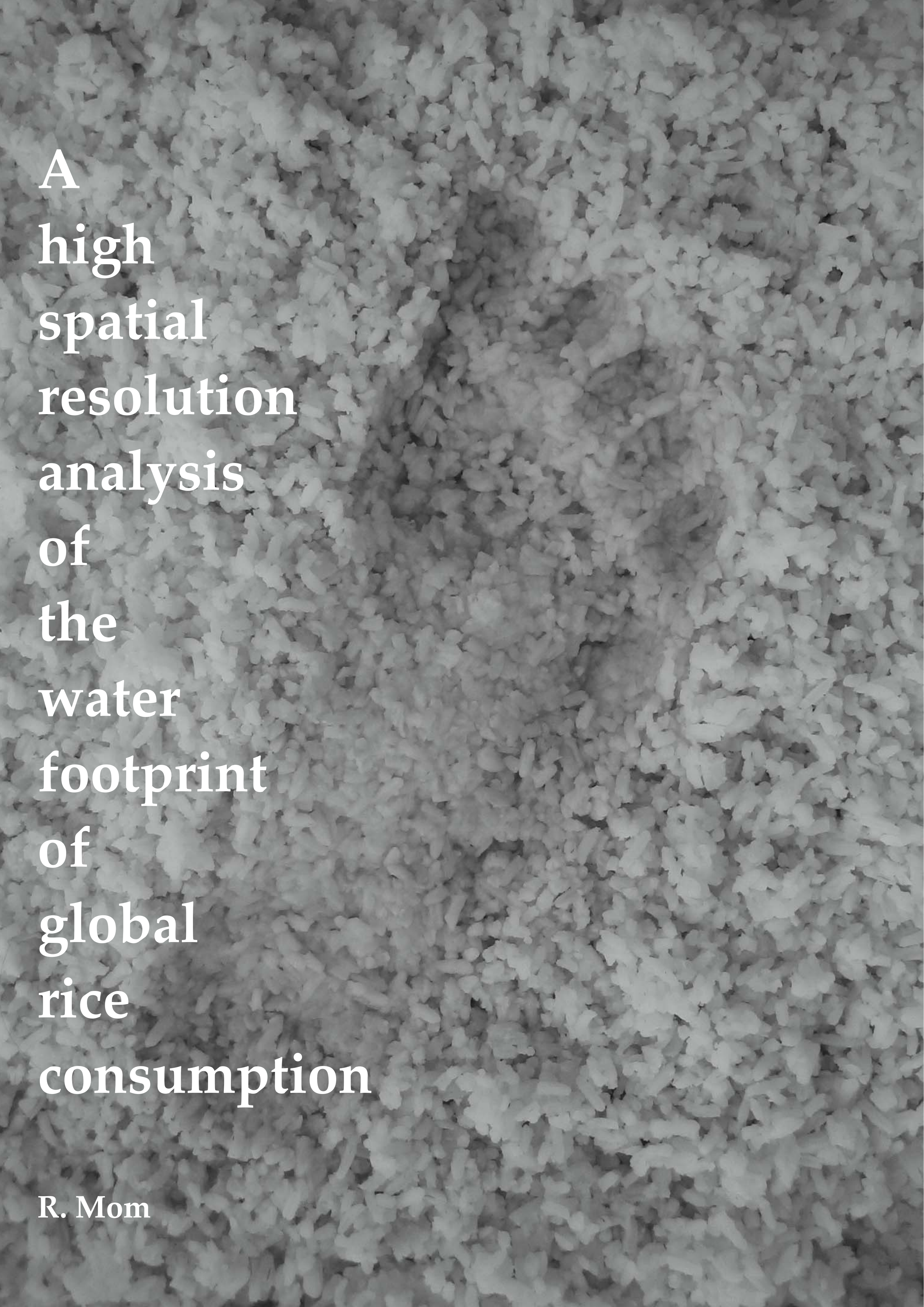

A high spatial resolution analysis of the water footprint of global rice consumption

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May 2007

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Master Thesis, University of Twente, Enschede, The Netherlands

Keywords: rice, water footprint, virtual water flows, global water saving, ORYZA2000

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"Water is life's matter and matrix, mother and medium. There is no life without water."

- Albert Szent-Gyorgyi -

Abstract

With the consumption of agricultural products people indirectly use water needed to produce the consumed product. By calculation of this 'virtual water' the 'water footprint' can be assessed. This water footprint depends on the use of both domestic and external water resources related to the production and trade of the concerned product(s) in respectively the own country and abroad. Of all agricultural products rice is one of the most water intensive crops and consumed by a large number of people living on the planet. This study aims to calculate the global water footprint of rice consumption for the period 1999 – 2003 using a top down approach.

The volume of water needed to produce rice depends on water depletion during rice growth. In this study only evapotranspiration was considered to be depleting. To simulate water-limited rice growth the crop model ORYZA2000 is used. The total volume of water used for rice production is calculated based on total rice production and its virtual water content (m^3 ton^{-1}). By integrating the model with GIS it is possible to calculate total water use for rice growth on a high resolution using spatial explicit weather and land use data.

Rice production has different impacts on domestic water resources. This study distinguishes three types of impact during the growth stage: evapotranspiration of infiltrated rainwater ('green' water footprint), evapotranspiration of ground- and/ or surface water for irrigation ('blue' water footprint) and water pollution ('grey' water footprint). Detailed trade data are needed to identify the location of impact and assess virtual water flows. These flows are derived from statistics on trade in rice products and their virtual water content in the country of origin.

For the period 1999 – 2003 an average of 919 billion m^3 $year^{-1}$ of water was used for the consumption of rice products. Of this total volume 65% is green water, 29% blue water and 6% grey water. Because relatively little rice is traded impacts of its consumption are typically domestic. The external water footprint is only 5% of the global water footprint.

Compared to other cereals, the international rice market is small relative to its production. Estimations show that with the import of rice products about 14 billion m^3 $year^{-1}$ of the global water resources can be saved. To save more water the rice market should expand, which is difficult because of government policies. Developing and applying new management strategies as well as breeding new varieties may save water more significantly. In this way water productivity can be improved and more rice can be grown with less water.

Preface

To provide information on water use related to consumption of products Arjen Hoekstra introduced the water footprint concept. After attending his oration I became more interested in multidisciplinary water management and his water footprint concept. I thought it would be interesting to use this concept for my Masters thesis and together with Arjen we decided to calculate the global water footprint concerning one of the thirstiest agricultural products in the world: rice.

After one year of research I finally finished my thesis. Although improvements can be made I am very content with the final product and I hope it can be of any scientific importance. I would like to say thank you to a number of people for their expertise, support and guidance during this study.

First of all I would like to thank both my supervisors Arjen and Maarten Krol for their support, advise, useful suggestions and criticism in finishing my thesis.

To Bas Bouman and Robert Hijmans of the International Rice Research Institute (IRRI) in the Philippines for their expertise, support and contributions to my research. Thank you both for the pleasant collaboration. Special thanks to Bas for giving me the opportunity for an internship at IRRI to collect my research data. Salamat po!

I would like to thank my Dad for his ever-present support and advice during my years of study. I think my mother will be proud on both of us.

To all of those who supported and encouraged me in finishing this thesis.

Especially, I thank Elly whose love, faith and patience helped me to complete this thesis.

Roy Mom

Almere, May 2007

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Acronyms and Abbreviations

CGIAR	Consultative Group on International Agricultural Research	*http://www.cgiar.org/*
CIA	Central Intelligence Agency	*https://www.cia.gov/*
CIAT	Centro Internacional de Agricultura Tropical	*http://www.ciat.cgiar.org/*
EPD	Environmental Protection Division	
FAO	Food and Agricultural Organization of the United Nations	*http://www.fao.org/*
IFA	International Fertilizer Industry Association	*http://www.fertilizer.org/ifa/*
IFDC	International Fertilizer Development Center	*http://www.ifdc.org/*
IPI	International Potash Institute	*http://www.ipipotash.org/*
IRRI	International Rice Research Institute	*http://www.irri.org/*
ITC	International Trade Centre	*http://www.intracen.org/*
IWMI	International Water Mangement Institute	*http://www.iwmi.cgiar.org/*
PDI	Phosphate and Potash Institute	
UN	United Nations	*http://www.un.org/*
USDA	United States Department of Agriculture	*http://www.ers.usda.gov/*
WARDA	West African Rice Development Association	*http://www.warda.org/*

1 Introduction

1.1 Global rice consumption

One of the water intensive crops in the agricultural sector is rice. In the period 1999 - 2003 the average paddy rice production was about 592 million metric ton (see Appendix B) to feed the people in the world. Figure 1-1 shows global rice production for the period 1999 – 2003.

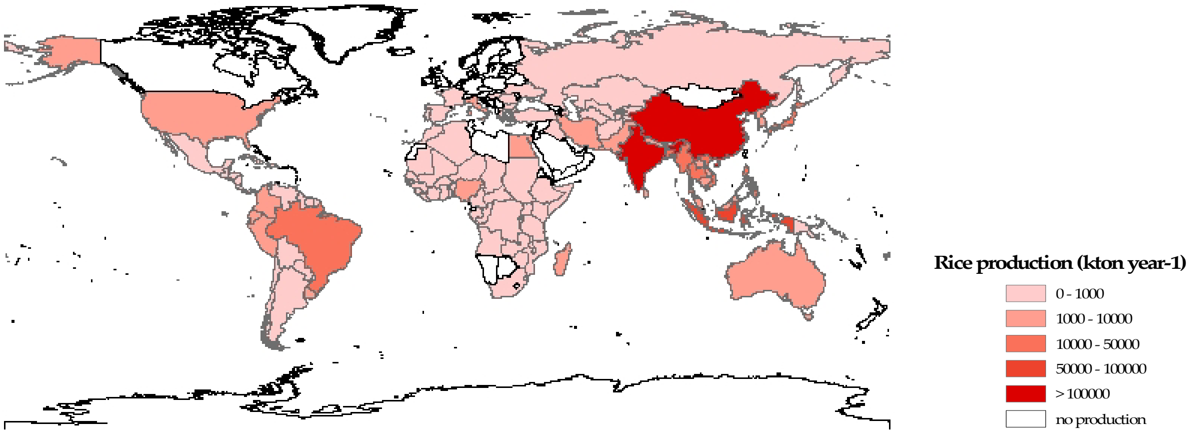


Figure 1-1: Global paddy rice production

For the largest number of people living on the planet rice is staple food. Average paddy rice consumption per capita is about 84 kg year^{-1}. In Table 1-1 paddy rice consumption in the major rice producing countries is depicted. In these countries about 90% of the globally produced paddy rice is consumed. Most of this rice is consumed in China (32%) and India (22%). In Laos consumption per capita is highest in the world: 306 kg year^{-1} (see Appendix C). Overall rice-based systems are essential to ensure food security.

Table 1-1: Food balance sheets of major rice producing countries (paddy equivalent). Period 1999 – 2003.

Country	Production quantity (kton year-1)	Import quantity (kton year-1)	Export quantity (kton year-1)	Domestic supply (kton year-1)	Feed and seed quantity (kton year-1)	Other net uses quantity (kton year-1)	Food consumption quantity (kton year-1)	Food consumption quantity (kg cap^{-1}year^{-1})
Bangladesh	36,856	1,119	3	37,973	534	5,068	32,371	230
Brazil	10,755	1,189	653	11,291	258	1,476	9,557	55
China	181,634	1,389	4,281	178,741	6,464	9,102	163,175	126
Egypt	5,865	41	812	5,094	312	694	4,088	59
India	128,319	142	4,712	123,750	7,487	3,299	112,963	109
Indonesia	51,370	3,566	320	54,616	2,342	7,629	44,645	208
Japan	11,101	1,343	550	11,894	239	552	11,103	87
Korea, Republic of	6,868	315	677	6,506	51	-34	6,488	138
Myanmar	21,663	60	279	21,445	1,955	4,798	14,692	305
Nepal	4,161	51	103	4,108	105	645	3,358	140
Pakistan	6,950	51	3,298	3,703	225	-178	3,656	25
Philippines	12,780	1,471	9	14,242	971	1,243	12,027	156
Thailand	26,387	24	12,430	13,981	1,813	3,171	8,997	146
United States of America	9,281	802	4,948	5,134	181	1,058	3,896	14
Viet Nam	33,010	40	3,187	29,862	1,558	8,382	19,922	251
World	591,326	38,054	43,316	585,968	28,066	53,786	504,116	84

Note: the world's total reflects the total of the countries as provided by FAO (FAO, 2007b)

Consumption patterns were based on food balance sheets provided by FAO (2007b). Supply for domestic utilization of rice depends on production, import, export and changes in stocks in a country. The amount of rice for domestic supply which is fed to livestock or used for other uses determines the availability of rice for human consumption.

The increasing demand for rice in combination with increasing water scarcity is a threat for food security and the sustainability of rice cultivation. This is one of the reasons many studies have been carried out on how to produce more rice with less water. The International Rice Research Institute (IRRI) does a lot of research in developing new varieties which use less water and have high yields. Also management strategies are developed (helping to close yield gaps and use less water for crop growth) and tested on their experimental farm.

The impact of rice consumption on global water resources can be mapped with the water footprint, a concept introduced by Hoekstra in 2002. This water footprint is defined as '*the total volume of fresh water that is used to produce the foods and services consumed by the individual, business or nation*'. Using this consumption based indicator as a tool to provide information on water use related to the consumption of products could be useful. With this concept one can also show the dependency of nations on water resources in other countries by showing virtual water flows as a result of trade.

1.2 Objective of the study

'The objective of this study is to map the impact of the consumption of rice products on global water resources by assessing and analysing the water footprint of each rice consuming country'.

This study carried out for rice is methodologically similar to an earlier study carried out for cotton (Chapagain *et al.* 2005). The time period in that study was 1997 – 2001. The current study took the period 1999 – 2003.

Since FAO's CROPWAT cannot be used for calculation of crop water requirements for rice, the rice specific model ORYZA2000 was used to simulate evapotranspiration rates. With this model it was possible to simulate water-limited rice growth by taking the influence of the soil-water balance on evapotranspiration rates into account. Hoekstra and Chapagain (2007a) used the model CROPWAT to calculate water use for agricultural crops (including rice) assuming crop growth without any shortage of water.

In contrast to Hoekstra and Chapagain (2007a) simulation of crop growth was done on a high resolution. To this end the crop model ORYZA2000 was integrated with GIS. This coupling made it possible to simulate rice growth using spatial explicit data (land use and climatology).

Because rice production has different impacts on different water resources a distinction was made between blue and green water use in the current study. The term 'green water use' is used for the impact of evapotranspiration of infiltrated rainwater used for plant growth and 'blue water use' for the use of ground- and/or surface water for irrigation. Also the influence of the use of fertilizers to sustain rice yields was taken into account by introducing a third component, 'grey water use'. This is the volume of water required to dilute amounts of nitrate in ambient water sources to such extent that amounts of nitrate do not exceed guideline values.

Like Hoekstra and Chapagain (2007a) a top down approach was used to assess the water footprint of global rice consumption. By using a top down approach it was possible to asses the with the trade in rice products associated virtual water flows, and identify the character of impact in the exporting country using the different types of water use.

Besides locating and characterizing the impacts from trade in rice products, importing rice products may generate global water savings. These savings are equal to the imported volumes multiplied by the volumes of water that would have been required to produce the commodity domestically (Chapagain *et al.*, 2006). As long as the water saving of the importing country exceeds the water loss of an exporting country there will be a net water saving (from a physical point of view). From an economic point of view countries can gain from trade using comparative advantages. The pros and cons of the trade should be weighted including the opportunity cost of the associated water. In general, blue water has a higher opportunity cost compared to green water. So if blue water is saved by trading commodities countries can gain from trade.

By using the crop model ORYZA2000 in combination with climate surfaces and a detailed database on crop distribution we believe to provide for a radically better estimate of the different types of water use in rice production.

1.3 Report outline

To asses the global water footprint of rice consumption we need to know how and under which conditions rice was grown. To discriminate the different water uses of the rice plant during the crop growth the water balance was assessed (Chapter 2).
An overview of the method followed to assess the water footprint is given in Chapter 3. To simulate rice growth on a high resolution the crop model ORYZA2000 was integrated with GIS. An overview of this simulation and the assumptions made for assessing rice growth on a global scale can be found in Chapter 4.
The results of the simulation were further processed by calculation of the virtual water content of the different rice products (Chapter 5) to assess virtual water flows and global water savings as a result of trade in rice products (Chapter 7). In Chapter 6 the impact of fertilizer use is described.
Together with the total volume of water used in rice production, virtual water flows resulted in the global water footprint which was analyzed (Chapter 8).
Chapter 9 of this thesis contains the final conclusion. Discussion and recommendations for further study are presented in Chapter 10.

2 Rice and water

2.1 Growing rice

Rice (*oryza sativa* (oruzu = rice)) refers to a species of grass which is cultivated as an important cereal for human nutrition grown under a wide range of climate, soil and water conditions. The cultigen is staple food for the largest number of people living on the planet and embedded in culture and economies of many developing countries.

The rice grains are enclosed in the lemma and palea of the flowers/spikelets on both the primary and secondary flowering branches (panicle) of the plant (see Figure 2-1). The number of grains a panicle consists of depends on the variety grown.

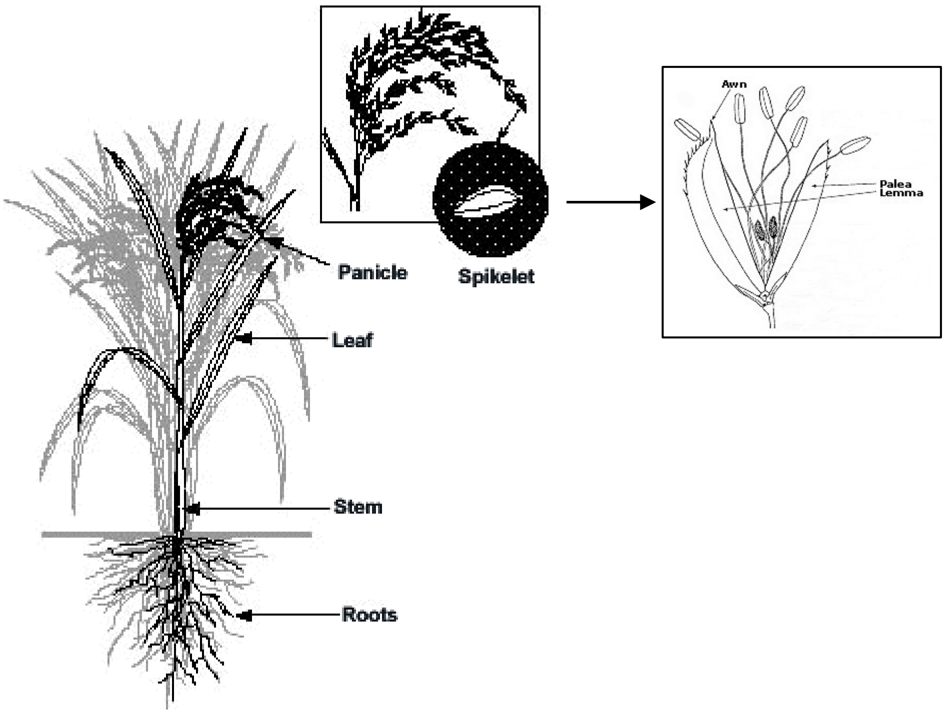


Figure 2-1: The rice plant (source: IRRI)

A rice grain has several layers. The seed consists of the true fruit, which is enclosed by the hull/ husk and bran, consists mainly of the embryo and endosperm. Grain length and thickness depending on the variety distinguish long, medium and round grain. One single grain weighs about 10 – 45 mg (Maclean *et al.*, 2002).

Rice fields are bunded with bunds/levees to catch rainwater and irrigation water (if applied) to ensure soil submergence. After the field is prepared (soaking, plowing and puddling (tillage at soil saturation)) the rice plants can be grown. Depending on the conditions under which rice is cultivated the cultigen can be transplanted or direct seeded. In transplanting rice the seedlings are first grown in a seedbed before they are transplanted to the main field. In direct seeding the seeds are directly sown to the main field. The growth duration of the rice plant depends on its variety and climate and is divided into 3 phases consisting of a series of stages (see Appendix D). Yields can be higher if rice is direct seeded because of the transplanting shock during transplanting.

Rice is mostly grown under (partially) flooded (anaerobic) lowland conditions (see Appendix H). These lowland conditions can be classified as irrigated and rainfed. Irrigated rice is grown on puddled soils in bunded fields with assured irrigation throughout the whole growing cycle. Because irrigation supplement rainfall the system can be divided into a wet (monsoon) and dry irrigated season depending on the supply. Compared to the wet season the rice crop in irrigated dry season areas cannot be grown without supplemental water because evapotranspiration is higher and water needs are greater because of less rainfall and other climatic factors. Therefore the plants need to be flooded artificially. The bunded fields of rainfed lowlands depend on the water supply provided by rainfall and floodwater. These fields are exposed to non-continuous flooding of variable depth and duration.

Besides these two 'ecosystems' rice can be grown under flood-prone (temporary or complete submergence) and upland (aerobic) conditions. Upland rice is grown in unbunded fields and therefore can have a high surface runoff. In this study rice production in flood-prone ecosystems was not taken into account. In Figure 2-2 an overview of the four conditions under which rice is grown is depicted.

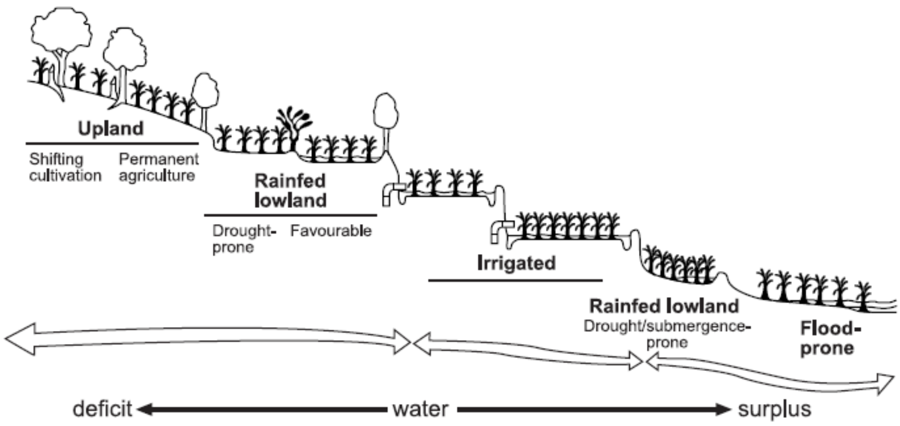


Figure 2-2: Rice ecosystems

2.2 Water balance

Looking at a puddled rice field (see Figure 2-3) the top of the plant's canopy to the bottom of the root zone, bounded by the bunds, over a growing season can be seen as the domain. The storage of water in this domain we denote with S. Water enters the domain as rainfall P and/or irrigation supply I (if not enough water for crop growth is available).

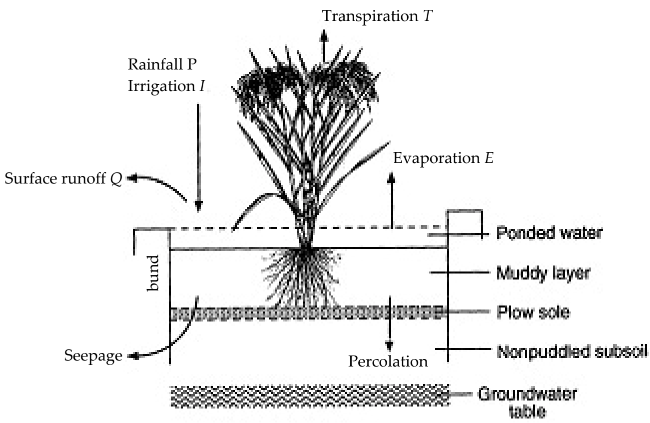


Figure 2-3: Water balance of a puddled rice field (Bouman et al. 2001b)

Transpiration *T* of the crop is the only 'productive' water component of the water balance in a rice field as it leads directly to crop growth and yield formation (Bouman, 2001a). Besides transpiration water is 'lost' by the process of evaporation *E* of water from the soil and ponded water layer. The remainder of the diverted water flows out of the domain as surface runoff *Q* or subsurface flows. In rice fields seepage and percolation are typical subsurface flows. Seepage is the laterally movement of water through the bordering bunds, and percolation is the vertical movement of water from the ponded water layer to below the root zone (Bouman and Tuong, 2000). The rate of both components depends on the soil (moisture conditions) and the depth of ponded water in relation to the distance from the soil surface to the groundwater table (hydrostatic pressure). If there is no ponded water, there is no hydrostatic pressure and therefore percolation and seepage rates are zero. Seepage and percolation (which are often inseparable (Wickham and Singh, 1978) and which efficiencies vary in time, with management and soil conditions) are combined in a field-average constant *SP*. This combination is justified by the fact that both are governed by the same hydraulic principles.

Knowing all components in a rice field the water balance of a lowland ecosystem can be assessed. The change in storage ΔS for these types of ecosystems can be written as:

$$\Delta S_{\text{lowland}} = P(+I) - E - T - SP - Q \qquad (1)$$

For upland rice environments freely draining loamy soils could be considered and therefore lateral in- or outflow are fully negligible.

In this study the different components of the water balance are simulated using the model ORYZA2000 (see Chapter 4).

2.3 Water use

To classify water balance components into water use categories Moldens' framework of water accounting was used (Molden, 1997). In terms of water accounting we defined water depletion as the use of both green and blue water to produce intended goods and/ or services that renders it unavailable for further use.

In a three-dimensional space and time (x, y, t) we considered only evaporation and transpiration (together evapotranspiration *ET*) inside the domain as being used for rice production and is thus depleted (see Figure 2-3). The domain can be seen from the top of the plant's canopy x_1 to the bottom of the root zone x_2, bounded by the bunds y_1 and y_2, over a growing season (from planting t_1 to harvesting t_2).

Subsurface flows like seepage and percolation only affect the consumptive water use of the rice plant indirectly (through their influence on water storage and evapotranspiration) and therefore can be classified as outflow. Rainfall and/or irrigation in excess of bund height leaves the domain as surface runoff. This runoff can be an input for a neighbouring field, but in a sequence of fields, neighbouring fields will pass on the runoff until it flows out of the domain (Bouman *et al.*, 2001b). Therefore we assumed runoff to be outflow. Like the subsurface flows, runoff affect the consumptive water use of the rice plant indirectly.

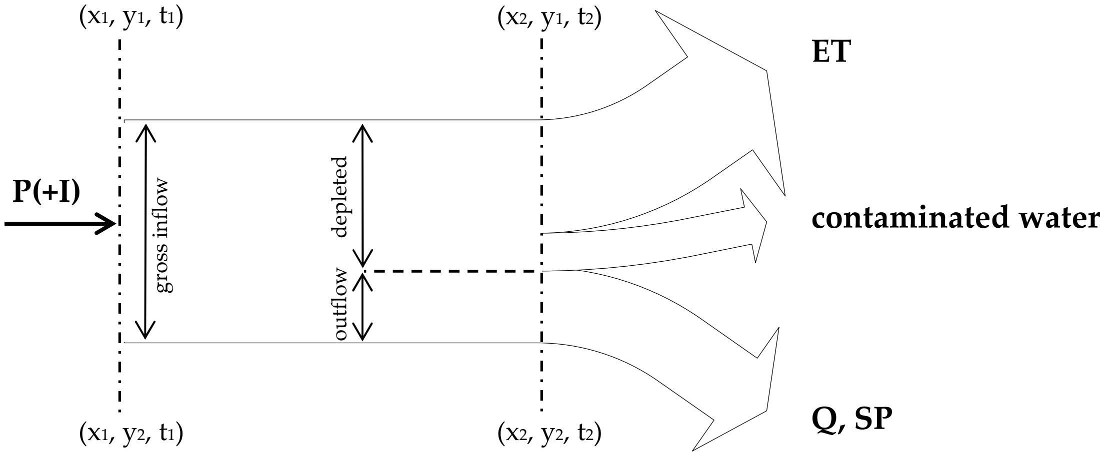


Figure 2-4: Water use at field level

Note: If at start of the simulation the soil is saturated net inflow can be greater than gross inflow because water is added to the storage. Therefore water depletion may be greater than gross inflow

Sometimes outflows contain traces of nitrogen or biocides. As long as the concentration of these contaminants are below a limit, water is still utilizable. In this study we considered an additional volume of water as depleted due to contamination of ambient water sources with agrochemicals (see Chapter 6).

We, thus, only calculated water use of the rice plant – the volume of depleted water – in the period from planting to harvest at field level. Losses during land preparation and irrigation losses due to application, distribution and system use were not taken into account. Therefore calculation of water use in rice production is a more conservative approach.

3 The water footprint of a crop

3.1 Water footprint

The water footprint of a nation *WFP* (m^3 $year^{-1}$) is defined as the volume of water actually used and made unavailable for other uses through the production of a commodity to fulfill consumption demands. This footprint consists of two parts referring to the use of domestic water resources versus the use of foreign water resources:
- the internal water footprint *IWFP* (the part of the footprint that falls inside the country);
- the external water footprint *EWFP* (the part of the footprint that presses on other countries in the world).

The total water footprint of a country is assessed by taking the domestic water use *TWU*, subtracting the flows of virtual water (see § 3.3) leaving the country *VWE* and add the virtual water flows that enters a country *VWI*.

$$WFP = IWFP + EWFP = TWU - VWE_{\text{dom}} + VWI - VWE_{\text{re-export}} \qquad (2)$$

Calculation of these components is methodology the same as described in Hoekstra and Chapagain (2007b).

3.2 Virtual water content

If a water footprint is assessed it is vital to quantify the flows of virtual water leaving and entering the country. Virtual water is defined as the volume of water used to produce a commodity (Allen, 1998a). The virtual water content of paddy rice VWC_{paddy} (m^3 ton^{-1}), the primary crop in levels of production, in a country, is calculated as the ratio of the total volume of water depleted (m^3 ha^{-1}) during the entire period(s) for rice growth, the crop water use *CWU*, to the yield (ton ha^{-1}).

$$VWC_{\text{paddy}} = \frac{CWU}{\text{yield}} \qquad (3)$$

note: in all cases the yield data provided by FAO (2007a) were taken

Crop water use

The crop water use is calculated by accumulation of daily evapotranspiration rates ET_{act} (mm ha^{-1} day^{-1}) over the complete growing period in an ecosystem of a country.

$$CWU = 10 \sum_{\text{dae}=1}^{\text{maturity}} ET_{\text{act}} \qquad (4)$$

The factor 10 is meant to convert mm of water used for rice production to m^3 ha^{-1} (1 mm = 10 m^3 ha^{-1}). The summation is done over the period from emergence of the crop to the day the rice plant reaches maturity (dae stands for days after emergence). This period depends on the method used for planting the rice plants.

In transplanting only the evapotranspiration during the period in the main field is summed (evapotranspiration from the relative small area of the seedbed is negligible). Therefore the growing period of transplanted rice in lowland ecosystems equals the number of days after emergence the plant reaches maturity minus the duration of the rice plant in the seedbed (sbdur).

$$CWU = 10 \sum_{\text{dae}=1}^{\text{maturity-sbdur}} ET_{\text{act}} \tag{5}$$

In upland ecosystems where seeds are directly sown on the main field equation (4) is valid. In Figure 3-1 an schematic overview is given of both methods of rice planting.

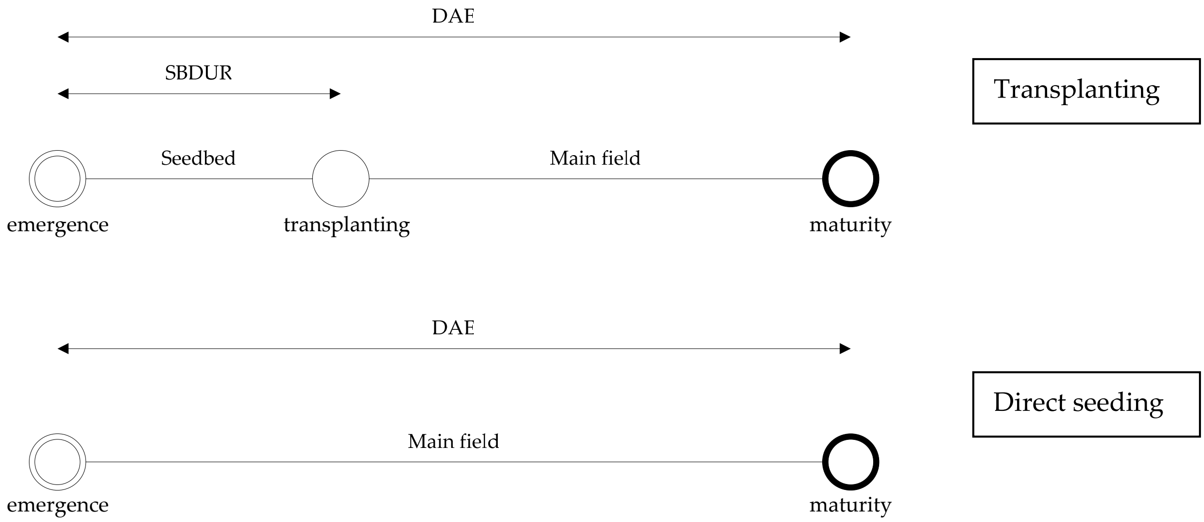


Figure 3-1: Transplanted and direct seeded rice

The total volume of water used for rice growth *TWU* (m^3) in a country equals the virtual water content multiplied with the total production of rice in a country.

$$TWU = VWC_{\text{paddy}} \times \text{production} \tag{6}$$

note: in all cases the by FAO (2007a) provided production data were taken

The global production average virtual water content $\overline{VWC_{\text{paddy;production}}}$ is calculated as the sum of the total volume of water used for rice growth in rice producing countries to the total of paddy rice production in these countries.

$$\overline{VWC_{\text{paddy;production}}} = \frac{\sum TWU}{\sum \text{production}} \tag{7}$$

Evapotranspiration

Evapotranspiration depends on climatic conditions, the variety grown, the availability of water and soil conditions. If water supply is ample the crop will not experience water limitations and the production situation will be potential. Rice grown under anaerobic conditions needs water to compensate consumption of the ponded water to mitigate the effects of water limitations. Because of this ponded water layer seepage and percolation is common in rice cultivation. Therefore water is 'lost' at field level affecting crop growth and thus evapotranspiration rates.

To take these water limitations into account the model ORYZA2000 (Bouman *et al.*, 2001) was used to simulate actual and potential evapotranspiration rates for different varieties grown under different conditions. These evapotranspiration rates are calculated from the reference evapotranspiration ET_0 (the evapotranspiration from a reference surface, an extensive surface of green grass of uniform height, actively growing, completely shading the ground and not short of water (Allen *et al.*, 1998b)) which is calculated using the Penman method (1948).

Both potential and actual evapotranspiration rates depend on the conditions of the soil/water layer and leaf area index *LAI* during the growth of the rice plant, continuously affecting the evapotranspiration rates during crop growth.

Different colors of water use

In this study a distinction was made between the impact of evapotranspiration of infiltrated rainwater ('green' water), the use of water for irrigation ('blue' water) and water depletion due to contamination ('grey' water). Therefore the total virtual water content for paddy rice is made out of a green, blue and grey component.

$$VWC_{\text{paddy}} = VWC_{\text{green}} + VWC_{\text{blue}} + VWC_{\text{grey}} \tag{8}$$

Green water

The green virtual water content VWC_{green} (m^3 ton^{-1}) is calculated as the ratio of the total volume of green water uses for crop growth CWU_{green} (m^3 ha^{-1}), to the yield. CWU_{green} equals the evapotranspiration rate of infiltrated rainwater in an ecosystem $ET_{\text{act;rainfed}}$.

$$VWC_{\text{green}} = \frac{CWU_{\text{green}}}{\text{yield}}, \text{ with } CWU_{\text{green}} = 10\sum_{\text{d=1}}^{\text{dae}} ET_{\text{act;rainfed}} \tag{9}$$

In irrigated ecosystems this volume depends on evapotranspiration rates contributed by both irrigation and rainfall on irrigated land.

Blue water

The crop water use of rice grown under irrigated conditions contains both the volume of green water and irrigation water CWU_{blue} (blue water). CWU_{blue} is the difference between actual evapotranspiration with irrigation $ET_{\text{act;irrigated}}$ and actual evapotranspiration without irrigation $ET_{\text{act;rainfed}}$ (thus contributed by rainfall) on irrigated land over the growing period. To calculate the blue virtual water content VWC_{blue} (m^3 ton^{-1}) the ratio of the volume of blue water used CWU_{blue} (m^3 ha^{-1}) to the yield is calculated.

$$VWC_{\text{blue}} = \frac{CWU_{\text{blue}}}{\text{yield}}, \text{ with } CWU_{\text{blue}} = 10 \sum_{\text{dae=1}}^{\text{maturity-sbdur}} \left(ET_{\text{act;irrigated}} - ET_{\text{act;rainfed}} \right) \tag{10}$$

The volume of green water use in irrigated ecosystems equals the total crop water use minus the volume of blue water use.

Figure 3-2 shows the daily distribution of the evapotranspiration rates for a grid within the administrative boundaries of Italy. Because in Italy rice can only be grown under irrigated conditions during the dry season in summers, actual evapotranspiration contributed by rainfall is very low. The latter results in a high volume of blue water use. However, without irrigation water the crop would have died and production would be very low.

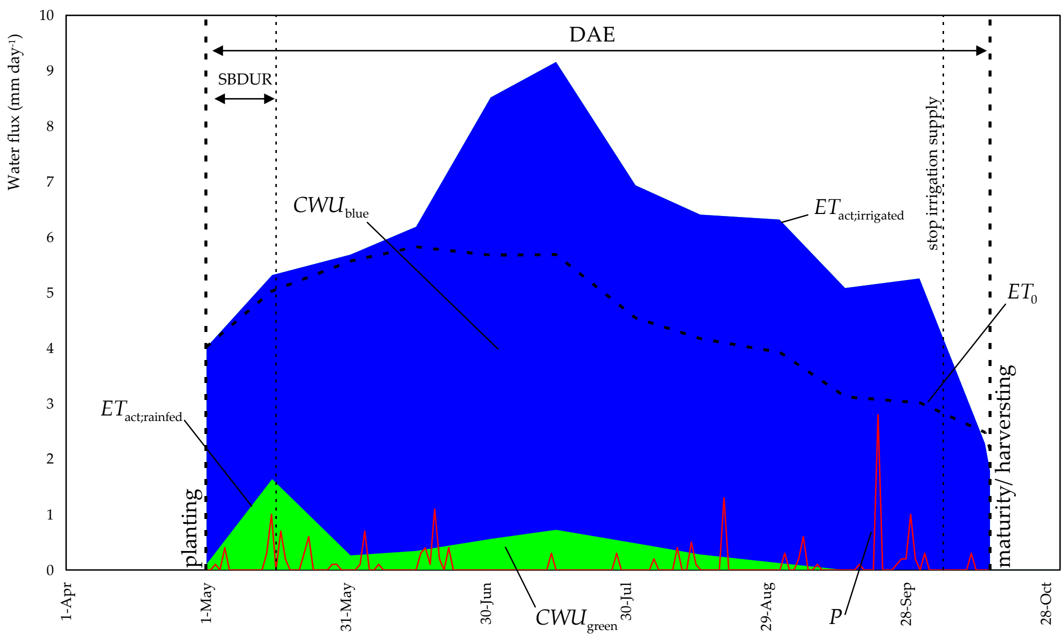


Figure 3-2: Evapotranspiration rates of a rice crop in Italy during it's growing season

CROPWAT uses a crop coefficient approach in which crop evapotranspiration is calculated by multiplying ET_0 by a crop coefficient K_c . According to Allen *et al.* (1998b) the crop coefficient for rice is maximum 1.2 (in the mid-season stage), and less than 1,0 for the end of the season. Compared to the crop coefficients used with CROPWAT larger crop coefficients were found for Italy with ORYZA2000 (maximal 1.7). An explanation for this difference can be found in the calculation of the reference evapotranspiration. Where CROPWAT uses the FAO Penman-Monteith method, ORYZA2000 uses the original Penman Monteith equation (Penman, 1948).

<u>Grey water</u>

The grey virtual water content VWC_{green} (m³ ton⁻¹) is calculated as the amount of agrochemicals that contaminates ambient water sources L (ton year⁻¹) divided by the maximum acceptable concentration of the agrochemical considered c_{max} (ton m⁻³) and rice production.

$$VWC_{grey} = \frac{L \times c_{max}^{-1}}{\text{production}} \qquad (11)$$

Products

The virtual water content of a processed rice product $VWC_{[p]}$ depends on the virtual water content of rough (paddy) rice, the product of which all other products are derived. When a rice plant reached maturity the grains are harvested and milled – stripping and separating the hull (husking) and bran layer from the cleaned paddy – creating white (milled) rice. The during the milling process damaged white rice is called broken rice and is separated. If only the hull is separated from the paddy, brown (husked) rice is obtained. It is also possible to process white rice out of brown rice. According to FAO only 4% of the white rice during the period 1999 – 2003 was obtained by milling brown rice. In Figure 3-3 an overview is given of the different rice products after processing of the primary crop.

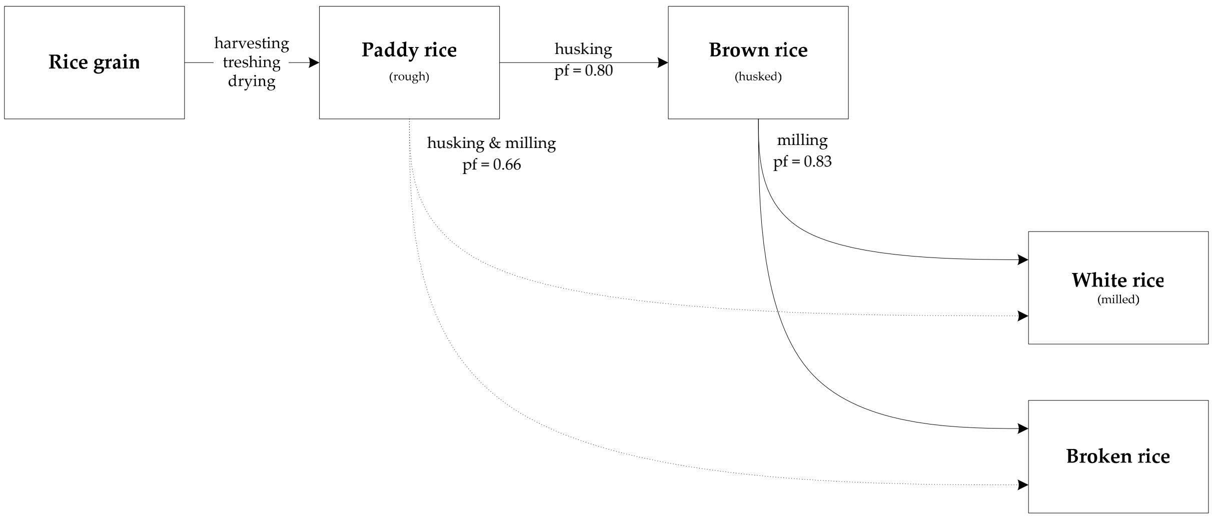


Figure 3-3: The product tree of rice

The processed products can be further processed. It is however chosen to include only the milled and unmilled rice products from the commodity group 13 (see Table 3-1) in this study.

Table 3-1: Rice products included in this study

Commodity group	Commodity subgroup	HS96	HS96 description
13	604	100630	semi milled or wholly milled rice, whether or not polished or glazed (white)
13	604	100640	broken rice
13	605	100610	rice in the husk (paddy or rough)
13	605	100620	husked (brown) rice

The virtual water content of paddy rice is distributed over different products. To do this in a logical way Chapagain and Hoekstra (2004) introduced the term product fraction $pf[\text{p}]$. The product fraction of a product is defined as the weight of the product (i.e. white rice) $W[\text{p}]$ obtained per ton of primary crop (paddy rice) $W[\text{paddy}]$.

$$pf[\text{p}] = \frac{W[\text{p}]}{W[\text{paddy}]} \tag{12}$$

The average husking and milling rate is 0.66 (one ton of paddy produces 0.66 ton of white rice). Efficiency differs by country depending on the milling process used. IRRI provides husking and milling rates for most of the countries included in this study (see Appendix E). For countries of which these rates are unknown the average rate is used. Byproducts of husking and milling are bran (<10%) and hulls (<25%). The fraction of brown rice depends on the efficiency of the husking process. According to the commodity tree in FAO (2003) the byproduct of husking, the hulls, are up to 25%. We assumed a husking rate of 0.80 (one ton of paddy rice produces 0.80 ton of brown rice). The product fraction of broken rice is the same as white rice. Because all products are derived from the paddy or an other processed product all fractions are less than 1.0 (= paddy).

The virtual water content of a rice product can be calculated using equation (13).

$$VWC_{[p]} = \frac{VWC}{pf[p]} \tag{13}$$

Note: to assess the green, blue and dilution virtual water content for the different rice products the virtual water contents of these components should be used.

We neglected the volume of water needed to process products.

3.3 Virtual water flows

After processing, the different rice products are ready to be consumed or traded. As a result of trade countries import or export water that is 'embedded' in rice products creating virtual water flows. The virtual water flow *VWF* (m^3 year^{-1}) from exporting country n_e to importing country n_i can be calculated by multiplying the total physical volume of product *p* exported $T_{[n_e,n_i,p]}$ (ton year^{-1}) with the virtual water content of the product $VWC_{[n_e,p]}$ (m^3 ton^{-1}) in the country of origin.

$$VWF = T_{[n_e,n_i,p]} \times VWC_{[n_e,p]} \tag{14}$$

Because it is not known whether only the domestically produced products, both imported and domestically produced products or only the imported products are exported we decided to use the simulated virtual water content in a country for assessing virtual water flows. For exporting countries of which the virtual water content is not simulated with ORYZA2000 or in which no rice production takes place the global average virtual water content was used to assess the volume of water traded by the export of rice products from these countries.

The total volume of the product imported from country B by country A $T_{[n_i,n_e,p]}$ equals the total volume exported to county A from country B $T_{[n_e,n_i,p]}$. The total virtual water import and export is the sum of the mutual trade by countries in rice products and, thus, can differ from each other.

$$VWI = \sum T_{[n_i,n_e,p]} \times VWC_{[n_e,p]} \tag{15}$$

$$VWE = \sum T_{[n_e,n_i,p]} \times VWC_{[n_e,p]} \tag{16}$$

Note: to assess flows of green, blue and dilution water for the different rice products the virtual water contents of these components should be used.

Because export may refer to both the export of rice products that are produces domestically, and the re-export of imported products or both, the virtual water export is made up of these two components:

- Virtual water export related to the export of domestically produced rice products (VWE_{domestic}); and
- Virtual water export related to the export of imported rice products ($VWE_{\text{re-export}}$).

Like Hoekstra and Chapagain (2007a) both components were estimated based on the relative share of the use of domestic water resources and the virtual water import respectively.

$$VWE_{\text{domestic}} = VWE \times \frac{TWU}{TWU + VWI} \tag{17}$$

$$VWE_{\text{re-export}} = VWE \times \frac{VWI}{TWU + VWI} \tag{18}$$

Trade data

To show impacts of rice consumption we needed to identify the location of the impacts. Therefore data on international trade in rice products were taken from the Personal Computer Trade Analysis System of the International Trade Centre (ITC, 2006). This database covers detailed trade data by country of origin and country of destination for the commodity groups used in this study. Like this it was possible to identify where rice was exported from. Use of the green, blue and grey virtual water content for calculating virtual water flows made it possible to identify the character of impact in the exporting country.

The quantities of the detailed import and export data were not similar with each other (i.e. what country A reports as import from country B will not correspond to what country B reports as its export to country A). We decided to use only those data provided by the countries reporting the import of rice products. According to Chapagain (personal communication (2006/2007)) these statistics are more reliable than countries reporting the export of rice products. If information about import from reporting countries is lacking calculation of virtual water flows using only detailed import data is a more conservative approach if these countries do in fact have import of rice products. Therefore we estimated import in these countries using mirror statistic. For example, if we want to estimate Bangladesh's import we look at what Bangladesh reports about imports. In case of Bangladesh it reports no trade flow. To estimate its import we looked at what exporting countries report about export to Bangladesh.

Countries which had a negative trade balance ($\text{production} + \text{import} - \text{export} < 0$) or for which data seems unreliable were excluded. In total 192 out of the 204 and 143 out of the 152 respectively available importing and exporting countries were taken into account to assess virtual water flows.

3.4 Overview

In Figure 3-4 the processing steps in the calculation of the water footprint of nations involving rice consumption are presented schematically.

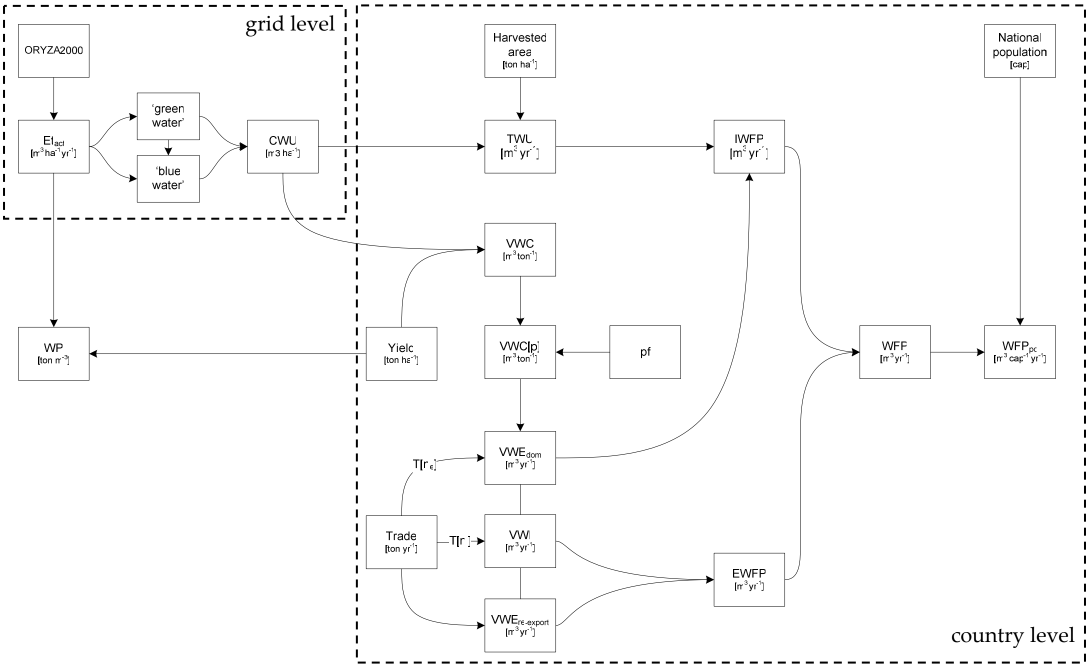


Figure 3-4: Schematic overview of the calculation of the water footprint of rice

3.5 Country coverage

In Asia more than 90% of the world's rice is produced and consumed. For most of the countries in Asia it is known where and under which conditions rice is grown. FAO (2007a) provides data on rice production for 115 countries in the world. For the sake of the simulation it was chosen to exclude countries for which the total rice production was less than 100 kton. The remaining 64 countries produce a total of 99.7% of the world's total rice production (see Appendix B) of which China and India produce more than half. In this report results for only the fifteen largest rice producing countries are presented. Results for all countries are listed in the Appendices.

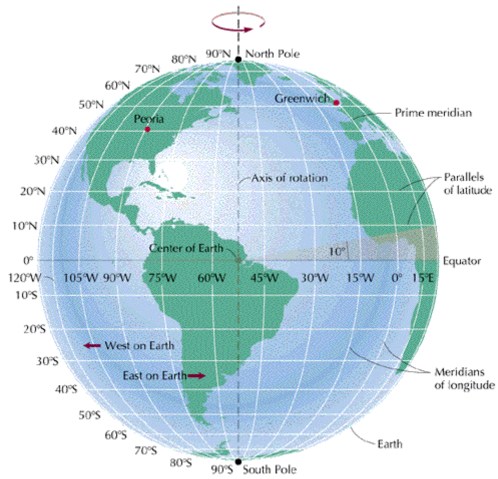
4 Simulating water use with ORYZA2000

4.1 How to simulate rice growth?

We used the ecophysiological crop model ORYZA2000 (Bouman *et al.*, 2001) to simulate the growth and development of both irrigated and rainfed lowlands as well as rainfed uplands and estimate the amount of evapotranspiration during crop growth. The distinction between lowland and upland ecosystems is important for estimating water use. In lowland systems, rice is typically transplanted and rice fields have bunds to retain ponded water. In upland rice farming, the crop is usually direct seeded and the fields have no bunds. If all calculations were based on rainfed lowlands an overestimation of evapotranspiration rates for uplands would be made, because of the potentially higher water stress under upland conditions.

ORYZA2000 was integrated with GIS to simulate crop growth at a spatial resolution of 10 by 10 arc-minutes (see example below), covering the whole world (from latitude 60°N to 60°S and from longitude 180°W to 180°E).

Example: Degrees longitude and latitude are usually divided into minutes (‘) and seconds (‘’). In each degree there are 60 minutes. Using grid cells of 10 by 10 arc-minutes as a spatial resolution means that between 60°S and 60°N there are 720 rows of 2160 grid cells each.



The earth’s mean circumference is about 40,041 km. In N-S direction one degree is about 111 km. Therefore each degree on a 10’ latitude/ longitude grid is approximately 18.5 km in N-S direction. At the equator, the E-W distance is about the same, but this distance decreases with latitude (and is zero at the poles). Therefore, the area of one grid cell is thus about 342,000 ha at the equator, and somewhat smaller elsewhere.

Integration was based on loose coupling using the GIZMO command in AVID-GIS (created by Robert Hijmans, and available at *http://www.diva-gis.org*).

AVID-GIS runs ORYZA2000 for each simulated grid one by one. Each grid was run for 24 planting times (with planting at the first and fifteenth of each month) resulting in 24 simulations of crop growth. This was done for the different varieties used in an ecosystem by latitude and repeated for all the ecosystems included in this study. To shorten simulation time a 'mask' was used to run ORYZA2000 only for those grid cells where rice is produced.

For each (grid cell) simulation ORYZA2000 generates output files which are read by AVID-GIS to store values of interest in output databases (grid layers). The following output grid files were generated:
- actual evapotranspiration ET_{act} (mm ha^{-1});
- duration of crop growth *dae* (days);
- amount of rainfall during crop growth *P* (mm ha^{-1});
- amount of irrigation water withdrawal during crop growth *I* (mm ha^{-1});
- amount of seepage and percolation *SP* (mm ha^{-1});
- amount of surface runoff Q, and (mm ha^{-1});
- yield (kg ha^{-1})[a]

Note: with ORYZA2000 it is possible to generate output on daily basis. Because we are interested in water use during crop growth only the cumulated value over the simulated period was stored

The output of the simulations was processed with AVID-GIS to aggregate the results from grid cells to larger regions and countries (see § 4.3).

In Figure 4-1 an overview is given of the different processing steps.

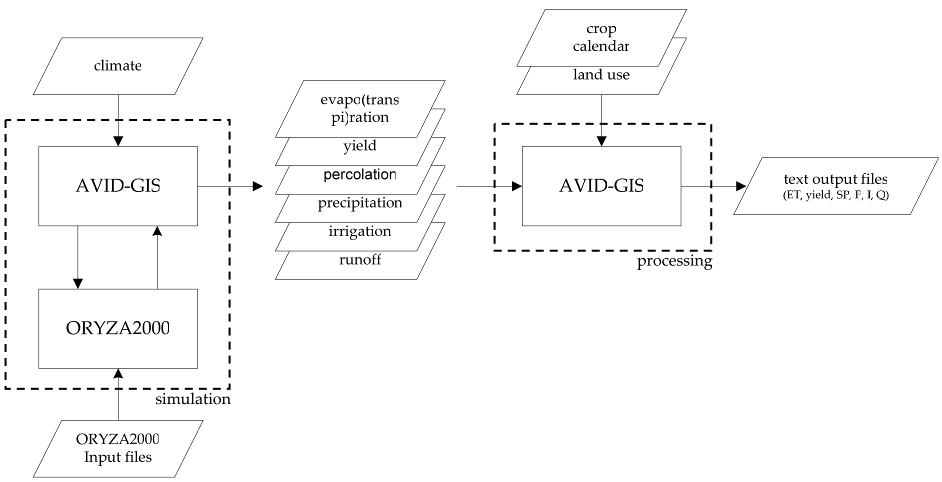


Figure 4-1: Simulation of rice production using louse coupling

4.2 Input

To simulate rice growth with ORYZA2000 we used input files containing (1) management data, (2) crop data, (3) soil data, (4) weather data and (5) land use data. Management, crop and soil data were read from external data files which contained characteristics for each particular ecosystem. The names of the input files are specified in the control file. Datasets in GIS contained information about weather and land use in each grid. General info about the different input files and the assumptions made are presented in this paragraph.

[a] In this study dry weight of paddy rice is calculated using a moisture content of 14%

4.2.1 Management data

Information about management conditions are located in the experiment data file. We choose to run ORYZA2000 with the dynamic soil-water balance modules LOWBAL and SAHEL (see § 4.2.3) to simulate the effects of water-limitation on evapotranspiration rates. These evapotranspiration rates were calculated from the reference evapotranspiration using the Penman equations (Penman, 1948). Because not much data was available on soil nitrogen supply and nitrogen fertilization in rice fields we ran ORYZA2000 without considering growth limitation by nitrogen.

Total duration of the crop growth cycle depends on the method (transplanting or direct seeding) used. For upland ecologies the method of direct seeding was used. For all rice grown under lowland conditions transplanting was used. For transplanted rice a seed bed duration of 14 days was assumed before the plants are transplanted to the main field. It was assumed that at day of emergence the soil is saturated (lowland) or at field capacity (upland). When the development stage (the plant’s physiological age) is 2.0, the crop reached maturity and can be harvested. We assumed a maximum total crop cycle of 200 days.

For the irrigated ecosystems we assumed that each time the simulated depth of ponded water in the field dropped below the threshold level of 10 mm a total of 25 mm irrigation water (IRRI) was applied. Application of irrigation water stops when the development stage was at 1.7. This development stage corresponds to about 10 days before harvesting (in tropical lowland, more elsewhere) that farmers stop applying additional water and let the soil dry out.

4.2.2 Crop data

The crop data file contains all the parameter values that characterize the rice crop. Worldwide, many different kind of varieties are used for rice production. Besides the traditional indica and japonica varieties cultivated, hybrid rice varieties have been developed and new varieties are bred to increase yields and reduce water use.

For every ecosystem two varieties were chosen as input for the model. Between 30°S and 30°N a tropical variety was chosen. Above and below this latitude a more temperate variety was used as input for the model. In Table 4-1 the varieties used in the different ecosystems are shown. The parameter values for all of these varieties were obtained through model calibration and validation using field experimental data.

Table 4-1: Rice varieties used in ORYZA2000

Variety	Latitude			Reference
	60° N - 30° N	30° N - 30° S	30° S - 60° S	
APO		upland		-
HD297	upland		upland	Feng L. *et al.* (2007)
IR64		rainfed		Boling *et al* . (2007)
IR72		irrigated		Bouman and Van Laar (2006)
XD90247	irrigated/ rainfed		irrigated/ rainfed	Feng L. *et al.* (2007)

These varieties are hopefully representative for the varieties actually grown. IR72, IR64 and APO are so-called mega-varieties grown on large areas in tropical Asia. We have not investigated the possible size of the uncertainty in our calculations due to varietal choice. If certain varieties are selected based on water availability, it would be possible that the varieties grown use less water or vice versa affecting the crop water use and thus have an impact on the water footprint.

4.2.3 Soil data

The soil data file contains all the data needed to run the soil-water balance module. Different soils were used depending on the ecosystem in which rice is grown. For the rainfed and irrigated lowlands a puddled clay soil (at IRRI) with bunds was taken. The rainfed upland soil is a loamy soil (non-puddled and without bunds).

To simulate water-limited production the soil-balance modules LOWBAL and SAHEL (Wopereis *et al.*, 1996) were used. The one-layer module LOWBAL was used for both rainfed and irrigated lowlands (irrigated lowlands are basically the same as rainfed lowland but with an input of additional water for crop growth). The rate for *SP* is fixed and thus independent of water regime. A field average rate for *SP* of 4 mm day^{-1} was assumed which is quite typical for lowland rice conditions (Bouman, personal communication (2006)). Because lateral and vertical flows depend on the depth of the ponded water layer the rate for *SP* can be less than 4 mm (which is the maximum rate). For upland rice the three layer homogeneous module SAHEL was used. If the amount of water stored in a layer is above field capacity (the highest water content a layer can obtain) water drains to the next layer or out of the profile. The values of moisture characteristics (water content at saturation, field capacity, wilting point and at air dryness) are taken from Bouman *et al.* (1994).

4.2.4 Weather data

In earlier studies the calculation of evapotranspiration was based on country averaged climatic data on a monthly basis. For this study we used a mean monthly climatology of surface climates over global land areas with a spatial resolution of 10 by 10 arc-minutes (New *et al.*, 2002). The required input variables needed to compute the reference evapotranspiration with Penman are available in this climatology. The climate data which were used to construct this climatology were collected from a network of station observations for the period 1961 – 1990. These data were interpolated using a spline algorithm in order to generate 'climate surfaces' (spatially interpolated climate data on grids). Hereby the algorithm was fitted as functions of latitude, longitude and elevation to the data within the specified domain of the interpolation.

From these monthly averages daily values were generated for usage per grid with ORYZA2000. The method as described by Geng *et. al* (1986) was used to generate daily rainfall data. For the other values linear interpolation between the monthly values was used.

4.2.5 Land use data

For each ecosystem a map was created to discriminate for each grid the area of land use. These areas are based on a compilation of national level statistical data building on a database for Asia by Huke and Huke (1997) by Hijmans.

4.3 Data processing

For the calculation of potential yields Hijmans (2003) determined the optimal planting time for a location (grid cell) after the simulations by selecting the month/ variety combination that led to the highest potential yield. However, in rice production this approach is likely not applicable because many regions have multiple seasons, and the cropping calendar is strongly influenced by water availability. In most of tropical Asia the rice cropping calendar is governed by hydrology, rainfall pattern and the availability of irrigation. Most of the time two seasons are distinguished: a wet main season and a dry second season. In most of the rainfed lowlands (and uplands) there is a single cropping system. If irrigation water is available it is possible to grow rice during the dry season and have a double cropping system.

It is also possible that, when determining planting time by selecting highest yield, a month is selected as the optimal but that harvesting would then be during typhoon season. In practice a farmer would accept a lower yield and plant his crop earlier or later to prevent a poor harvest. Use of a simple criterion to select planting time in a country is thus not easy.

Based on experts knowledge at IRRI (Bouman, Buresh, Peng, and Tuong; personal communication (2006)) and rice cropping calendars provided by Maclean *et al.* (2002) we made a map for the rice producing countries in the world. We distinguished two planting seasons. It is assumed that the first planting season concerns all ecosystems. The second season only concerns irrigated ecosystems. In Appendix F an overview of planting seasons in countries is given. This map is used as a mask to pick out the planting time of the simulated crop growth with ORYZA2000 for each grid cell. In this study we assumed the planting time is the median of the range rice can be planted (see example below).

Example: In Italy rice can be planted between day 91 (April 1st) and day 151 (May 31st). Because planting time is the median of the range in which rice can be planted, in Italy rice was planted on the 1st of May (day 121). The simulation with that particular starting time was selected out of the 24 simulations for grid cells within the administrative boundaries for Italy.
Normally rice is harvested somewhere between September and October. Maturity was reached after 177 days from start of simulation and was thus harvested in October.

To assess the simulated output on national level, for each ecosystem the generated variables x (e.g. ET_{act}) in the jth grid in county i $x_{\text{ecosystem}}[i,j]$ is multiplied with the rice area of that particular cell $A_{\text{ecosytem}}[i,j]$ and aggregated over the total number of simulated grids in that country $N[i]$.

$$x_{\text{ecosystem}}[i] = \sum_{j=1}^{N[i]} \left(x_{\text{ecosytem}}[i,j] \times A_{\text{ecosytem}}[i,j] \right) \qquad (19)$$

For this purpose the datasets concerning land use were used to identify the area of upland, rainfed or irrigated lowland in the grid.

The total rice planting area in a country used for processing were not similar to data provided by FAO's statistical database (2007a). In order to use country averaged rice statistics on yield, production and area from this database for the period 1999 – 2003, we calculated the average simulated variable for country i $\overline{x[i]}$ as the ratio of the total variable of all ecosystems in a country used for rice production to the sum of the areas of the ecosystems in a country.

$$\overline{x[i]} = \frac{\sum x_{\text{ecosystem}}[i]}{\sum A_{\text{ecosystem}}[i]} \qquad (20)$$

For a more detailed description of the use of model to simulate rice growth we refer to Appendix G.

4.4 Model performance

Different studies (Feng L. *et al.*, 2007; Bouman *et al.*, 2007; Jing Q. *et al.*, 2007; Belder *et al.*, 2007; Boling *et al.*, 2007; and Bouman and Van Laar, 2006) show that simulations with ORYZA2000 satisfactorily match measured crop variables in both calibration and validation experimental data sets for different types of rice under different conditions. Grain yields have been simulated with an accuracy of 11 – 16% (RMSE) at field scale.

The simulated national average rice yields were compared with the statistical rice yields FAO (2007a) provided for the period 1999 - 2003. A graphical comparison between the simulated and statistical yields is depicted in Figure 4-2.

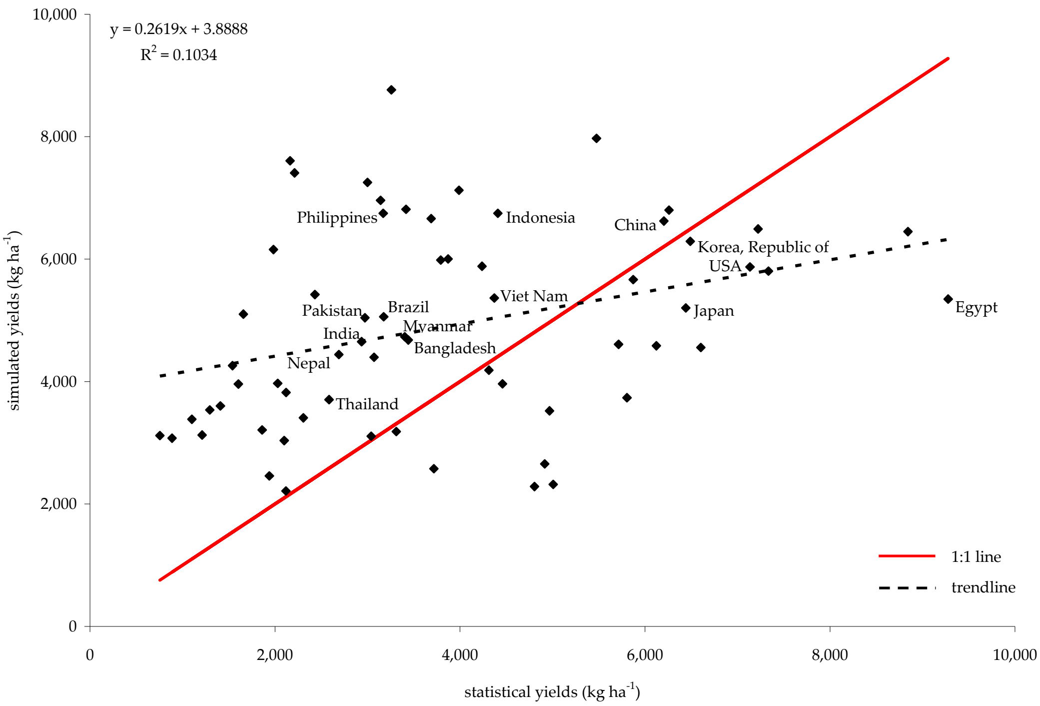


Figure 4-2: Simulated versus statistical yield.

For most of the 64 countries for which rice growth was simulated in this study the simulated and statistical yield considerably differ from each other. The trend line in the figure above is not close to the 1:1 line and goodness-of-fit parameters, like the coefficient of determination R^2, are low. With ORYZA2000 a global paddy rice production of about 800 million ton (an average for the period 1999 – 2003) would be found if the simulated yields in the rice producing countries are multiplied with the harvested area FAO provided for these countries. This is 135% of the global paddy rice production (590 million ton) provided by FAO.

In practice farmers grow rice under suboptimal conditions and management. In this study only water is assumed to be the limiting factor and therefore simulated yields differ from the statistical ones. In reality a rice plant may suffer from biotic stresses like weeds, pests and diseases causing a economic loss in production (yield loss). Also natural disasters (e.g. typhoons) can cause yield losses. We did not consider growth limitations due to nutrients (N, P and K).

Because of the diversity in cropping systems in Asia it was difficult to discriminate areas under different planting times. The rice calendar made for selection of planting time may differ locally and therefore rice growth, and thus production, could differ if rice is not simulated to be grown at the same time as farmers do in practice. It is also possible that rice was simulated under rainfed lowland conditions instead of irrigated conditions (discriminating land use is not for every country well documented). In those cases yields would be lower because of the water limitations under rainfed conditions. Together with the other assumptions made in the study, the local conditions may explain the difference between the simulated and statistical yield.

5 Virtual water content of rice

5.1 The virtual water content of paddy rice

With ORYZA2000 the volume of water used for rice production is simulated for the 64 largest rice producing countries (see Appendix H). These countries contribute for more than 99% to the global rice production. In Table 5-1 the top 15 of rice producing countries is given.

Table 5-1: Rough rice production and yields in the top 15 rice producing countries. Period 1999 – 2003.

Countries	Production (kton yr^{-1})	Contribution to global production	Yield (ton ha^{-1})
Bangladesh	37,002	*6%*	3.44
Brazil	10,755	*2%*	3.17
China	181,634	*31%*	6.20
Egypt	5,865	*1%*	9.28
India	128,319	*22%*	2.94
Indonesia	51,370	*9%*	4.41
Japan	11,101	*2%*	6.44
Korea, Republic of	6,868	*1%*	6.49
Myanmar	21,663	*4%*	3.40
Nepal	4,161	*1%*	2.69
Pakistan	6,950	*1%*	2.97
Philippines	12,780	*2%*	3.17
Thailand	25,927	*4%*	2.58
United States of America	9,281	*2%*	7.13
Viet Nam	33,010	*6%*	4.37
Other	45,152	*8%*	-
World	591,837	-	-

Note: the world's total reflects the total of the countries as provided by FAO (FAO, 2007a)

China and India are the two largest rice producing countries in the world. Despite of a total area for rice production which is approximately 1.5 times the size of the rice area in China, rice production in India is less which is expressed in the difference in yields for both countries. In India farmers are more dependent on rainfall (only 49% of the rice production is under irrigation).

In some countries the blue crop water use exceeds the amount of green water used for rice production (see Table 5-2). Especially in countries where rice production is only possible using irrigation (like Egypt).

Table 5-2: Water input and depletion in major rice producing countries. Period 1999 – 2003.

Countries	Water input ($m^3\ ha^{-1}$)			Water depletion ($m^3\ ha^{-1}$)		
	P	I	Total	CWU_{green}	CWU_{blue}	CWU
Bangladesh	7,659	3,356	11,015	3,153	1,969	5,122
Brazil	6,929	3,452	10,381	3,883	728	4,611
China	5,863	4,625	10,489	4,386	2,185	6,571
Egypt	1	12,964	12,965	368	9,645	10,013
India	7,263	2,277	9,540	3,862	1,344	5,206
Indonesia	7,425	2,951	10,376	4,516	1,763	6,280
Japan	8,160	4,844	13,005	5,622	1,778	7,400
Korea, Republic of	8,309	2,843	11,152	5,181	1,195	6,375
Myanmar	9,941	922	10,863	3,696	496	4,193
Nepal	7,818	851	8,669	3,945	341	4,287
Pakistan	2,663	9,166	11,829	2,355	5,763	8,118
Philippines	7,541	3,027	10,569	4,183	1,609	5,792
Thailand	5,899	913	6,813	3,699	551	4,249
United States of America	2,903	10,178	13,081	2,644	7,003	9,647
Viet Nam	5,770	2,857	8,627	3,740	1,457	5,197

Total volumes of water use and virtual water content for the major rice producing countries are presented in Table 5-3. The global production average virtual water content is 1455 $m^3\ ton^{-1}$. The global volume of water use for rice production is 861 $km^3\ year^{-1}$. The green component is more than twice the blue component.

Table 5-3: Virtual water content of paddy rice for major rice producing countries. Period 1999 – 2003.

Countries	Volume of water use ($km^3\ yr^{-1}$)		Production* ($kton\ yr^{-1}$)	Virtual water content ($m^3\ ton^{-1}$)	
	Green	Blue		Green	Blue
Bangladesh	34	21	37,002	916	572
Brazil	14	7	10,755	1,316	641
China	128	64	181,634	707	352
Egypt	0	6	5,865	40	1,040
India	169	59	128,319	1,315	458
Indonesia	53	21	51,370	1,024	400
Japan	10	3	11,101	873	276
Korea, Republic of	5	1	6,868	798	184
Myanmar	24	3	21,663	1,086	146
Nepal	6	1	4,161	1,466	127
Pakistan	6	13	6,950	792	1,939
Philippines	17	6	12,780	1,319	508
Thailand	37	6	25,927	1,431	213
United States of America	3	9	9,281	371	982
Viet Nam	28	11	33,010	856	333
Sub-total	*534*	*231*	*546,685*	-	-
Average	-	-	-	*977*	*423*
Other	61	33	43,654	1,390	762
Total	595	264	590,339	-	-
Average	-	-	-	*1,007*	*448*
World	596	265	591,837	-	-

* source: FAO (2007a)

5.2 Comparison to earlier studies

If we had used the crop water requirements found by Hoekstra and Chapagain (2007a) we would have estimated 1345 km^3 $year^{-1}$ for rice growth during the period 1999 – 2003 (see Appendix I). In this study we found a global volume of water use of 859 km^3 $year^{-1}$.

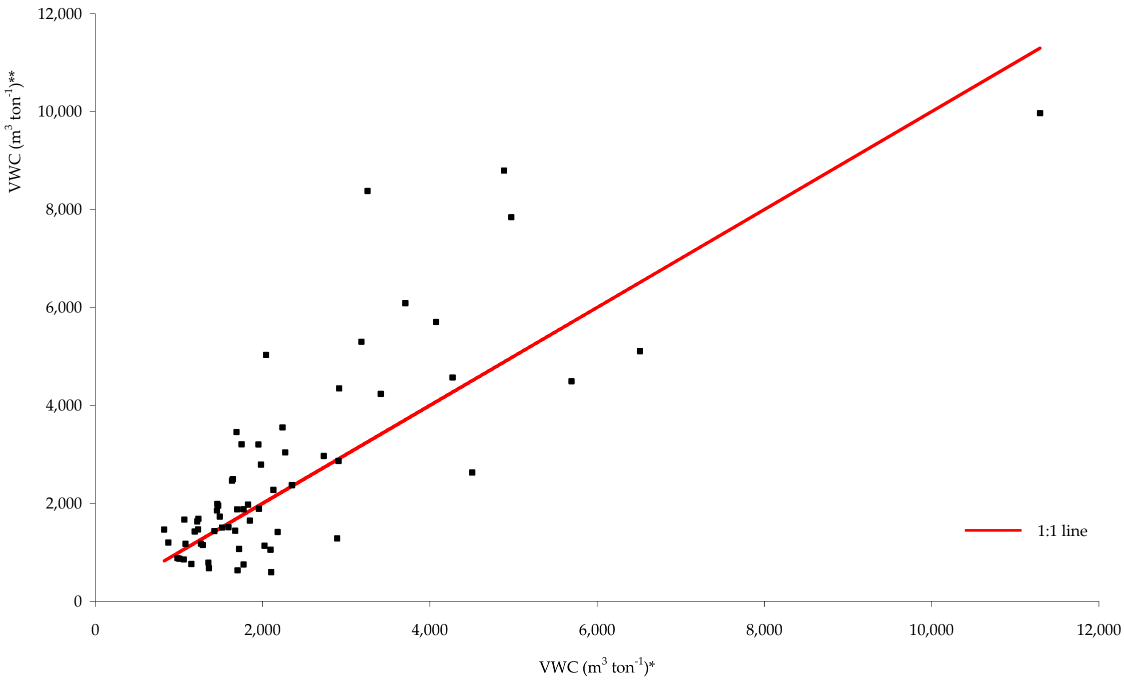
The main reasons for the difference in these volumes of water used for rice production can be found in:

- the assumptions made with respect to water depletion;
- simulating water-limited crop growth;
- simulating crop growth on a high spatial resolution using specific weather and land use data;
- the use of different crop models.

Hoekstra and Chapagain assumed subsurface flows to be depleted. Therefore they added 300 mm ha^{-1} of water for percolation during the growing period in addition to the consumptive water use of the rice plant. We considered these flows only to affect the consumptive water use of the rice plant indirectly and available for further use within the basin. Therefore they should not be considered to be depleted. If Hoekstra and Chapagain had only assumed evapotranspiration as depleted, total water use would be 892 km^3 $year^{-1}$ (see Appendix I), which deviates only 4% from the total volume used for rice growth in this study.

Besides a difference in water accounting we simulated water use assuming water-limited crop growth. Hoekstra and Chapagain calculated crop water requirements for rice growth and assumed rice grows without any shortage of water. Assuming crop water requirements are fully met may thus lead to an overestimation of actual crop water use (especially in rainfed lowlands and uplands). In irrigation lowlands this overestimation would be less because production is about potential with respect to water input.

In Figure 5-1 the difference between the virtual water contents of rice producing countries is depicted. Compared to the virtual water contents found for this study Hoekstra and Chapagain both overestimate and underestimate water use (see Appendix I). Therefore the small difference in water use between both studies may be coincidence



* VWC ORYZA2000
** VWC Hoekstra and Chapagin (2007a) if outflow was considered not to be depleted.

Figure 5-1: Virtual water content of rice using a different methodology

Integration of ORYZA2000 with GIS made it possible to simulate rice growth using a GIS-based climatology and specify areas of land use at a high resolution (10 by 10 arc-minutes). We believe this approach gives a more accurate estimation of water use during crop growth than the method used by Hoekstra and Chapagain (2007a). To compare results at a higher resolution we used data from Kampman (2007) who used the same methodology as described in Chapagain *et al.* (2005) to calculate water use of rice in states of India. In Table 5-4 an overview of the differences in water use is presented between both Kampman's methodology and the methodology we used in this study.

Hoekstra and Chapagain (2007) found an average crop water use of 5520 m^3 ha^{-1} (without depetion of outflow). Kampman showed that calculation at a higher resolution resulted in a water use of 7163 km^3 ha^{-1}. Compared to Kampman the with ORYZA2000 simulated average crop water use for rice growth in India was about 27% less. A reason for this difference in water depletion can be attributed to the difference in model and methodology used for simulating rice growth in both studies. An other explanation can be found in the use of different input data (e.g. weather data and variety). Differences in the volumes of blue water used for rice growth can be found in the different approach of calculating blue water use.

Table 5-4: Calculation of water use concerning rice production in states of India using different methodologies

State	crop water use (m^3 ha^{-1})			crop water use (m^3 ha^{-1})		
	Blue*	Green*	Total	Blue**	Green**	Total
Andhra Pradesh	4379	4258	8636	4099	3149	7249
Assam	183	5734	5917	71	3600	3672
Bihar	858	5695	6554	358	3980	4338
Delhi	4993	4385	9378	3233	3797	7030
Gujarat	2910	4560	7470	1471	4625	6096
Haryana	5355	4168	9523	3510	3228	6737
Himachal Pradesh	624	4417	5041	1807	4596	6403
Jammu & Kashmir	3243	3721	6964	2277	3628	5905
Karnataka	3101	4560	7661	3266	3332	6597
Kerala	942	6116	7058	791	4600	5391
Madhya Pradesh	481	5315	5795	229	4408	4637
Maharashtra	841	5682	6522	763	4417	5180
Orissa	618	6412	7029	869	4240	5110
Punjab	4649	4233	8882	3181	3172	6353
Rajasthan	3996	3531	7527	3772	3616	7388
Tamil Nadu	4550	4647	9197	3900	3002	6903
Uttar Pradesh	1851	5385	7236	838	4286	5123
West Bengal	1407	5160	6567	290	3727	4017
Total	1887	5275	7163	1344	3862	5206

* source: Kampman (2007)
** source: ORYZA2000

On a global scale differences between water use for rice growth are negligible compared to what Hoekstra and Chapagain found if they would have assumed outflow to be depleted. However, on country level water use may differ considerably. Where Hoekstra and Chapagain overestimated water use for countries like India and Thailand, water use for China was underestimated compared to the simulation with ORYZA2000. These differences are likely due to the use of a different crop model in simulating water use for rice growth. Also the use of different input data may affect the results. We believe modeling water use in rice producing countries with the rice growth model ORYZA2000 gives a better estimation, mainly because CROPWAT is not supposed to be used for the calculation of crop water requirements for rice. Compared to the calculation of water use for rice growth in India by Kampman, Hoekstra and Chapagin underestimated water use. Nevertheless, we believe modeling water use on a high resolution using spatial explicit data is a more realistic approach resulting in better results.

5.3 The virtual water content of rice products

In Figure 3-3 the processing steps were shown that transform the harvested rice grain into paddy, brown, white and broken rice. The virtual water content of the grain is attributed to the products as described in § 3.1. For the major rice producing countries the green and blue virtual water content of the products are presented in Table 5-5. In Appendix J the virtual water content of rice products for all simulated countries can be found.

Table 5-5: Virtual water content of rice products. Period 1999 – 2003.

Country	paddy rice		brown rice		white/ broken rice	
	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	blue (m^3 ton^{-1})	green (m^3 ton^{-1})
Bangladesh	572	916	715	1,145	854	1,368
Brazil	641	1,316	801	1,644	942	1,935
China	352	707	440	884	503	1,010
Egypt	1,040	40	1,300	50	1,552	59
India	458	1,315	572	1,644	683	1,963
Indonesia	400	1,024	500	1,280	588	1,506
Japan	276	873	345	1,091	378	1,196
Korea, Republic of	146	1,086	182	1,358	235	1,752
Myanmar	127	1,466	159	1,833	189	2,189
Nepal	1,939	792	2,424	991	2,894	1,183
Pakistan	508	1,319	634	1,649	781	2,030
Philippines	184	798	230	998	256	1,109
Thailand	213	1,431	266	1,789	323	2,169
United States of America	982	371	1,227	463	1,402	529
Viet Nam	333	856	417	1,070	513	1,317
Average	*448*	*1,007*	*560*	*1,259*	*680*	*1,530*

The virtual water content of a processed product is larger than the virtual water content of paddy rice. The reason for this difference can be found in the weight loss if paddy rice is processed into products.

5.4 Water productivity

The production of rice faces competition from other water uses and therefore the sustainability of irrigated rice systems is threatened. To compete this fresh water challenge water needs to be used more efficiently. In 2000 Kofi Annan called for an increase in water productivity by using the expression 'more crop per drop' (Annan, 2000). Particularly in areas which experience 'physical' water scarcity an increase in water productivity is vital to sustain production (and food security in most developing countries) and prevent environmental degradation.

Water productivity *WP* is a measure of performance expressed as the ratio of output (benefit) to input, i.e. water. In rice production yield is the primary physical output of the use of water. At plant level it is of interest to assess this efficiency by looking at the conversion of the volume of water used for process depletion (i.e. evapotranspiration) into yield. Therefore we were interested in the productivity of the volume of water used for evapotranspiration WP_{ET}. Compared to the virtual water content this efficiency (kg m^{-3}) is the inverse of the virtual water content.

$$WP_{\mathrm{ET}} = VWC^{-1} = \frac{\text{yield}}{CWU} \qquad (21)$$

Like Liu *et al*. (2007) we specified the contribution of blue water to water productivity on irrigated lands. Therefore we calculated both rainfed water productivity RWP_{ET} and irrigated water productivity IWP_{ET} on irrigated lands using equations (22) and (23).

$$RWP_{\mathrm{ET}} = \frac{\mathrm{yield}_{\mathrm{rainfed}}}{CWU_{\mathrm{green}}} \tag{22}$$

$$IWP_{\mathrm{ET}} == \frac{\mathrm{yield}_{\mathrm{irrigated}} - \mathrm{yield}_{\mathrm{rainfed}}}{CWU_{\mathrm{blue}}} \tag{23}$$

where $\mathrm{yield}_{\mathrm{rainfed}}$ is the yield contributed by green water on irrigated lands and $\mathrm{yield}_{\mathrm{irrigated}}$ is the yield due to the use of blue water. In all cases the simulated yield was taken because FAO only provide statistics on yields for a country as a whole, which covers all ecosystems and not ecosystems in particular.

To show the contribution of blue water use to yields we compared both water productivities with each other. In Table 5-6 water productivities for both seasons of irrigated lowlands in the major rice producing countries are presented

Table 5-6: Water productivity of irrigated lowlands in major rice producing countries

Country	irrigated lowland							
	first season				second season			
	$\mathrm{yield}_{\mathrm{irrigated}}$ (kg ha^{-3})	$\mathrm{yield}_{\mathrm{rainfed}}$ (kg ha^{-3})	$\mathrm{IWP}_{\mathrm{ET}}$ (kg m^{-3})	$\mathrm{RWP}_{\mathrm{ET}}$ (kg m^{-3})	$\mathrm{yield}_{\mathrm{irrigated}}$ (kg ha^{-3})	$\mathrm{yield}_{\mathrm{rainfed}}$ (kg ha^{-3})	$\mathrm{IWP}_{\mathrm{ET}}$ (kg m^{-3})	$\mathrm{RWP}_{\mathrm{ET}}$ (kg m^{-3})
Bangladesh	5,046	4,223	1.17	0.95	7,576	1,005	1.34	0.44
Brazil	7,694	1,694	1.19	0.44	-	-	-	-
China	6,742	2,903	1.59	0.66	8,014	3,115	2.70	0.74
Egypt	5,347	131	0.54	0.36	-	-	-	-
India	6,324	2,728	1.76	0.68	6,248	418	0.92	0.21
Indonesia	8,702	5,613	2.18	1.03	8,838	1,580	1.60	0.55
Japan	5,203	3,215	1.12	0.57	-	-	-	-
Korea, Repulblic of	6,845	3,896	1.82	0.77	-	-	-	-
Myanmar	6,332	5,585	2.96	1.31	8,715	20	1.52	0.03
Nepal	6,782	3,783	2.89	0.91	-	-	-	-
Pakistan	5,041	382	0.81	0.16	-	-	-	-
Philippines	7,749	5,827	2.27	1.13	8,787	1,164	1.80	0.46
Thailand	6,818	4,353	2.12	1.04	7,636	299	1.22	0.27
United States	5,872	397	0.78	0.15	-	-	-	-
Vietnam	6,683	3,482	1.88	0.89	7,061	2,157	1.51	0.71

The use of blue water for rice growth results in higher yields where green water is limiting. Also the use of blue water results in a higher productivity than if rice would only be grown with green water. In relative water scarce countries like Egypt without blue water yields are very low. In China blue water use is 35% from ET in the first season and 30% in the second season. Yields increased considerably compared to yields under irrigated conditions.

In Appendix K water productivity for all countries for which rice growth is simulated with ORYZA2000 is presented. We also included the water productivity of rice grown on rainfed lowlands and uplands.

More rice, less water: possibilities

According to Tuong *et al.* (2004) enhancement of WP at plant level may result from breakthroughs in rice breeding. An increase of grain yields can therefore be achieved by improvements of (a) the amount of biomass produced by photosynthesis and (b) the amount of biomass portioned to the grains (harvest index).

At field level water inputs can be reduced by integrating water management strategies like alternate wetting and drying (AWD), aerobic rice systems and saturated soil culture (SSC). These technologies can reduce both evaporation losses (especially from water surfaces) and outflows by reducing the duration fields are flooded.

6 Water quality

6.1 Biocides

Biocides like pesticides (insecticides en herbicides) have been considered as the only reliable methods to suppress pests in agriculture and sustain yields. Although its effectiveness the use of biocides has side effects. These chemicals can disrupt the biological control by devastating populations of beneficial species in the habitat which are natural predators to suppress a pest population. Disrupting this natural control can lead to outbreaks of pests instead of controlling them. Also chemicals can affect both the quality of human health and the environment directly as well indirectly.

Most of the applied biocides in the tropics is lost through volatilization or transformed by (photo-)chemical decomposition or biological degradation. However, less is known about the toxicity of the residual components (Bouman *et al.* 2006). Also little is known about quantities of biocides used in rice production. Farm surveys may give insight in the number of sprays. However, these intensive surveys are site specific and can therefore not be generalized. Because the behavior of a farmer depends on its fundamental perception sprays differ from locations (Heong, personal communication (2006)). Therefore it was decided not to include biocide use in this study.

6.2 Nitrogen

Besides the biochemical process of photosynthesis the rice plant requires macronutrients for growth of which nitrogen N is the limiting nutrient in rice cultivation. The nitrogen requirement of the various plant organs depends on growth stage and the method of planting (transplanting or direct seeding). Most of this nitrogen is obtained by plants from the soil. However, the supply is often limited to sustain rice yields (especially under aerobic conditions). Therefore compound fertilizers are applied providing extra nutrients. These fertilizers can be added in either organic or inorganic form. According to Buresh and De Datta (1990) urea is most applied in tropical areas as N fertilizer.

The impact of fertilizer use depends on the amount of fertilizer applied and the plants fertilizer uptake. If there is a mismatch between demand and supply excessive nutrients may leach out of the root zone contaminating both groundwater and surface water affecting both environments as well as human health. We assumed the impact of nutrients like potassium K and phosphorus P to be low because of its mobility. Therefore they are not taken into account in this study.

Nitrogen cycle

Like any other plant the rice plant must secure their nitrogen in fixed form incorporated in inorganic compounds like ammonium NH_4 or nitrate NO_3. The movement and transformation of the nitrogen components between the atmosphere, biosphere and geosphere – the nitrogen cycle (see Figure 6-1) – takes place through critical processes like, immobilization/mineralization and (de-)nitrification. Besides these transformation processes nitrogen is lost by crop removal, leaching and runoff with surface water. The magnitude and nature of N losses vary depending on the timing and method of N application, source of N fertilizer, soil chemical and physical properties, climatic conditions and crop status (Peng *et al.* 2002).

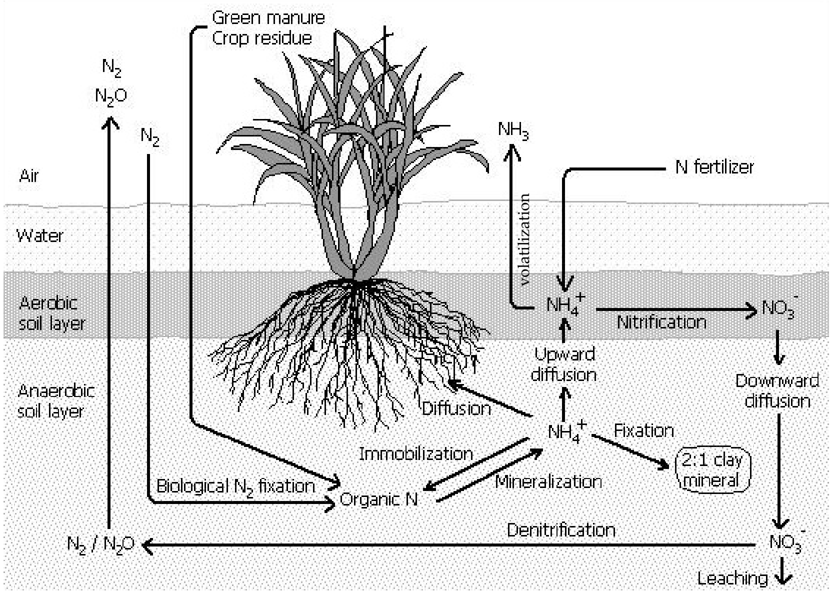


Figure 6-1: Nitrogen cycle (source: Buresh, personal communication (2006))

Most of lowland rice fields are continuous or intermittent submerged with water. Therefore the supply of oxygen is greatly diffused (the diffusivity of oxygen in water is less than in air) affecting N-transformations. Compared to aerated soils the transformation processes are the same. An unique feature of submerged soils is the simultaneous formation and loss of N by nitrification-denitrification within the adjacent aerobic and anaerobic soil layers (Buresh, personal communication (2006)). Therefore not nitrate but ammonium is the dominant and stable form of inorganic N in lowland rice soils. Different ^{15}N tracers studies were conducted to quantify and manage N losses of applied N fertilizer (urea). Most of the nitrogen applied to a rice field is lost through crop removal, ammonia volatilization and nitrification-denitrification.

Denitrification was considered to be the main pathway for N losses in submerged agricultural soils. In puddled soils that remained saturated or submerged more than 90% of the urea was lost through volatilization of ammonia (Buresh and De Datta, 1990). Management strategies like alternate soil drying and wetting account for nitrification-denitrification losses of urea of 12 to 16% (Buresh *et al*., 1993). In the more aerated rainfed upland soils nitrification-denitrification losses of N fertilizer applied may be higher.

Recovery efficiency *RE* of N fertilizer use of lowland soils is low. The uptake of applied N fertilizer ranges from 30% to 50% (De Datta, 1986) in the tropics and has not improved throughout the years. In China were most of the nitrogen fertilizer is used in world's rice production (IFA, 2002) a recovery efficiency *RE* of 30% – 35% is observed in rice fields. However, there are states in which *RE* is significantly below average mostly because of indigenous N supply to sustain yields and bad timing of the fertilizer application (Peng *et al.* 2002).

Leaching is normally not an important process on lowland rice soils. Outcomes show that a high leaching potential of the soluble nitrate with excess soil water is counterbalanced by transformation processes under anaerobic conditions (Bouman *et al.* 2002). However, some fertilizer N applied may be lost as an inorganic form and accumulate in ground water and other water bodies through runoff and leaching. Despite the environment concern of these processes little is known about N transportation from fields. In uplands in China leaching rates of 0.5 – 4.2% of applied N have been found. In lowland rice rates were higher (3.1 – 9.0%). For runoff a maximum of 7% was found (Xing and Zu, 2000).

Effects of nitrogen use

Like ammonia, enrichment of aquatic ecosystems with nitrate – a process called eutrophication – results in prolific algal bloom. When these excessive growth of algae reduces the amount of dissolved oxygen to hypoxic levels aquatic life may be killed. Also some types of algae can produce toxins which may be hazardous to other aquatic (in-) vertebrates.

Beside nitrate and ammonium the unstable nitrite may encourage plant proliferation. Moreover, nitrite is toxic to aquatic life at relatively low concentrations. Because ground water and surface water are both sources of drinking water, contamination of these water bodies may also be a risk for human health. If ingested in water and not converted to nitrite, nitrate is less harmful. However, long term exposure of the human body to high levels of nitrate may cause health problems on the long-term like cancer (although data are inconclusive). Nitrite however is an immediate health concern if absorbed in blood. Because nitrite is able to oxidize the protein haemoglobin (Hb) to methemoglobin (metHb), the oxygen transporting capacity of the blood cells is reduced (in contrast to Hb, metHb is unable to carry oxygen) producing physical stress. Especially infants (< 6 months) may suffer from this blood disorder Methemoglobinemia, or the so-called blue baby syndrome

6.3 Dilution water

Quantitative estimations of agrochemical's fate as a result of leaching and runoff requires complex mathematical models. Various efforts have been made (Miao *et al.*, 2003) to simulate leaching and runoff of agrochemicals from rice to assess environmental impacts on field level. Looking at the scope of this study it is impossible to give an detailed prescription of how much of the agrochemicals used in rice fields may contaminate water bodies. Therefore it depends on too many factors which are not available on global scale. It was however possible to give an estimation on how many of the applied agrochemicals *may* contaminate water bodies and calculate the volume of dilution water by multiplying it with a given guideline value. This is however a more conservative approach.

The amount of fertilizer applied depends on the rice production system and is site specific. Compared to irrigated ecosystems, N fertilizer is applied in much smaller amounts in rainfed lowlands and uplands. In these systems climatic and abiotic stresses (drought and flooding) as well a smaller yield potential are the main reasons why these input is less (Doberman and Fairhurst, 2000). IFA (2002) provides statistics about fertilizer use per crop for selected countries and years. We assumed the application rate of the 34 countries provided by IFA remained the same throughout the years in order to calculate fertilizer consumption for the period 1999 – 2003.

The amount of N fertilizer contaminating ambient water sources *L* is the remainder of N which has not been recovered by the rice plant or transformed by processes in the soil. We assumed 5% of the applied N fertilizer is accumulated in ground water and water bodies. Using equation (11) we calculated the grey virtual water content for which we used the same standard of 10 mg L^{-1} $NO_3 - N$ as the permissible limit for nitrate in drinking water as Chapagain *et al*. (2005) used for the cotton study. In Table 6-1 available fertilizer applications provided by IFA *et al*. (2002) and the volume of dilution water required is given for the major rice producing countries.

Table 6-1: Fertilizer N application and the volume of water needed to dilute the nitrate that is contaminating water bodies in major rice producing countries. Period 1999 – 2003.

Country	Production (kton)	Area fertilized (ha)	N application rate (kg ha^{-1})	N consumption (ton yr^{-1})	Nirogen contaminating water bodies (ton yr^{-1})	Volume of dilution water (km^3 yr^{-1})	VWC_{grey} (m^3 ton^{-1})
Bangladesh	37,002	10,754,034	72	774,290	38,715	3.9	105
Brazil	10,755	2,371,310	40	94,852	4,743	0.5	44
China	181,634	29,274,307	145	4,244,774	212,239	21.2	117
Egypt	5,865	632,261	119	75,239	3,762	0.4	64
India	128,319	32,770,800	68	2,218,583	110,929	11.1	86
Indonesia	51,370	10,485,851	105	1,101,014	55,051	5.5	107
Japan	11,101	1,723,400	78	134,425	6,721	0.7	61
Korea, Republic of	6,868	1,058,181	110	116,400	5,820	0.6	85
Myanmar	21,663	3,820,175	35	133,706	6,685	0.7	31
Pakistan	6,950	2,338,360	52	122,062	6,103	0.6	88
Philippines	12,780	3,426,533	51	174,753	8,738	0.9	68
Thailand	25,927	9,030,231	62	559,874	27,994	2.8	108
United States of America	9,281	1,235,767	150	185,365	9,268	0.9	100
Viet Nam	33,010	6,798,438	115	781,820	39,091	3.9	118
Other	27,065	6,127,843	-	338,976	16,949	1.7	63
Average	-	-	-		-	-	97
Total	**569,590**	**121,847,490**	-	**11,056,136**	**552,807**	**55.3**	**-**

Note: the total reflects the total of the countries provided by IFA *et al.* (2002)

Compared to the total volume of water used for rice growth about 6.5% is needed for dilution of accumulated N fertilizer in ground water and water bodies. One should keep in mind we only took a look at nitrogen fertilizer. If information about the use of biocides were available a probably higher grey volume would be needed to dilute contaminated water bodies.

To assess virtual water flows the average grey virtual water content is used for the rice-exporting countries which are not provided by IFA.

6.4 Resumé

An overview of the three components of the virtual water content of the different rice products in the major rice producing countries is presented in Table 6-2. In Appendix J an overview for all rice producing countries can be found. The global production averaged paddy virtual water content is 1552 m^3 ton^{-1}. The global volume of water use for rice production is estimated to be 919 km^3 year^{-1} (see Appedix H)

Table 6-2: Total virtual water content of rice products for major rice producing countries. Period 1999 – 2003.

	paddy rice				brown rice				white/ broken rice			
	blue	green	green	total	blue	green	grey	total	blue	green	grey	total
	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})	(m^3 ton^{-1})
Bangladesh	572	916	105	1,593	715	1,145	131	1,991	854	1,368	156	2,378
Brazil	641	1,316	44	2,000	801	1,644	55	2,501	942	1,935	65	2,942
China	352	707	117	1,176	440	884	146	1,470	503	1,010	167	1,680
Egypt	1,040	40	64	1,144	1,300	50	80	1,429	1,552	59	96	1,707
India	458	1,315	86	1,859	572	1,644	108	2,324	683	1,963	129	2,775
Indonesia	400	1,024	107	1,531	500	1,280	134	1,914	588	1,506	158	2,252
Japan	276	873	61	1,209	345	1,091	76	1,512	378	1,196	83	1,657
Korea, Republic of	146	1,086	31	1,263	182	1,358	39	1,579	235	1,752	50	2,037
Myanmar	127	1,466	97	1,690	159	1,833	121	2,113	189	2,189	145	2,523
Nepal	1,939	792	88	2,819	2,424	991	110	3,524	2,894	1,183	131	4,208
Pakistan	508	1,319	68	1,895	634	1,649	85	2,369	781	2,030	105	2,916
Philippines	184	798	85	1,067	230	998	106	1,334	256	1,109	118	1,482
Thailand	213	1,431	108	1,752	266	1,789	135	2,191	323	2,169	164	2,655
United States of America	982	371	100	1,452	1,227	463	125	1,815	1,402	529	143	2,074
Viet Nam	333	856	118	1,308	417	1,070	148	1,635	513	1,317	182	2,012
Average	*448*	*1,007*	*97*	*1,552*	*560*	*1,259*	*121*	*1,940*	*680*	*1,530*	*147*	*2,357*

7 Virtual water flows

7.1 Trade in rice

In relation to its production the rice market has always been relatively 'thin'. The demand of Asian and African countries (as a result of policies and production setbacks) in the early 1990's gave rise to the trade volume in relation to production leading to a 'deepening' of the market (Calpe, 2004). Over the period 1999 - 2003 trade in rice products (paddy, white, brown and broken rice) was 3.7% of global paddy rice production. However, the rice market is, compared to other major cereal products (like wheat (20%) and maize (14%)) still thin (FAO, 2007c).

To explain this relative thin rice market with 'deep' cuts one should take a look at the importance of rice cultivation in developing countries. In developing countries rice is staple food for large segments of the population. To achieve food security countries need to be self sufficient. Therefore trade in rice remains a residual option (Calpe, 2004).

Supply of rice is highly concentrated. In the period 1999 – 2003 the top 10 of major exporters of rice, like Thailand and Vietnam, are responsible for about 90% of the total supply to partner countries. In contrast to the supply side the demand side is geographically dispersed. Here the top 10 importers only account for about 43% of the total (see Appendix L).

Of all rice products included in this study, trade in white rice is strongly dominant. Over the period 1999 - 2003 trade in white rice was about 70% of the total import of paddy, brown, white and broken rice.

7.2 Virtual water flows

As mentioned before trade in rice products brings along flows of 'embedded' water. These virtual water flows between countries can be calculated using equation (14). The results of both virtual water import and export are shown in Appendices M and N.

Over the period 1999 – 2003 the calculated virtual water flows between countries in relation to the international trade in rice products was estimated to be 51 km^3 $year^{-1}$. Almost 58% of these flows refer to green water and about 36% to blue water and less than 6% to grey water. The top 15 of rice producing countries contribute to 82% of the global virtual water exports (see Table 7-1).

Table 7-1: Virtual water export from the top 15 rice producing countries. Period 1999 – 2003.

Country	VWE_{blue} ($km^3\ yr^{-1}$)	VWE_{green} ($km^3\ yr^{-1}$)	VWE_{grey} ($km^3\ yr^{-1}$)	VWE_{total} ($km^3\ yr^{-1}$)	Contribution to global VWE
Bangladesh	0.00	0.00	0.00	0.00	0.0%
Brazil	0.03	0.07	0.00	0.10	0.2%
China	1.32	2.65	0.44	4.40	8.7%
Egypt	0.41	0.02	0.03	0.45	0.9%
India	1.89	5.42	0.36	7.67	15.2%
Indonesia	0.01	0.01	0.00	0.02	0.0%
Japan	0.08	0.26	0.02	0.37	0.7%
Korea, Republic of	0.00	0.00	0.00	0.00	0.0%
Myanmar	0.03	0.21	0.01	0.24	0.5%
Nepal	0.00	0.00	0.00	0.00	0.0%
Pakistan	2.70	1.10	0.12	3.93	7.8%
Philippines	0.00	0.00	0.00	0.00	0.0%
Thailand	1.78	11.99	0.90	14.68	29.0%
United States of America	3.91	1.48	0.40	5.79	11.4%
Viet Nam	0.98	2.52	0.35	3.85	7.6%
Others	5.22	3.43	0.46	9.10	18.0%
Global	18.36	29.15	3.08	50.60	

Note: the total presented for China not include trade statistics from Taiwan, Hong Kong and Macau, only mainland.

Of these countries Thailand is the largest exporter of green water in particular. Most of the virtual water is imported with rice products like white and broken rice by countries like Nigeria and Indonesia. In Figure 7-1 virtual water flows between Thailand, Nigeria and Indonesia are shown. The largest exporter of blue water are the USA of which most is attributed to the export of paddy and white rice to countries as Mexico and Japan.

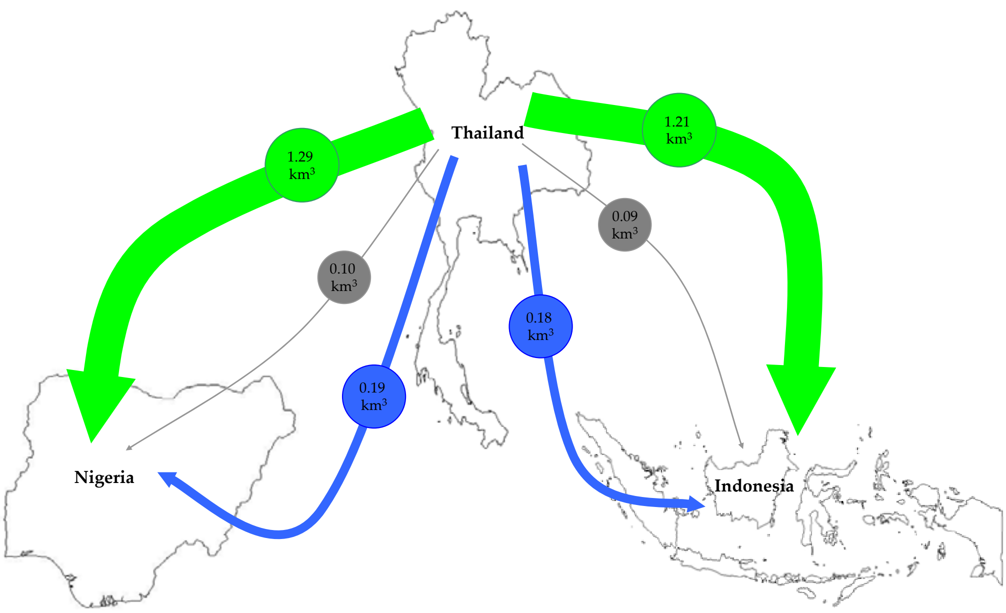


Figure 7-1: Virtual water export from Thailand to Nigeria and Indonesia

Exporting countries face environmental externalities (e.g. water depletion) from foreign rice consumers.

Import of virtual water in the major rice producing countries is, compared to export, relatively small (26%). Of all major rice producing countries in the world Indonesia is the biggest importer of water related to the import of rice products (see Table 7-2). Most of the virtual water import is related to the import of white (57%) and broken rice (33%). Regarding the import of white rice about 76% of the water use is green (mainly pressing in Thailand (39%) and Vietnam (28%). Almost 29% of the blue water use presses in countries like Viet Nam (26%) and China (21%). With the import of broken rice dominantly green water is imported (72%), mainly from Thailand (47%) and Viet Nam (31%).

Table 7-2: Virtual water import by the top 15 rice producing countries. Period 1999 – 2003.

Country	VWI_{blue} ($km^3\ yr^{-1}$)	VWI_{green} ($km^3\ yr^{-1}$)	VWI_{grey} ($km^3\ yr^{-1}$)	VWI_{total} ($km^3\ yr^{-1}$)	Contribution to global VWI
Bangladesh	0.41	1.19	0.08	1.68	3.3%
Brazil	1.23	0.66	0.07	1.96	3.9%
China	0.08	0.51	0.04	0.63	1.2%
Egypt	0.01	0.04	0.00	0.05	0.1%
India	0.03	0.02	0.00	0.05	0.1%
Indonesia	1.10	2.97	0.32	4.39	8.7%
Japan	0.69	0.60	0.10	1.39	2.7%
Korea, Republic of	0.08	0.14	0.02	0.25	0.5%
Myanmar	0.00	0.01	0.00	0.02	0.0%
Nepal	0.02	0.06	0.00	0.08	0.2%
Pakistan	0.00	0.01	0.00	0.01	0.0%
Philippines	0.44	1.19	0.13	1.76	3.5%
Thailand	0.00	0.01	0.00	0.01	0.0%
United States of America	0.21	0.71	0.06	0.98	1.9%
Viet Nam	0.00	0.01	0.00	0.01	0.0%
Others	14.04	21.03	2.26	37.33	73.8%
Global	18.36	29.15	3.08	50.60	

Note: the total presented for China not include trade statistics from Taiwan, Hong Kong and Macau, only mainland.

The virtual water flow related to the trade of rice products is about 5.5% of the total volume of water used for rice production. Therefore the impact on foreign water resources is small, compared to a product like cotton. The total virtual water flow related to the international trade in rice products is about 25% of the flow related to trade in cotton products (Chapagain *et al.*, 2005).

In Figure 7-2 the average national virtual water balances are depicted showing countries that have net virtual water import (green colored) or export (red colored). Major rice producing countries like China and India have net virtual water export. Indonesia has a net virtual water import.

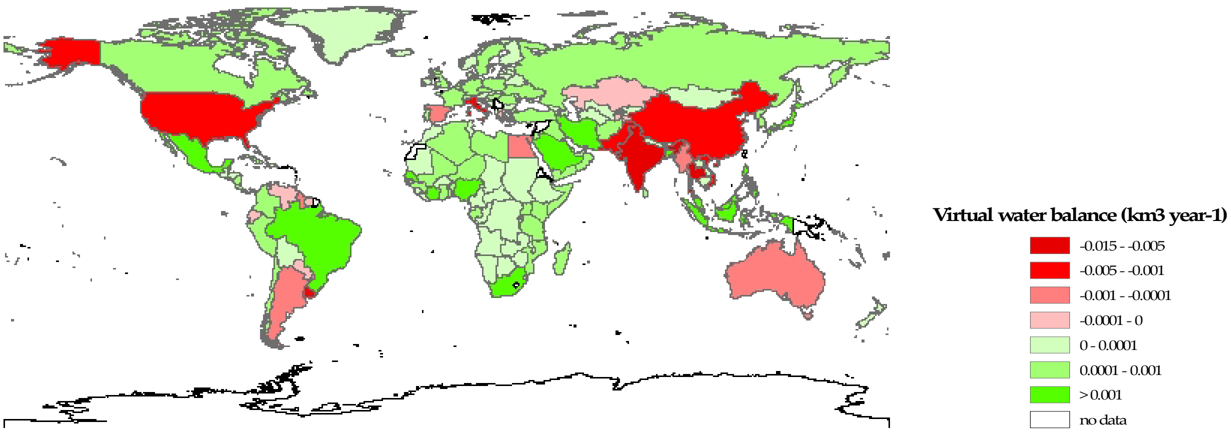


Figure 7-2: National virtual water balances

Virtual water flows between and within different world regions are presented in Table 7-3. Therefore the world has been classified into 8 regions: Africa, Asia, Central America and Caribbean, Europe, Middle East, North America, Oceania and South America. To distinguish which country lies in which world region 'The World Factbook 2007' (CIA, 2007) was used.

Table 7-3: Virtual water flows between and within world regions related to the trade in rice products (km³ year⁻¹). Period 1999 - 2003

	Africa	Asia	Central America and Caribbean	Europe	Middle East	North America	Oceania	South America	Total VWE
Africa	0.29	0.01	0.00	0.16	0.22	0.00	0.00	0.00	0.69
Asia	11.15	13.34	0.75	2.16	6.61	1.09	0.27	0.18	35.55
Central America and Caribbean	0.00	0.00	0.04	0.03	0.00	0.00	0.00	0.00	0.08
Europe	0.48	0.07	0.04	2.72	0.17	0.01	0.00	0.01	3.50
Middle East	0.02	0.04	0.00	0.01	0.62	0.00	0.00	0.00	0.70
North America	0.51	1.13	1.27	0.73	0.58	1.25	0.02	0.32	5.80
Oceania	0.01	0.25	0.00	0.06	0.26	0.05	0.08	0.00	0.71
South America	0.10	0.01	0.34	0.42	0.47	0.04	0.01	2.19	3.58
Total VWI	12.57	14.85	2.43	6.28	8.93	2.44	0.38	2.71	50.60

Of all regions Asia and North America are the biggest exporters of water related to the trade in rice products. Together they are responsible for 82% of the global volume of virtual water export. Of these flow most is imported by African and Asian countries. Asia is exporting about 70% of the total volume of virtual water traded internationally. About 90% of the total volume of virtual water import in Asia originates from countries within the region (which is about 38% of the total volume of water exported). Africa is importing about 25% of the global virtual water flows. About 89% of this volume depends on the import from Asian countries. Logically most colored water is imported by Asian and Africa countries (see Appendix O).

When we compare the share of the blue component in the world's rice production to the blue component in the export of rice products in the world, the component of rice at the world market (36%) is higher than the blue component used for global rice production (29%). This difference can be explained if we compare the global export averaged virtual water content to the global production averaged virtual water content of rice products (see Table 7-4). The export averaged virtual water content $\overline{VWC_{[export,p]}}$ of a rice product is calculated as the ratio of the sum of virtual water export from countries to the total export of the rice product.

$$\overline{VWC_{[\text{export,p}]}} = \frac{\sum T_{[\text{e,i,p}]} \times VWC_{[\text{e,p}]}}{\sum T_{[\text{e,i,p}]}} \tag{24}$$

Table 7-4: Global export averaged vs. global production averaged VWC

	paddy rice				brown rice				white rice				broken rice			
	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	grey (m^3 ton^{-1})	total (m^3 ton^{-1})	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	grey (m^3 ton^{-1})	total (m^3 ton^{-1})	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	grey (m^3 ton^{-1})	total (m^3 ton^{-1})	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	grey (m^3 ton^{-1})	total (m^3 ton^{-1})
Export average VWC	1,015	436	91	1,542	977	890	114	1,982	837	1,470	149	2,456	667	1,627	157	2,451
Production average VWC	448	1,007	97	1,552	560	1,259	121	1,940	680	1,530	147	2,357	680	1,530	147	2,357

Next to India and Thailand, the USA is one of the biggest exporters of rice products in the world. In the USA mainly blue water is used for the production of rice. About 68% of total paddy import is exported from the USA. Therefore the share of the blue virtual water content of paddy rice in the world market is higher than the blue component used for rice production. Also countries like Pakistan, Uruguay and Spain contribute to this difference by exporting rice products for which mainly blue water is used. Most of the white rice traded in the world is exported by countries which mainly use green water for the production of rice (Thailand) and therefore the green component of white rice is higher than blue component. Overall the share of the export average blue virtual water content is higher than its production average, resulting in a higher share of the blue component of rice at the world market.

Besides trade in rice products also food aid shipments bring along virtual water flows. Over the period 1999 – 2003 an average of about 1.3 million tons of rice (FAO, 2007c) were 'donated' to 'hungry' people in developing countries in order to free them from hunger. Hunger exists because of natural disasters (e.g. floods and droughts), war/ conflicts, poverty, lack of agricultural infrastructure and over-exploitation of the environment. The virtual water flow of these shipments add up to only 4% of the total volume of water concerning trade in rice products (it is assumed that paddy rice is donated). About 51% of these flows refers to green water. Of all known donors the USA and Japan are the largest exporters of water. The USA is the biggest exporter of blue water. In Table 7-5 an overview of the 5 largest importers (the 'hungry') and exporters (donors) is depicted.

Table 7-5: Virtual water flows concerning food aid shipments. Period 1999 – 2003.

Country	VWI_{blue} (km^3 yr^{-1})	VWI_{green} (km^3 yr^{-1})	VWI_{grey} (km^3 yr^{-1})	VWI_{total} (km^3 yr^{-1})	Country	VWE_{blue} (km^3 yr^{-1})	VWE_{green} (km^3 yr^{-1})	VWE_{grey} (km^3 yr^{-1})	VWE_{total} (km^3 yr^{-1})
Korea, Dem People's Rep	0.17	0.38	0.04	0.59	United States of America	0.40	0.15	0.04	0.59
Indonesia	0.14	0.07	0.01	0.22	Japan	0.09	0.28	0.02	0.38
Iraq	0.07	0.11	0.01	0.19	China	0.03	0.06	0.01	0.10
Philippines	0.07	0.02	0.01	0.10	Italy	0.03	0.02	0.00	0.05
Mozambique	0.03	0.06	0.01	0.09	Australia	0.03	0.00	0.00	0.04
Other	0.30	0.30	0.04	0.63	Others	0.20	0.43	0.04	0.67
Global flows	*0.77*	*0.94*	*0.12*	*1.83*	Global flows	*0.77*	*0.94*	*0.12*	*1.83*

Food aid shipments were not included in the calculation of the global water footprint. Therefore water footprints of both providing and receiving countries of food aid are somewhat over- and underestimated. In case of donor countries the water footprint is overestimated because export of food aid is consumed by the citizens of these countries. In countries which are receiving food aid less rice is available for consumption and thus the water footprint is underestimated.

7.3 Water savings

Virtual water trade generates 'physical' water savings in countries that import products. These national water savings can save water at global level if there is a trade flow from countries with a high to countries with a low water productivity. On the contrary there may also be a net water loss. To give an indication of the consequences of international virtual water flows on water budgets we calculated global water savings through international trade in rice products for only the with ORYZA2000 simulated countries, covering 68% of global total trade in rice products. The average global volume of virtual water flows related to the trade in rice products between the for with ORYZA2000 simulated countries was estimated to be 34 km^3 year^{-1} (an average for the period 1999 – 2003). This estimate was based on the virtual water content of products in the exporting countries.

Like Chapagain et al. (2006) the global water saving ΔS_{g} through trade the trade of rice products from exporting country n_{e} to importing country n_{i} was calculated by multiplying the amount of trade between the two countries with the difference between the water productivities of the trading partners.

$$\Delta S_{\mathrm{g}}\left[n_{\mathrm{e}}, n_{\mathrm{i},} p\right] = \left(VWC\left[n_{\mathrm{i}}, p\right] - VWC\left[n_{\mathrm{e}}, p\right]\right) \times T\left[n_{\mathrm{e}}, n_{\mathrm{i}}, p\right] \qquad (25)$$

If the water productivity in the exporting country is lower than the productivity in the importing country there will be a net water loss and ΔS_{g} has a negative sign. The total global water saving was obtained by summing up the global water savings of all trades.

We found the global water saving by trade in rice products to be 14 km^3 year^{-1}, saving about 41% of the international virtual water flows related to the trade in rice products and 1.5% of the global water use for rice growth in the with ORYZA2000 rice producing countries (see Table 7-6). In Appendix P the global water savings per country are presented. The contribution of the different rice products are presented in Table 7-7. Because most white rice is traded internationally this product is responsible for 85% of the total global water saving.

Table 7-6: Global water saving. Period 1999 – 2003.

	blue	green	grey	total
Global sum of virtual water exports, assessed on the basis of the virtual water content in the exporting countries (km^3 year^{-1})	11.69	19.80	2.12	33.61
Global sum of virtual water imports, assessed on the basis of the virtual water content in the importing countries (km^3 year^{-1})	19.39	25.95	1.88	47.21
Global water saving (km^3 year^{-1})	7.70	6.15	-0.24	13.60
Saving compared to the sum of international virtual water flows related to the trade in rice products	65.9%	31.0%	-11.5%	40.5%
Saving compared to the global water use for rice growth	2.9%	1.0%	-0.4%	1.5%

Like the virtual water content the global water saving is made out of a green, blue and grey component. About 66% of the international blue virtual flow related to the trade in rice products is saved by importing products rather than producing them domestically. In countries like Iraq and Iran, where rice is only grown under irrigated conditions most blue water is saved. The trade flow between Thailand – Iraq is the biggest blue water saver (3.1 km^3 $year^{-1}$). Since blue water has a higher opportunity cost than green water these countries gain from importing rice products because it saves blue water resources. The biggest green water save is generated by the export of white rice from China to Côte d'Ivoire (1.54 km^3 $year^{-1}$). In Figure 7-3 global water savings and losses associated with international trade in rice products are presented. Only the trade flows that save more than 0.50 km^3 $year^{-1}$ of green and blue water are shown.

Table 7-7: Global water saving per rice product. Period 1999 – 2003.

Product	Water saving (km^3 $year^{-1}$)			
	blue	green	grey	total
Paddy rice	-0.52	0.69	0.01	0.18
Brown rice	0.05	0.28	-0.01	0.32
White rice	7.59	4.09	-0.20	11.49
Broken rice	0.57	1.08	-0.05	1.61
Total	7.70	6.15	-0.24	13.60

The biggest rice importing country in the world, Indonesia, saves only 0.01 km^3 $year^{-1}$ of water. Despite of a global blue water saving of 0.04 km^3 $year^{-1}$ Indonesia has a global green water loss of 0.03 km^3 $year^{-1}$. This loss results from the import of white and broken rice from Thailand of which its green water use for rice growth is relatively high compared to Indonesia. Green water savings from China and Viet Nam can partially compensate the global green water loss.

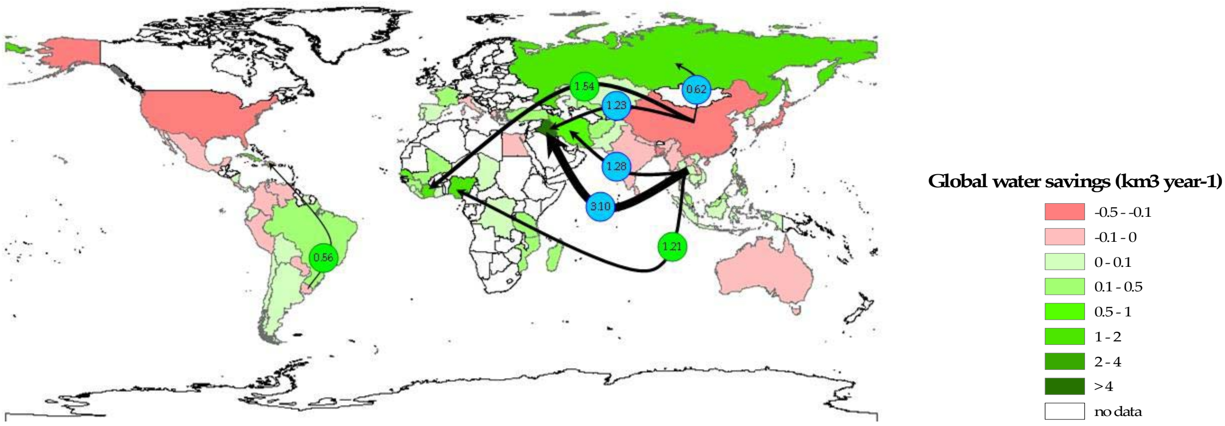


Figure 7-3: Global water savings and losses per country. Period 1999 – 2003.

8 Water footprints

A nation's water footprint *WFP* (m^3 $year^{-1}$) of rice is defined as the total amount of water that is used to produce rice consumed by the inhabitants of the nation including two components: the part of the footprint that falls inside the country (internal water footprint *IWFP*) and the part of the footprint that presses on other countries in the world (external water footprint *EWFP*). This distinction refers to the use of domestic water resources versus the use of foreign water resources. We assumed that domestic supply for human consumption equals total rice production and net import of rice products in a country (stock changes were not taken into account).

The global water footprint related to the consumption of rice products is estimated to be 919 km^3 $year^{-1}$, which is 151 m^3 $year^{-1}$ per capita in average. About 65% of this footprint is due to the use of green water, another 29% to the use of blue water and about 6% to the dilution water requirements (see Table 8-1). In Figure 8-1 the composition of the water footprint in the major rice producing countries is shown. In Appendix Q the composition of the water footprint is presented per country.

Hoekstra and Chapagain (2007a) found an average global water footprint of 7450 km^3 $year^{-1}$ for the period 1997 – 2001. This includes the use of green and blue water, but excludes the grey water use. Of this footprint 86% was related to agricultural products. If Hoekstra and Chapagain would have considered outflow as depleted in rice production they would have found a global agricultural water footprint of 5920 km^3 $year^{-1}$. In this study we found the total volume of the water footprint related to rice consumption without the grey component to be 861 km^3 $year^{-1}$. Therefore, about 14% of the global agricultural water footprint is related the consumption of rice products.

Table 8-1: The global water footprint related to rice consumption (km^3 $year^{-1}$). Period 1999 – 2003.

	WFP_{blue}	WFP_{green}	WFP_{grey}	WFP_{total}	Contribution to total WFP
IWFP	247.5	568.6	54.5	870.6	95%
EWFP	17.4	27.6	2.9	48.0	5%
WFP_{total}	264.9	596.3	57.4	918.6	
Contribution to total WFP	29%	65%	6%		

Note: the IWFP and EWFP at global scale refers to respectively the aggregated internal and external footprint of all nations of the world

Because of the thin rice market the impact on foreign water resources by countries is small. Only 5% of the water footprint presses in other countries, which is relatively small compared to a product like cotton of which this external water footprint is 44% (Chapagain *et al.*, 2005).

With a water footprint of about 231 km^3 $year^{-1}$ India has the largest water use related to rice consumption and contributes for 25% to the global water footprint of rice. Almost all of the water footprint in India is from the use of internal water resources. An overview per region is presented in Appendix R.

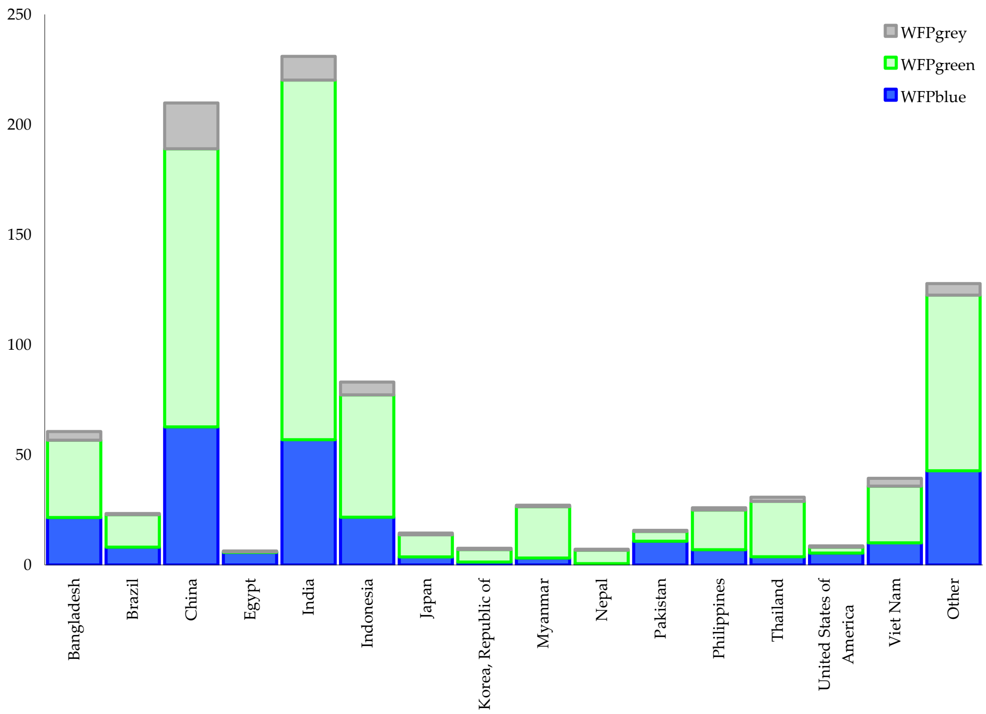


Figure 8-1: Water footprints of major rice producing countries (km³ year⁻¹)

Although India has the highest water footprint related to rice consumption, the highest water footprints per capita were found in Cambodia, Laos, Myanmar and Thailand. In Cambodia the water footprint per capita is almost 5 times the average water footprint per capita. Most low water footprints were found in industrialized countries like the USA and countries in Europe. are shown In Figure 8-2 water footprints per capita WFP_{cap} (m^3 cap^{-1} $year^{-1}$) for all rice consuming countries in the world are presented.

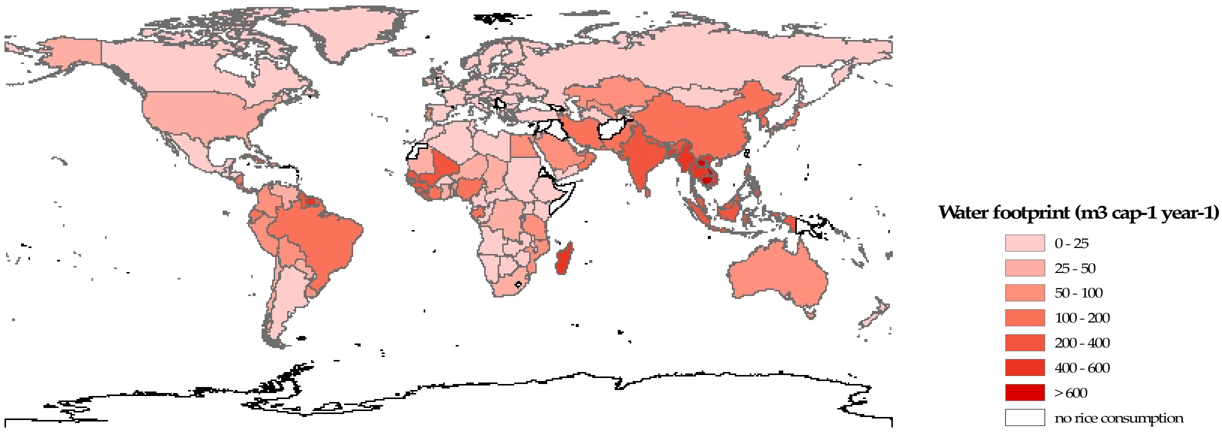


Figure 8-2: Average water footprint per capita

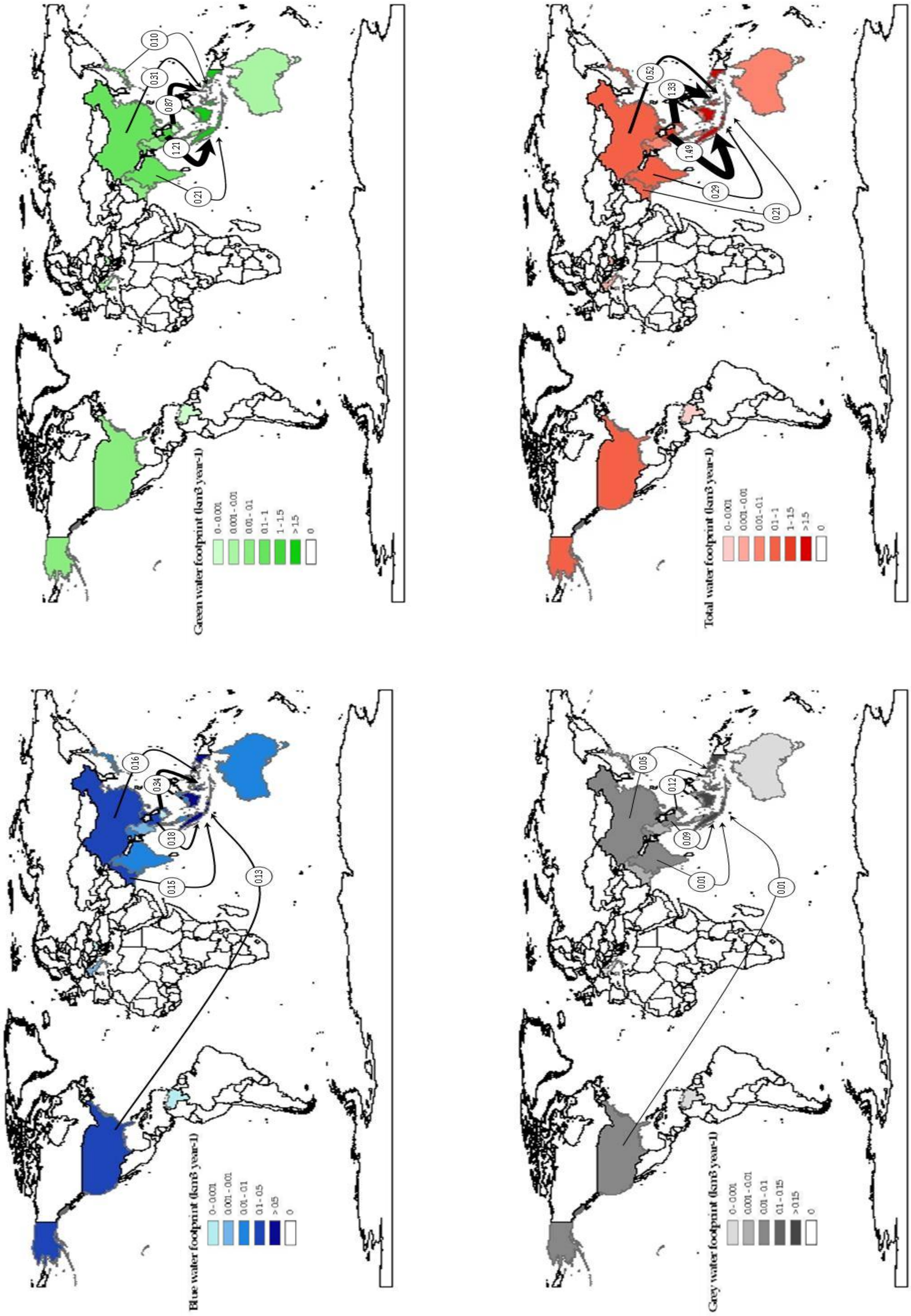


Figure 8-3: Impact of consumption of rice products by citizens of Indonesia on the world's water resources. Period 1999 – 2003

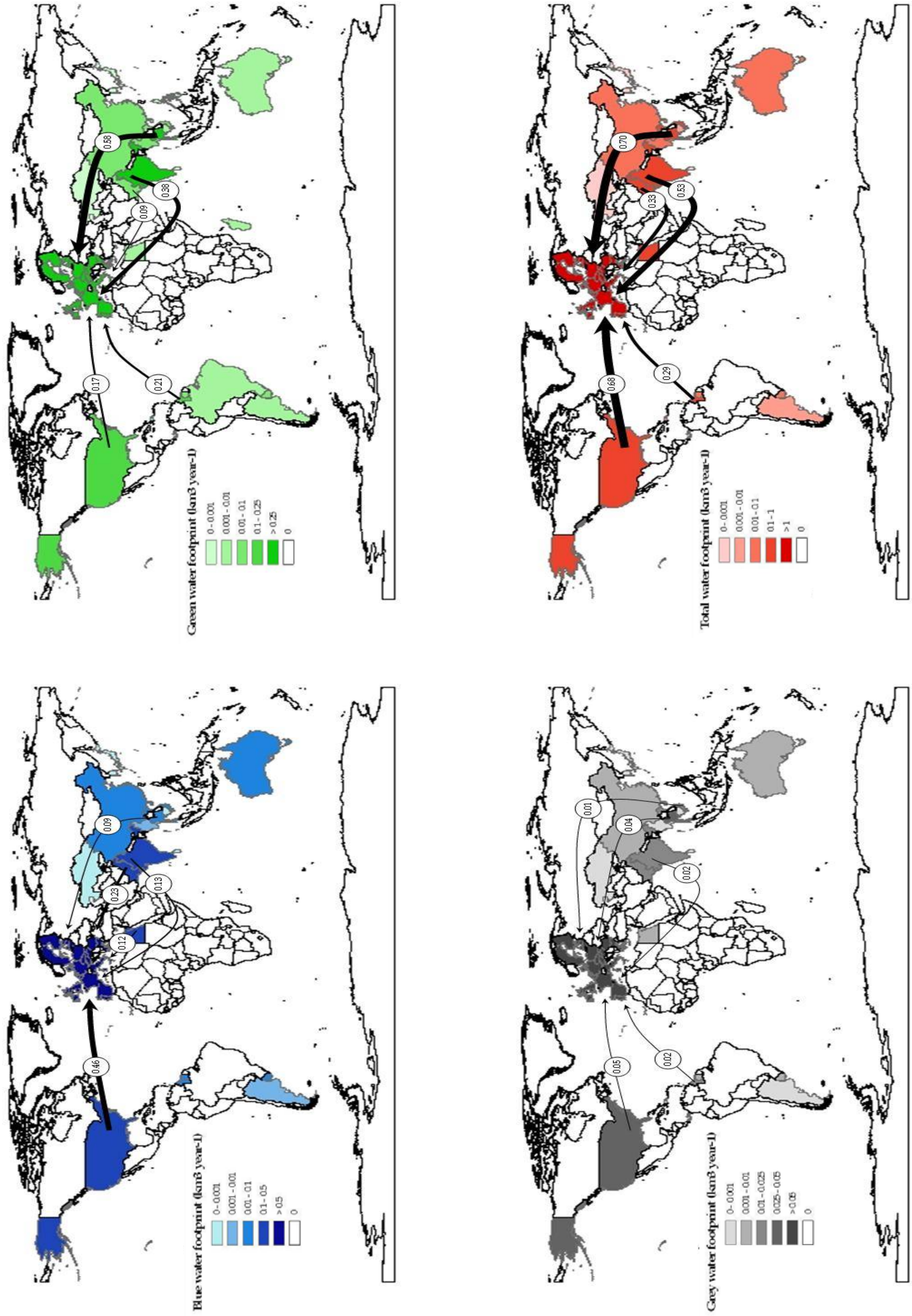


Figure 8-4: Impact of consumption of rice products by citizens of EU27 on the world's water resources. Period 1999 – 2003

Of all countries Indonesia has the largest external water footprint (4.39 km^3 $year^{-1}$). To show the impact of rice consumers from India on external water resources an impact map shown in Figure 8-3 was made. The map shows the internal water footprint of Indonesia plus the 'direct' external water footprint in other countries. The external water footprint from countries which had no rice production but do report export were neglected. The arrows show the tele-connections between the area of consumption and the areas of impact. Only the virtual water import (m^3 $year^{-1}$) from the five major countries that export rice to Indonesia are depicted in order to prevent creating an incomprehensible map.

A similar map was created to show the impact of rice consumers in the 27 countries of the European Union (EU27). About 69% of EU's rice related water footprint (6.43 km^3 $year^{-1}$) lies outside the EU. About 46% of the virtual water import is from countries within the EU27. To create the impact map we excluded both rice trade within the EU and import from non-producing rice countries. Figure 8-4 shows the impact of rice consumers from the EU27 on the world's water resources.

We used a top down approach to calculate the water footprint of rice consumption. In stead of assessing the water footprint of a nation by calculating the domestic supply of rice products one could also consider to multiply the virtual water content of a rice commodity with the consumption of it: the bottom up approach. Food balance sheets provide information about rice consumption (paddy equivalent) in a country. To compare both approaches a calculation was made for the major rice producing countries.

Food balance sheets only provide statistics for 154 of the 206 countries used for assessing the water footprint using the top down approach. Compared to the bottom up approach (see Table 8-2) a higher water footprint was found using the top down approach. The difference between both approaches is about the same as the ratio of domestic supply over the total rice quantity used for food consumption provided by food balance sheets (= 0.86). In Thailand less rice is provided for human consumption than assumed: the water footprint for Thailand would be about 2 times lower if the bottom up approach was followed. In Appendix S an overview for all countries can be found.

Table 8-2: Top down versus bottom up approach for major rice producing countries. Period 1999 – 2003.

Country	top down approach				bottom up approach			
	WFP_{blue} (km^3 $year^{-1}$)	WFP_{green} (km^3 $year^{-1}$)	WFP_{grey} (km^3 $year^{-1}$)	WFP_{total} (km^3 $year^{-1}$)	WFP_{blue} (km^3 $year^{-1}$)	WFP_{green} (km^3 $year^{-1}$)	WFP_{grey} (km^3 $year^{-1}$)	WFP_{total} (km^3 $year^{-1}$)
Bangladesh	21.58	35.09	3.95	60.63	18.52	29.66	3.39	51.57
Brazil	8.09	14.74	0.54	23.37	6.12	12.57	0.42	19.12
China	62.72	126.27	20.83	209.82	57.46	115.36	19.07	191.89
Egypt	5.70	0.25	0.35	6.31	4.25	0.16	0.26	4.67
India	56.86	163.36	10.74	230.96	51.69	148.57	9.77	210.02
Indonesia	21.64	55.58	5.82	83.04	17.85	45.73	4.78	68.37
Japan	3.67	10.02	0.75	14.45	3.06	9.69	0.67	13.43
Korea, Republic of	1.35	5.63	0.60	7.58	1.19	5.18	0.55	6.92
Myanmar	3.14	23.34	0.66	27.14	2.14	15.96	0.45	18.56
Nepal	0.55	6.16	0.41	7.12	0.43	4.92	0.33	5.68
Pakistan	10.78	4.41	0.49	15.68	7.09	2.90	0.32	10.31
Philippines	6.93	18.05	1.00	25.98	6.10	15.87	0.82	22.79
Thailand	3.74	25.13	1.90	30.77	1.92	12.88	0.97	15.77
United States of America	5.40	2.67	0.59	8.66	3.82	1.44	0.39	5.66
Viet Nam	10.03	25.75	3.56	39.34	6.64	17.05	2.36	26.05
World	260.77	593.04	57.19	911.01	225.19	511.25	49.21	785.65

We only took a look at the availability of rice for human consumption. A part of the domestic supply is used for feed, seed and other purposes of which an unknown part could be attributed to food consumption. Therefore the water footprint tends to be underestimated by using a bottom up approach and overestimated using the top down approach.

9 Conclusion

The global water footprint of rice consumption has been estimated to be 919 km^3 $year^{-1}$. This is about 4% of the total volume of Lake Baikal, the largest fresh water lake on earth (containing 0.06% of the total volume of fresh water on earth). Assuming a constant rate of rice consumption it would take about 26 years to desiccate if the lake is not fed.

Compared to green water use (65%) only 29% of the water footprint consists of the use of blue water. Nevertheless, blue water use is of importance to sustain yields and thus secure food security in countries where rice is staple food. Water productivities show that if irrigation water was applied to the field, water productivity increased. About 83% of the global volume of blue water for rice production is used by Asian countries. Within Asia only 27% of this total volume of blue water is used for rice production. On a relative scale countries in the Middle East, North America and Oceania use most blue water for their rice production, up to 100% (e.g. Egypt). Blue water use affects the environment more than green water use. Water used for irrigation is now lost to the atmosphere where else it stayed in the ground or would be available for other purposes. The opportunity cost of blue water is therefore larger than green water. However, without the use of blue water production would not meet its demand and threatens food security in most countries. Moreover, in dry countries no rice growth is possible without irrigation water. The same goes for multiple growing seasons within a year in tropical countries.

Pollution does not seem to be a large factor in defining water resources depletion by rice consumption. Most of the N fertilizer applied is transformed by processes under anaerobic conditions and recovered by the plant itself. Little nitrogen is accumulated in ground water and other water bodies and therefore relatively little water is needed for dilution. Only 6% of the total volume of the water footprint (57 km^3 $year^{-1}$) is needed to dilute N polluted water bodies.

The size of the water footprint is for 95% determined by the use of water for rice consumption within countries. Compared to global rice production, international trade in rice products is relatively small. The impact of rice consumers on foreign resources is about half of the external water footprint related to the consumtion of cotton products, which Chapagain *et al*. (2005) estimated to be 44% of its total water footprint (256 km^3 $year^{-1}$). Compared to cotton, rice can be seen as a subsistence crop rather than a tradable commodity. To achieve food security countries need to be self sufficient and trade in rice remains a residual option.

In assessing the global water footprint of rice consumption we used a top down approach. Therefore we assumed the total volume of rice for domestic supply equals rice consumption. Food balance sheets provided by FAO indicate that consumption of rice (paddy equivalent) is about 86% of domestic supply. If a bottom up approach was followed the global water footprint of rice consumption would be about 786 km^3 $year^{-1}$, which is about 86% of the water footprint found with the top down approach in this study.

To simulate rice growth at a global scale we used the crop growth model ORYZA2000 (Bouman *et al.*, 2001) and integrated it with GIS. This 'loose coupling' made it possible to use a climatology of surface climates with a high spatial resolution (New et al, 2002) and allocate the different ecosystems used for rice production in a country (Huke and Huke, 1997). Simulation of water use for rice growth on a high resolution using ORYZA2000 differs from the volumes found in earlier studies. If Hoekstra and Chapagain (2007a) considered outflow to be depleted they would have found a similar volume of water use for rice growth on a global scale. Because water use on country level were both under- and overestimated compared to the volumes found with ORYZA2000 this difference may be coincidence. The main reason for the differences on country level could be found in the use of a different crop model to simulate rice growth. We believe modeling water use with the rice growth model ORYZA2000 will provide for a radically better estimate of water use, rather than using CROPWAT which at present cannot be used for the calculation of crop water requirements for rice in a country. Integrating the model with GIS makes it also possible to use spatial explicit data for an even better estimation of water use for rice growth in a country. Therefore a more accurate estimate of the water footprint can be made.

Chapagain *et al.* (2006) showed that global water savings are sustainable if products are exported from water efficient to water inefficient countries if the price of an exported commodity reflects the opportunity costs and negative externalities in exporting countries. Because of the relative thin market relatively little water could be saved by trading rice products compared to the trade in other cereals like wheat and maize. Importing rice products from water efficient countries rather than producing it domestically saves global water resources by 14 km^3 $year^{-1}$, which is about 2% of the total volume of water used for rice growth. Predominantly blue water, which has a higher opportunity cost than green water, is saved. More water can be saved globally if countries with a relative low water productivity import their rice products from countries with a higher productivity. To save more global water resources by importing rice products, the rice market should expand. This is difficult because of government interventions protecting national economies and food security. Changing rice policies may 'free' the rice market, but may also have socio economic impacts for both importing and exporting countries. For now global water resources could be saved more significantly by developing and applying new agricultural management strategies. If rice would be grown using less water an increase in yield potential would be needed to sustain yields. Therefore water productivity studies are important to show the possibilities of producing more rice with less water using new management strategies and varieties.

10 Discussion and recommendations

In calculating the water footprint of global rice consumptions we had to make choices affecting the findings in this study. To discuss these choices and their consequences we added this Chapter. We also give recommendations for further study.

To assess virtual water flows we multiplied the volume of a product exported with the virtual water content of the product in the country of origin. For exporting countries of which the virtual water content is not simulated with ORYZA2000 or in which no rice production takes place the global average virtual water content is used. Because it is not known whether the export refers to the export of rice products that are produces domestically, to the re-export of imported products or to both an error may be made in assessing virtual water flows using the domestic virtual water content $VWC_{[e,p]}$ only.

We recommend to study the effect on the water footprint by taking the weighted average of the virtual water content $\overline{VWC_{[e,p]}}$ to calculate virtual water flows. This average is the ratio of the total volume of water import from countries and the volume of water used for rice growth domestically in the importing country to the quantity of rice products imported and produced domestically:

$$\overline{VWC_{[e,p]}} = \frac{\sum\left(T_{[e,i,p]} \times VWC_{[e,p]}\right) + TWU}{\sum\left(T_{[e,i,p]}\right) + \text{production}} \tag{26}$$

Calculation should account for the complicating fact that some countries import rice products from re-exporting countries which on their turn export products form re-exporting countries.

Calculation of the virtual water content was based on statistical data provided by FAO and the with ORYZA2000 calculated water use. With ORYZA2000 production efficiency was generally larger than yields provided by FAO. By using the simulated water use with a less efficient production management to calculate the virtual water content in combination an inconsistency is introduced: with the same volume of water depleted rice growth is less efficient. The difference between the statistical and simulated yield is governed by nutrient limitations, biotic stresses, natural disasters and harvest losses. These limitations have their effect on growth and thus water use. We, however, believe these limitations may have a moderate effect on water depletion. Because the development of leaves is not as good as under potential conditions there will be less photosynthesis and thus transpiration. A less developed crop cover on the other hand will lead to more evaporation from the soil/ water layer and evapotranspiration rates would therefore be about the same (despite the simulated yield). Although this approach will not produce perfect results it is probably the best option to calculate the virtual water content. If we had used both the ORYZA2000 simulated water use and yield to calculate the virtual water content the global average virtual water content would be underestimated (1079 m^3 ton^{-1}).

To assess the water footprint at a global scale we had to make assumptions regarding water depletion. For example, we assumed a maximum seepage and percolation rate of 4 mm day^{-1}. Percolation and seepage flows are governed by soil factors, the depth of the ponded water layer and length and state of the bunds. Because soil and management strategies differ locally SP rates may be different from the one we assumed. We assumed that subsurface flows affect the consumptive water use of the plant indirectly. In rainfed lowlands and uplands less water would be depleted if (seepage) and percolation rates were higher. In irrigated lowlands water depletion could still be the same at the cost of blue water use.

Other assumptions may also have effects on water use during crop growth. It was beyond the scope of this study to analyze the influence of these (or other possible) assumptions on water depletion (and thus the water footprint indirectly). We therefore recommend to study the effect of assumptions with respect to the simulation of rice growth with ORYZA2000. We also recommend to simulate rice growth under nitrogen limited conditions varying the amount in different splits and timings of application to derive relationships between yield and water use. Like this it should be possible to indicate the 'error' made by using the with the model simulated water use for rice growth and statistical yields for calculating the virtual water content of paddy rice.

Because we started the simulation with a saturated soil for lowland ecologies and a soil at field capacity for upland ecologies, the plant can use water from the soil even if there have not been any rainfall before the plant was planted. Therefore the volume of green water used for crop growth can be larger than the total amount of rainfall during the period from planting till harvesting. Thereby green water use can be overestimated leading to an underestimation of blue water use. A better approach would have been to have a water balance start at least a month before planting (and irrigate if needed in irrigated lowlands). Like this it is possible to start with a dryer soil at start of the simulation if water is evaporated from the field.

For calculation of the virtual water content we only took water depletion for rice growth during the growing stage into account. Water use during land preparation would add an extra volume to the total of water used for rice production. To include water use during land preparation we advise to add 250 mm ha^{-1} (Bouman, personal communication (2006)) of depleted water to the total water use needed for rice growth in a country. Therefore an extra volume of 379 km^3 $year^{-1}$ would be needed for rice production globally, resulting in a total water use of 1297 km^3 $year^{-1}$ for rice production. Although we did not account for water depletion during land preparation, we implicitly took the water needed for land preparation into account by assuming a saturated soil at start of the simulation and let the soil dry out as it the rice plant reaches maturity. We also neglected water needed to process rice products. Like this the calculation of the water footprint is a more conservative approach, underestimating the volume needed for water depletion of processes besides evapotranspiration during the period from planting to harvesting.

If possible the rice calendar used for this study should be improved to distinguish growing seasons by state (or at an even higher resolution) and ecosystem within a country. Also a different approach to select planting time can be used. It is likely to take the average of the simulated variables over the period rice can be planted. An other option is to select the time that leads to the highest yield during the range rice can be planted as planting time. We only used planting time as criteria for simulation of rice growth. The crop growth cycle ends when the rice plant reaches maturity or the maximum of 200 days after start is exceeded. In practice harvesting may be earlier or later than maturity (depending on local conditions). Therefore it would be practical if besides planting ranges also harvesting ranges are used for the simulation.

To simulate crop growth for each grid daily weather data were generated from a climatology of surface climates. Because of time availability limitations it was only possible to generate these daily data once. In this way it was possible that (un-)favorable weather conditions were generated affecting daily crop growth. If for each grid more daily data could be generated the average could be used for simulating crop growth excluding the effect of generating (un-) favorable weather conditions.

We used the model ORYZA2000 to simulate water-limited rice growth. In earlier studies the model CROPWAT was used to calculate water use for agricultural products. To attribute differences between both models we recommend to run CROPWAT within AVID by using the same input data (e.g. rice distribution by ecosystem and weather data).

The command line version of DIVA-GIS, AVID-GIS was used to integrate ORYZA2000 with GIS. Hijmans (2003) used this tool successfully to map the effect of climate change on global potato production. Adjustments were needed to use AVID-GIS with ORYZA2000. Despite integration of ORYZA2000 with GIS using AVID-GIS was successful, refinements could be made to let it work more efficient and smoothly. If in the near future spatial explicit data about soil, nutrient use and varieties grown are available AVID-GIS needs to be adapted if one wants to use these data as input for the model to simulate rice growth in order to give an even more accurate estimate of water use in rice production.

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Appendices

Appendix A: Glossary

<u>Virtual water</u> (Hoekstra and Chapagain (2007b))

Virtual water content: the volume of freshwater used to produce a product (a commodity, good or service), measured at the place where the product was actually produced (production-site definition). It refers to the sum of the water use in the various steps of the production chain. The virtual water content of a product consists of three components:

- *blue component:* the volume of irrigation water evaporated during production of the product. In this study blue water use is quantified by calculating the difference between actual evapotranspiration of the rice plant with and without irrigation water on irrigated lands;
- *green component:* the volume of rainwater evaporated during production;
- *grey component:* the volume of water that became polluted during crop growth quantified by calculating the volume of water required to dilute pollutants emitted to the natural water system during its production process to such an extent that the quality of the ambient water remains beyond agreed water quality standards.

Virtual water export: the volume of virtual water associated with the export of products from the country/ region of origin.
Virtual water import: the volume of virtual water associated with the import of products to the country/region.
Virtual water balance: is the net import of virtual water, which is equal to the gross import of virtual water minus the gross export. A positive virtual-water balance implies net inflow of virtual water to the country from other countries. A negative balance means net outflow of virtual water.

<u>Water footprint</u> (Hoekstra and Chapagain (2007b))

Water footprint: the total volume of freshwater used to produce the foods and services consumed. The total water footprint breaks down into the blue, green and grey components.
Internal water footprint: the part of the footprint that falls inside the country (using domestic water resources for consumption of the product)
External water footprint: the part of the footprint that falls outside the country (using foreign water resources for consumption of the product)

More information about the water footprint concept can be found on *www.waterfootprint.org*

<u>Nitrogen cycle</u>

Denitrification: reduction of nitrate into gaseous nitrogen by anaerobic respiration.
Immobilization: transformation of nitrate and ammonium to organic nitrogen by soil micro-organisms
Mineralization: transformation of organic nitrogen to ammonium by soil micro-organisms
Nitrification: oxidation of ammonium into nitrate
Volatilization: conversion of ammonia into ammonia gas

Appendix B: Rice production

Region/ country	Production (kton year^{-1})		Harvested Area (ha)		Yield (ton ha^{-1})
Africa	**16,947**	**2.9%**	**7,389,410**	**4.9%**	**2.29**
Chad	121	*0.7%*	93,279	*1.3%*	1.29
Congo, DR	329	*1.9%*	435,241	*5.9%*	0.76
Cote d'Ivoire	634	*3.7%*	340,917	*4.6%*	1.86
Egypt	5,865	*34.6%*	632,261	*8.6%*	9.28
Ghana	250	*1.5%*	119,270	*1.6%*	2.10
Guinea	817	*4.8%*	509,700	*6.9%*	1.60
Liberia	147	*0.9%*	133,440	*1.8%*	1.10
Madagascar	2,623	*15.5%*	1,212,974	*16.4%*	2.16
Mali	811	*4.8%*	382,428	*5.2%*	2.12
Mozambique	156	*0.9%*	175,389	*2.4%*	0.89
Nigeria	3,074	*18.1%*	2,180,400	*29.5%*	1.41
Senegal	211	*1.2%*	86,633	*1.2%*	2.43
Sierra Leone	240	*1.4%*	198,254	*2.7%*	1.21
Tanzania	686	*4.0%*	413,562	*5.6%*	1.66
Asia	**535,801**	**90.5%**	**135,481,110**	**89.4%**	**3.95**
Afghanistan	286	*0.1%*	144,200	*0.1%*	1.98
Bangladesh	37,002	*6.9%*	10,754,034	*7.9%*	3.44
Cambodia	4,140	*0.8%*	2,039,915	*1.5%*	2.03
China	181,634	*33.9%*	29,274,307	*21.6%*	6.20
India	128,319	*23.9%*	43,694,400	*32.3%*	2.94
Indonesia	51,370	*9.6%*	11,650,945	*8.6%*	4.41
Japan	11,101	*2.1%*	1,723,400	*1.3%*	6.44
Kazakhstan	217	*0.0%*	72,307	*0.1%*	3.00
Korea, DPR	2,105	*0.4%*	570,771	*0.4%*	3.69
Korea, Republic of	6,868	*1.3%*	1,058,181	*0.8%*	6.49
Laos	2,286	*0.4%*	744,629	*0.5%*	3.07
Malaysia	2,145	*0.4%*	682,998	*0.5%*	3.14
Myanmar	21,663	*4.0%*	6,366,958	*4.7%*	3.40
Nepal	4,161	*0.8%*	1,546,422	*1.1%*	2.69
Pakistan	6,950	*1.3%*	2,338,360	*1.7%*	2.97
Philippines	12,780	*2.4%*	4,031,215	*3.0%*	3.17
Russia	494	*0.1%*	149,060	*0.1%*	3.31
Sri Lanka	2,869	*0.5%*	839,774	*0.6%*	3.42
Thailand	25,927	*4.8%*	10,033,590	*7.4%*	2.58
Uzbekistan	230	*0.0%*	104,180	*0.1%*	2.21
Viet Nam	33,010	*6.2%*	7,553,820	*5.6%*	4.37
Central America and Caribbean	**2,239**	**0.4%**	**660,663**	**0.4%**	**3.39**
Costa Rica	244	*10.9%*	56,637	*8.6%*	4.31
Cuba	624	*27.9%*	191,520	*29.0%*	3.26
Dominican Republic	642	*28.7%*	133,572	*20.2%*	4.80
Haiti	113	*5.1%*	53,540	*8.1%*	2.12
Nicaragua	254	*11.4%*	83,645	*12.7%*	3.04
Panama	252	*11.3%*	109,493	*16.6%*	2.31
Europe	**2,717**	**0.5%**	**431,673**	**0.3%**	**6.29**
France	108	*4.0%*	18,936	*4.4%*	5.71
Greece	158	*5.8%*	21,854	*5.1%*	7.22
Italy	1,342	*49.4%*	219,223	*50.8%*	6.12
Portugal	147	*5.4%*	24,995	*5.8%*	5.87
Spain	844	*31.1%*	115,141	*26.7%*	7.33
Middle East	**2,924**	**0.5%**	**725,754**	**0.5%**	**4.03**
Iran	2,426	*83.0%*	572,454	*78.9%*	4.24
Iraq	142	*4.8%*	91,900	*12.7%*	1.54
Turkey	356	*12.2%*	61,400	*8.5%*	5.80
North America	**9,575**	**1.6%**	**1,366,875**	**0.9%**	**7.01**
Mexico	295	*3.1%*	66,068	*4.8%*	4.46
United States of America	9,281	*96.9%*	1,300,807	*95.2%*	7.13
Oceania	**1,173**	**0.2%**	**138,079**	**0.1%**	**8.50**
Australia	1,153	*98.3%*	130,367	*94.4%*	8.84
South America	**20,461**	**3.5%**	**5,403,156**	**3.6%**	**3.79**
Argentina	970	*4.7%*	177,238	*3.3%*	5.48
Bolivia	296	*1.4%*	152,755	*2.8%*	1.94
Brazil	10,755	*52.6%*	3,387,586	*62.7%*	3.17
Chile	124	*0.6%*	25,045	*0.5%*	4.97
Colombia	2,413	*11.8%*	481,863	*8.9%*	5.01
Ecuador	1,292	*6.3%*	347,581	*6.4%*	3.72
Guyana	491	*2.4%*	126,710	*2.3%*	3.87
Paraguay	110	*0.5%*	27,606	*0.5%*	3.99
Peru	2,025	*9.9%*	306,662	*5.7%*	6.60
Suriname	177	*0.9%*	46,742	*0.9%*	3.79
Uruguay	1,083	*5.3%*	172,960	*3.2%*	6.26
Venezuela	701	*3.4%*	142,615	*2.6%*	4.92
Other	**1,498**	**0.3%**	**662,593**	**0.4%**	**2.26**
World	**591,837**		**151,596,722**		**3.90**

Period 1999 – 2003 (source: FAO (2007a))

Note: only the for the simulation used countries (66) are presented. The world's total is the total of rough production from countries (118) provided by FAO

Appendix C: Food balance sheets

Country	Population	Production quantity (kton year^{-1})	Import quantity (kton year^{-1})	Export quantity (kton year^{-1})	Domestic supply (kton year^{-1})	Feed and seed quantity (kton year^{-1})	Other net uses quantity (kton year^{-1})	Food consumption quantity (kton year^{-1})	Food consumption quantity (kg cap^{-1}year^{-1})
Albania	3,131,000	0	36	0	36	0	-1	36	12
Algeria	30,764,600	0	190	0	190	22	1	168	5
Angola	12,801,200	7	113	4	116	0	8	108	8
Argentina	37,525,400	970	28	576	423	33	203	187	5
Armenia	3,095,400	0	34	0	34	0	9	25	8
Australia	19,345,600	1,153	117	764	506	11	239	256	13
Austria	8,107,000	0	94	4	90	0	17	72	9
Azerbaijan, Republic of	8,228,000	18	36	0	54	1	4	49	6
Bangladesh	140,880,400	36,856	1,119	3	37,973	534	5,068	32,371	230
Barbados	268,200	0	10	4	6	0	-2	8	28
Belarus	9,987,600	0	43	5	38	0	4	35	3
Belgium	10,273,400	0	510	310	104	21	29	53	5
Belize	245,400	12	3	0	15	0	4	11	43
Benin	6,393,800	52	162	1	212	1	33	178	28
Bolivia	8,480,200	296	11	0	307	8	54	244	29
Bosnia and Herzegovina	4,035,400	0	16	0	16	0	2	14	3
Brazil	174,022,600	10,755	1,189	653	11,291	258	1,476	9,557	55
Brunei Darussalam	342,000	0	43	0	43	1	9	34	98
Bulgaria	8,031,200	17	39	4	52	6	0	47	6
Burkina Faso	12,270,600	98	284	3	380	2	7	370	30
Burundi	6,455,000	59	2	0	61	1	14	47	7
Cambodia	13,479,200	4,140	168	8	4,300	228	936	3,136	233
Cameroon	15,417,200	56	339	2	394	1	37	356	23
Canada	31,016,000	0	452	18	434	0	94	340	11
Cape Verde	445,000	0	47	0	47	0	5	42	94
Central African Republic	3,764,400	25	5	0	30	1	2	28	7
Chad	8,106,600	121	1	0	122	5	8	109	13
Chile	15,417,600	124	178	2	301	4	55	241	16
China	1,292,195,400	181,634	1,389	4,281	178,741	6,464	9,102	163,175	126
Colombia	42,820,800	2,413	152	175	2,390	372	48	1,970	46
Comoros	726,200	17	28	0	45	2	-5	49	67
Congo, Dem Republic of	49,984,800	329	17	0	345	18	-13	340	7
Congo, Republic of	3,538,800	1	74	0	75	0	-3	78	22
Costa Rica	4,009,800	224	102	30	296	4	-3	295	74
Côte d'Ivoire	16,094,800	634	869	16	1,487	178	192	1,117	69
Croatia	4,439,200	0	20	1	19	0	2	17	4
Cuba	11,234,600	624	685	7	1,302	123	210	969	86
Cyprus	789,200	0	10	0	10	1	1	8	11
Czech Republic	10,258,200	0	93	16	78	1	7	69	7
Denmark	5,336,000	0	88	26	62	4	20	38	7
Dominica	78,000	0	2	0	2	0	1	1	13
Dominican Republic	8,483,800	642	64	8	698	13	121	564	66
Ecuador	12,614,400	1,292	15	119	1,188	32	283	873	69
Egypt	69,167,000	5,865	41	812	5,094	312	694	4,088	59
El Salvador	6,311,200	39	81	9	111	1	18	93	15
Estonia	1,352,200	0	13	1	12	0	1	11	8
Ethiopia	67,286,200	15	18	0	34	0	3	31	0
Fiji Islands	822,200	15	44	0	58	1	2	56	68
Finland	5,187,000	0	53	5	47	0	2	45	9
France	59,581,000	108	773	190	691	147	40	505	8
French Polynesia	237,000	0	13	0	13	0	1	12	49
Gabon	1,281,200	1	119	1	119	0	29	90	70
Gambia	1,350,000	28	115	1	142	1	64	77	57
Georgia	5,215,600	0	16	0	16	1	1	14	3
Germany	82,348,400	0	564	145	420	1	13	405	5
Ghana	20,037,000	250	459	3	706	7	175	524	26
Greece	10,926,000	158	34	52	139	16	12	111	10
Grenada	80,600	0	6	0	6	0	3	3	40
Guatemala	11,731,000	42	62	6	98	1	3	94	8
Guinea	8,236,400	817	389	0	1,206	25	254	927	113
Guinea-Bissau	1,409,000	85	30	0	115	8	-23	130	92
Guyana	761,200	491	1	338	153	33	20	101	132
Haiti	8,112,200	113	441	1	553	5	13	536	66
Honduras	6,618,000	13	100	2	111	0	41	70	11
Hungary	9,967,200	9	77	1	85	4	1	80	8
Iceland	284,600	0	3	0	2	0	0	2	7
India	1,033,101,000	128,319	142	4,712	123,750	7,487	3,299	112,963	109
Indonesia	214,334,000	51,370	3,566	320	54,616	2,342	7,629	44,645	208

Country	Population	Production quantity (kton year^{-1})	Import quantity (kton year^{-1})	Export quantity (kton year^{-1})	Domestic supply (kton year^{-1})	Feed and seed quantity (kton year^{-1})	Other net uses quantity (kton year^{-1})	Food consumption quantity (kton year^{-1})	Food consumption quantity (kg cap^{-1}year^{-1})
Iran, Islamic Rep of	67,267,800	2,426	1,743	18	4,151	552	57	3,542	53
Ireland	3,864,800	0	43	2	41	0	9	32	8
Israel	6,172,800	0	158	0	158	0	58	99	16
Italy	57,498,400	1,341	204	1,014	531	70	-44	505	9
Jamaica	2,603,800	0	143	10	132	3	11	118	45
Japan	127,240,800	11,101	1,343	550	11,894	239	552	11,103	87
Jordan	5,181,800	0	204	38	166	0	12	154	30
Kazakhstan	15,573,600	217	34	21	229	12	34	183	12
Kenya	31,026,400	47	196	2	241	1	-46	286	9
Korea, Dem People's Rep	22,400,400	2,105	895	1	2,999	290	368	2,341	104
Korea, Republic of	47,123,800	6,868	315	677	6,506	51	-34	6,488	138
Kyrgyzstan	4,993,000	18	10	0	27	1	3	23	5
Laos	5,404,800	2,286	42	0	2,328	254	418	1,656	306
Latvia	2,350,600	0	14	1	13	0	1	12	5
Lebanon	3,536,600	0	87	5	82	0	35	47	13
Liberia	3,083,200	147	98	12	233	6	4	223	72
Libyan Arab Jamahiriya	5,341,800	0	216	0	216	33	53	130	24
Lithuania	3,481,200	0	17	3	14	0	-1	15	4
Macedonia,The Fmr Yug Rp	2,034,600	13	3	3	13	1	3	9	4
Madagascar	16,448,000	2,623	239	2	2,860	176	351	2,332	142
Malawi	11,612,800	88	9	3	94	3	4	87	7
Malaysia	23,475,000	2,145	616	263	2,499	76	-170	2,592	110
Maldives	300,000	0	25	0	25	0	4	21	70
Mali	12,271,600	811	193	13	991	41	56	894	73
Malta	390,800	0	5	0	5	0	1	4	11
Mauritania	2,727,600	76	35	0	111	29	5	76	28
Mauritius	1,197,800	0	105	0	105	0	0	106	88
Mexico	100,441,200	295	751	22	1,023	4	129	891	9
Moldova, Republic of	4,277,600	0	16	0	15	0	1	14	3
Mongolia	2,531,400	0	29	0	29	0	3	25	10
Morocco	29,594,400	29	11	0	40	1	2	37	1
Mozambique	18,196,400	156	190	1	344	13	67	264	15
Myanmar	48,192,000	21,663	60	279	21,445	1,955	4,798	14,692	305
Nepal	24,066,800	4,161	51	103	4,108	105	645	3,358	140
Netherlands	15,981,800	0	416	261	155	25	8	122	8
New Zealand	3,814,400	0	69	6	63	0	12	51	13
Nicaragua	5,204,200	254	106	13	347	13	31	303	58
Niger	11,152,200	70	223	1	292	6	10	275	25
Nigeria	117,834,000	3,074	1,456	20	4,510	148	232	4,130	35
Norway	4,493,000	0	40	0	40	1	7	32	7
Pakistan	146,287,600	6,950	51	3,298	3,703	225	-178	3,656	25
Panama	3,006,800	252	17	7	262	5	25	232	77
Paraguay	5,606,000	110	8	11	107	2	6	100	18
Peru	26,356,600	2,025	149	8	2,166	35	209	1,922	73
Philippines	77,140,400	12,780	1,471	9	14,242	971	1,243	12,027	156
Poland	38,642,400	0	163	6	157	12	27	118	3
Portugal	10,031,200	147	155	29	272	4	-1	270	27
Romania	22,430,000	2	139	2	139	0	0	138	6
Russian Federation	144,817,400	494	696	23	1,166	34	39	1,093	8
Rwanda	7,931,600	17	22	0	39	0	0	39	5
Saint Lucia	147,000	0	5	0	5	0	3	2	12
Sao Tome and Principe	153,000	0	8	0	8	0	1	7	44
Saudi Arabia	22,836,400	0	1,186	10	1,176	2	41	1,133	50
Senegal	9,627,200	211	1,036	11	1,236	6	183	1,047	109
Serbia and Montenegro	10,546,000	0	26	0	26	0	0	26	2
Seychelles	79,600	0	9	0	9	4	2	3	43
Slovakia	5,394,600	0	56	4	53	3	5	45	8
Slovenia	1,988,000	0	28	4	24	0	2	21	11
Solomon Islands	450,200	5	34	0	39	0	8	30	68
South Africa	44,342,800	3	926	68	862	0	64	798	18
Spain	40,854,000	844	193	512	525	20	21	483	12

Country	Population	Production quantity (kton year^{-1})	Import quantity (kton year^{-1})	Export quantity (kton year^{-1})	Domestic supply (kton year^{-1})	Feed and seed quantity (kton year^{-1})	Other net uses quantity (kton year^{-1})	Food consumption quantity (kton year^{-1})	Food consumption quantity (kg cap^{-1}year^{-1})
Sri Lanka	18,751,800	2,869	263	4	3,127	91	399	2,637	141
Sudan	32,163,400	11	53	7	56	0	1	55	2
Suriname	428,800	177	4	60	121	27	38	56	130
Sweden	8,863,000	0	83	20	64	0	2	62	7
Switzerland	7,171,600	0	138	4	134	53	13	68	9
Syrian Arab Republic	16,973,200	0	420	2	419	0	-7	425	25
Tanzania, United Rep of	35,549,800	686	222	21	887	32	34	821	23
Thailand	61,562,400	26,387	24	12,430	13,981	1,813	3,171	8,997	146
Timor-Leste	729,000	52	44	0	96	1	8	87	119
Togo	4,676,600	69	85	8	146	3	5	138	30
Trinidad and Tobago	1,293,600	5	52	8	49	4	3	42	32
Tunisia	9,623,000	0	41	0	41	0	6	35	4
Turkey	69,296,200	356	465	36	786	9	40	737	11
Turkmenistan	4,717,600	58	8	0	66	2	12	51	11
Uganda	24,266,200	114	65	2	178	8	5	165	7
Ukraine	49,300,000	76	100	3	174	5	-3	172	3
United Arab Emirates	2,878,400	0	894	364	530	22	314	194	67
United Kingdom	59,095,000	0	770	130	641	22	169	449	8
United States of America	288,016,800	9,281	802	4,948	5,134	181	1,058	3,896	14
Uruguay	3,366,200	1,083	6	1,035	54	24	8	22	7
Uzbekistan	25,305,200	230	79	1	308	18	18	272	11
Venezuela,Bolivar Rep of	24,750,800	701	47	51	698	17	156	526	21
Viet Nam	79,219,000	33,010	40	3,187	29,862	1,558	8,382	19,922	251
Yemen	18,682,200	0	488	0	488	0	-15	503	27
Zimbabwe	12,728,800	1	31	3	29	0	-2	31	2
World	6,029,131,800	591,326	38,054	43,316	585,968	28,066	53,786	504,116	84

Period 1999 – 2003 (source: FAO (2007b))

Appendix D: Growth stages of the rice plant

Growth of the rice plant can be divided into three phases (see figure B-1) which consists of a series of stages.

Figure B-1: growth stages of the rice plant

Vegetative phase

- Stage 0 – *Germination to emergence*: After seeding the coleorhiza protrudes first enclosing the radicle (primary root). After this primary root breaks through the covering the coleoptile which encloses the young shoot emerges;
- Stage 1 – *Seedling*: When the coleoptile is pushed above the soil surface leaves emerge. Also roots and rootlets develop;
- Stage 2 – *Tillering*; The seedling grow and develops branched tillers consisting of the culm, roots and leaves. The culm is the jointed stem of rice made up of a series of (inter-)nodes bearing the leaves. Primary tillers originate form the lowest nodes and give rise to both secondary and tertiary tillers.

Reproductive phase

- Stage 3 – *Panicle initiation and heading*: The panicle is born on the uppermost culm bearing the spikelets which develop into grains which are born on the primary and secondary branches. The spikelet consists of the floret including the protective hull (lemma and palea) and flower. After panicle exsertion (heading) spikelet anthesis (flowering) begins;
- Stage 4 – *Flowering*: In the floret is the flower consisting of the pistil and stamens. At flowering the florets open and the pollens are shed from the emerged stamens fertilizing the ovule of the pistel. After this the florets are closed. When the spikelets are in bloom it is possible for the ovary to ripen

Ripening phase

- Stage 5 – *Grain stage*: The rice grain is the ripened ovary. The endosperm (white rice) is enclosed by the hull together referred as brown (hulled) rice. This phase is subdivided into milky, dough and maturity stages after which rice can be harvested.

For a more detailed description about growth stages and morphology of the rice plant we refer to *http://www.knowledgebank.irri.org/pu_growthMorph.htm*

Appendix E: Product fractions

Country	Husking & milling rate	Country	Husking & milling rate
Afghanistan	0.65	Korea, Republic of	0.72
Argentina	0.65	Laos	0.60
Australia	0.72	Liberia	0.60
Bangladesh	0.67	Madagascar	0.64
Bolivia	0.70	Malaysia	0.64
Brazil	0.68	Mali	0.66
Cambodia	0.63	Mexico	0.67
Chad	0.69	Mozambique	0.67
Chile	0.65	Myanmar	0.62
China	0.70	Nepal	0.67
Colombia	0.65	Nicaragua	0.65
Congo, DR	0.66	Nigeria	0.66
Costa Rica	0.65	Pakistan	0.67
Cote d'Ivoire	0.64	Panama	0.67
Cuba	0.66	Paraguay	0.67
Dominican Republic	0.65	Peru	0.69
Ecuador	0.60	Philippines	0.65
Egypt	0.67	Portugal	0.65
France	0.65	Russia	0.66
Ghana	0.67	Senegal	0.65
Greece	0.63	Sierra Leone	0.60
Guinea	0.65	Spain	0.66
Guyana	0.60	Sri Lanka	0.68
Haiti	0.60	Suriname	0.63
India	0.67	Tanzania, United Republic of	0.67
Indonesia	0.68	Thailand	0.66
Iran	0.66	Turkey	0.65
Iraq	0.67	United States	0.70
Italy	0.67	Uruguay	0.70
Japan	0.73	Uzbekistan	0.66
Kazakhstan	0.66	Venezuela	0.65
Korea, DPR	0.69	Viet Nam	0.65
		Average	*0.66*

Source: http://www.irri.org/science/ricestat/index.asp

Appendix F: Cropping calendar

Country	First Season planting	Second Season planting
Afghanistan	April - June	-
Argentina	October - November	-
Australia	October - November	-
Bangladesh	April - May	December - February
Bolivia	October - November	-
Brazil		
North	March - May	-
Central	October - December	-
South	October - November	-
Cambodia	June - July	November - January
Chad	June - July	January - February
Chile	October - November	-
China		
North	Mid April - Mid May	-
Northeast	Mid April - May	-
Northwest	Mid April - End April	-
Central	Mid May	-
Southwest	Mid March - Mid April	-
South	Mid February - Mid March	July
Colombia	August - October	March - April
Congo, DR		
North	January - March	-
South	September - October	-
Costa Rica	June - July	November - December
Cote d'Ivoire	April - June	December - February
Cuba	March - April	-
Dominican Republic	March - April	-
Ecuador	December - February	May - July
Egypt	May	-
France	April - May	-
Ghana	May - June	January - February
Greece	April - May	-
Guinea	April - June	December - February
Guyana	January - February	-
Haiti	October - November	-
India		
North	June - July	-
Central	June - July	November - April
South	May - July	August - December
Indonesia		
Java	October - March	April - June
Sulawesi	May - June	November - February
North Sumatra	July - November	May - June
South Sumatra	October - January	June - July
Iran	May - June	-
Iraq	May - June	-
Italy	April - May	-
Japan	April - June	-
Kazakhstan	May - May	-
Korea, DPR	April - May	-
Korea, Republic of	May - June	-
Laos	May - July	December - January
Liberia	April - July	-
Madagascar	October - November	-
Malaysia		
Peninsular	September - October	April - May
Sabah	June - August	-
Sarawak	October - November	-
Mali	May - July	January - March
Mexico	March - April	-
Mozambique	November - January	-
Myanmar	June - August	November - December
Nepal	June - August	-
Nicaragua	April - May	-
Nigeria		
North	June - July	January - February
South	April - May	November - December
Pakistan	May - July	-
Panama	April - May	September - October
Paraguay	September - December	-
Peru	January - February	-
Philippines	June	December - January
Portugal	April - May	-
Russia	May - June	-
Senegal	June - July	February - March
Sierra Leone	April - July	-
Spain	April - May	-
Sri Lanka	October - November	April - May
Suriname	January - February	-
Tanzania	December - February	June - July
Thailand		
North and Central	May - July	December - January
South	September - November	April - May
Turkey	May - June	-
United States	April - June	-
Uruguay	October - December	-
Uzbekistan	May - May	-
Venezuela	July - August	November - December
Viet Nam		
North	July	January - Mid February
Central	July	January - April
Coastal	July - August	-
Deep Flooded	November	April - May
Mekong	September	December - March
South	July - Mid December	December - April

The cropping calendar is based on experts knowledge at IRRI (Bouman, Buresh, Peng, and Tuong; personal communication (2006)) and rice cropping calendars provided by Maclean *et al.* (2002)

Appendix G: Simulating rice growth with ORYZA2000

The most important input data files of ORYZA2000 are described in this Appendix. For a detailed description of these input files we refer to '*ORYZA2000: modeling lowland rice*' (Bouman *et al*., 2001). To visualize the description an example data file is used showing the demand lines for a simulation of a crop in an irrigated lowland. It should be noted that some options used in the example data file can be different for the other simulated ecosystems. All input data files used for the simulation with ORYZA2000 can be found on the DVD-R (`\afstuderen\ORYZA2000\Input\Oryza\*.dat`)

Input data

<u>Control file</u>
The names of the external input data files (containing the model parameter values ORYZA2000 need to read for its simulation) are specified in the control file (`control.dat`). This control file is produced by AVID-GIS using the GIZMO command. To use the command a initialization file (`.ini`) was used. This initialization file contains configuration information about data ORYZA2000 needed to use for the simulation. Because we chose to use different varieties at different latitudes per ecosystem multiple initialization files were made specifying latitude/longitude.

The `.ini` files can be found on the DVD-R (`\afstuderen\ORYZA2000\Input\Ini-files\<ecosystem>\*.ini`)

```
*----------------------------------------------------------------------*
* CONTROL.DAT                                                          *
* Run control file for ORYZA2000 model                                 *
*----------------------------------------------------------------------*

   FILEON = 'gizmo_res.dat'                             ! Output file
   FILEOL = 'gizmo_MODEL.LOG'                           ! Log file
   FILEIR = 'gizmo_RERUNS.DAT'                          ! Rerun file
   FILEIT = 'timer_<ecosystem>.dat'                     ! Experimentdata
   FILEI1 = 'var_<crop>.dat'                            ! Crop data
   FILEI2 = 'soil_<soil-water balance module>.dat'      ! Soil data
```

The experiment, crop and soil data files to be used are specified in the initialization file.

<u>Experiment data file</u>
The experiment data file (`timer_<ecosystem>.dat`) contains command lines providing information on the run modes of ORYZA2000 and the site and experimental conditions of the simulation run. A user can select the command lines by removing the asterisk * for their preferred choice and inserting an asterisk in front of the discarded option.

```
*------------------------------------------------------------------*
* 1. Selection of modes of running                                 *
*------------------------------------------------------------------*
```

In this study ORYZA2000 is run in exploration mode. Therefore the crop emerges at start date (EMD = STTIME).

```
*--  RUNMODE is mode of running ORYZA
*RUNMODE = 'EXPERIMENT'       ! ORYZA simulates particular experiment
RUNMODE ='EXPLORATION'        ! ORYZA used for exploration (STTIME = EMD)
```

To simulate water limitations a dynamic soil-water balance module is used. The type of module depends on the ecosystem for which rice growth is simulated (see soil data file)

```
*--  PRODENV is Water production situation setting
*PRODENV = 'POTENTIAL'        ! Potential production
PRODENV = 'WATER BALANCE'     ! Production may be water-limited
```

Because not much data is available on soil nitrogen supply and nitrogen fertilization in rice fields ORYZA2000 was run without considering growth limitation by nitrogen.

```
*--  NITROENV is Nitrogen production situation setting
NITROENV = 'POTENTIAL'        ! Potential production
*NITROENV = 'NITROGEN BALANCE'   ! Production may be nitrogen-limited
```

For the calculation of evapotranspiration rates the Penman equations are used. The Penman module requires weather data which are available in GIS.

```
*--  ETMOD is method for evapotranspiration calculation:
ETMOD = 'PENMAN'             ! Penman-based (Van Kraalingen & Stol,1996)
*ETMOD = 'PRIESTLEY TAYLOR'  ! Priestley-Taylor (")
*ETMOD = 'MAKKINK'           ! Makkink (Van Kraalingen & Stol, 1996)
```

```
*------------------------------------------------------------------*
* 2. Timer data for simulation                                     *
*------------------------------------------------------------------*
```

Start of the modules is controlled by the rerun file providing information about the start day (STTIME) and at how many time steps after simulation (FINTIM) the model should stop.

```
*------------------------------------------------------------------*
* 3. Weather station and climatic data for simulation              *
*------------------------------------------------------------------*
```

All daily climate data are generated from climate surfaces in GIS (New et al., 2002) and written to the weather file to be used by ORYZA2000. The input parameters to be used with the Penman method are specified in the initialization file.

```
*------------------------------------------------------------------*
* 4. Establishment data
*------------------------------------------------------------------*
```

Varieties grown in lowland ecosystems are transplanted. Emergence of the crop is therefore in the seedbed. After 14 days (SBDUR = 14) the plants are transplanted to the main field. In upland ecosystems the crop emerges in the main field and is thus direct-seeded.

```
*--  ESTAB is method of establishment: 'TRANSPLANT' or 'DIRECT-SEED'
ESTAB='TRANSPLANT'
*ESTAB='DIRECT-SEED'
```
→ *enable this command line in upland ecosystems*

```
* Transplanting and sowing date
EMD    = 1          ! Day of emergence (either direct, or in seed-bed)
SBDUR  = 14         ! Seed-bed duration (days between emerging and transplanting)
```

```
*------------------------------------------------------------------*
* 5. Management parameters                                         *
*------------------------------------------------------------------*
```

No changes were made with respect to the management parameters

```
*-------------------------------------------------------------*
* 6. Irrigation parameters                                    *
* Need only to be filled-in when PRODENV = 'WATER BALANCE'    *
*-------------------------------------------------------------*
```

In irrigated ecosystems 25 mm of irrigation water is supplied if the simulated depth of the ponded water layer in the field drops below 10 mm (SWITIR = 2). Supply of irrigation water stops if the development stage is 1.7 (Bouman, personal communication 2006).
In rainfed lowlands and uplands SWITR = 0

```
DVSIMAX = 1.7 ! Development stage after which no more irrigation is supplied

** Select from the following options:
*SWITIR = 0 ! No irrigation  → enable this command line in rainfed and upland ecosystems
*SWITIR = 1 ! Irrigation supplied as input data
SWITIR = 2 ! Irrigation at minimum standing soil water depth
*SWITIR = 3 ! Irrigation at minimum soil water potential
*SWITIR = 4 ! Irrigation at minimum soil water content
*SWITIR = 5 ! Irrigation at x days after disappearance of standing water

** If SWITIR = 2-5, supply amount of irrigation IRRI (mm)
IRRI   = 25. ! Irrigation gift (mm)

** If SWITIR = 2, supply minimum standing water depth WL0MIN (mm)
** below which irrigation water is applied
WL0MIN = 10. ! Minimum standing water depth (mm)

*--------------------------------------------------------------------*
* 7. Nitrogen parameters                                             *
*--------------------------------------------------------------------*
```

If input of nitrogen fertilizer application and soil nitrogen supply was available ORYZA2000 was run with a dynamic nitrogen balance. Because production mode with respect to nitrogen is potential none of the parameters in this section are read by the model.

Crop data file
The crop data file (`var_<crop>.dat`) contains all the parameter values that characterize the rice crop. For this study parameters for the different varieties were obtained through model calibration and validation using field experimental data at IRRI.

Soil data file
The soil data file (`soil_<soil water balance model>.dat`) contains all data to run the soil- water balances LOWBAL (lowlands) and SAHEL (upland). In both irrigated and rainfed lowlands a puddled clay soil with bunds is taken. It is assumed that at the beginning of the simulation the soil is saturated and there is a fixed rate for seepage and percolation SP of 4 mm day^{-1} (Bouman, personal communication 2006). The upland soil is a loamy soil (non-puddled and without bunds). The values of moisture characteristics (water content at saturation, field capacity, wilting point and at air-dryness) are taken from Bouman et al. (1994).

Rerun file
Reruns are controlled by the initialization file. In a rerun ORYZA2000 is executed again with new values of selected parameters. To run each grid for 24 planting times ORYZA2000 was run with different start days.

Simulation

To use GIZMO the application "avid.exe" was started opening a DOS window. The initialization file was run from the prompt using the command line "gizmo <crop>.ini". For each grid between the specified latitude/longitude in the initialization file ORYZA2000 simulates 24 rice growth cycles with different starting times.

To simulate rice growth ORYZA2000 uses daily weather data to calculate evapotranspiration rates. The values of these input parameters were generated from the climatology of surface climates. For each grid daily values were generated.

After each simulation ORYZA2000 creates output files which are read by AVID-GIS. The values of interest (specified in the initialization file) are stored in output databases (which can be used for further processing). When the output is stored rice growth in the neighbouring grid is simulated. This process continues for all grids between the specified latitude/ longitude.
After all cells are passed the next initialization file was run. The process was repeated until for all varieties used for simulation of rice growth in the different ecosystems output databases were generated.

Processing

For each ecosystem 4 datasets of grid layers were generated by AVID-GIS during the simulation: 2 datasets for the variety used between 30°S and 30°N (30°S – 0°N and 0°S – 30°N) and 2 datasets above/ below these latitudes (60°S – 30°S and 30°N – 60°N). To create one dataset the individual datasets are merged. The outcome of this processing step is one dataset containing all stored values of interest (ha^{-1}) for 24 possible planting times for grids between latitude 60°S – 60°N.

To select the right planting time for a grid a map containing cropping calendars for all rice producing countries in this study was used as a mask.

In order to prevent including cells with low values of yields a mask is used to exclude/ re-classify these values. In irrigated ecosystems all cells with a yield beneath 2 ton ha^{-1} are excluded. In rainfed and upland ecosystems this threshold is lower, 1 ton ha^{-1}. The same mask is used to exclude the values of the other parameters of the grid cells belonging to the excluded yield.

To assess the simulated variables on national level each grid within the administrative boundaries was multiplied with the area of land use in that particular cell and aggregated over the total number of cells in that country.

The results of the processing steps were written into text output files (.txt). For each variable text files were written containing values per country. These data were used for calculation of the water footprint of rice consumption. All text output files can be found on the DVD-R (\afstuderen\ORYZA2000\Output\<ecosystem>\Results\Countries*.txt)

For processing of the simulated data scripts were made which were run from the prompt using the command line "script.dsc" in AVID-GIS. These scripts can be found on the DVD-R (\afstuderen\ORYZA2000\Output\<ecosystem>\script.dsc).

Appendix H: Virtual water content of rice

Country	Area* (ha)	Production* (kton $year^{-1}$)	Volume of water use (km^3 $year^{-1}$)				Virtual water content (m^3 ton^{-1})				% irrigated lowland	% rainfed lowland	% rainfed upland
			Green	Blue	Grey	Total	Green	Blue	Grey	Total			
Afghanistan	144,200	286	0.09	1.77	0.03	1.89	309	6204	97	6610	100%	0%	0%
Argentina	177,238	970	0.62	1.10	0.03	1.75	638	1135	33	1807	100%	0%	0%
Australia	130,367	1,153	0.17	1.40	0.11	1.68	147	1211	97	1456	100%	0%	0%
Bangladesh	10,754,034	37,002	33.91	21.17	3.87	58.95	916	572	105	1593	43%	51%	6%
Bolivia	152,755	296	0.66	0.00	0.00	0.67	2240	0	10	2250	0%	0%	100%
Brazil	3,387,586	10,755	14.15	6.89	0.47	21.51	1316	641	44	2000	40%	0%	60%
Cambodia	2,039,915	4,140	7.92	1.49	0.05	9.46	1913	359	13	2284	19%	80%	1%
Chad	93,279	121	0.37	0.02	0.01	0.40	3089	167	97	3352	11%	0%	89%
Chile	25,045	124	0.03	0.23	0.01	0.27	228	1876	97	2200	100%	0%	0%
China	29,274,307	181,634	128.41	63.96	21.22	213.59	707	352	117	1176	93%	6%	2%
Colombia	481,863	2,413	2.11	0.00	0.26	2.37	874	0	108	982	0%	0%	100%
Congo, DR	435,241	329	1.61	0.00	0.03	1.64	4886	0	97	4984	0%	0%	100%
Costa Rica	56,637	244	0.30	0.00	0.04	0.34	1218	0	162	1381	0%	0%	100%
Cote d'Ivoire	340,917	634	1.20	0.04	0.06	1.30	1896	55	97	2048	8%	0%	92%
Cuba	191,520	624	0.81	0.66	0.06	1.53	1298	1057	97	2452	100%	0%	0%
Dominican Republic	133,572	642	0.68	0.00	0.07	0.76	1065	0	112	1177	0%	0%	100%
Ecuador	347,581	1,292	1.95	0.01	0.10	2.06	1511	5	81	1597	0%	0%	100%
Egypt	632,261	5,865	0.23	6.10	0.38	6.71	40	1040	64	1144	100%	0%	0%
France	18,936	108	0.04	0.18	0.01	0.24	415	1681	97	2193	100%	0%	0%
Ghana	119,270	250	0.43	0.01	0.02	0.46	1709	40	97	1847	5%	0%	95%
Greece	21,854	158	0.03	0.17	0.02	0.22	198	1088	97	1383	100%	0%	0%
Guinea	509,700	817	2.27	0.11	0.04	2.42	2776	140	50	2966	10%	0%	90%
Guyana	126,710	491	0.55	0.17	0.05	0.76	1122	337	97	1556	62%	0%	38%
Haiti	53,540	113	0.19	0.00	0.01	0.20	1690	0	97	1787	0%	0%	100%
India	43,694,400	128,319	168.76	58.72	11.09	238.57	1315	458	86	1859	49%	39%	12%
Indonesia	11,650,945	51,370	52.62	20.54	5.51	78.67	1024	400	107	1531	59%	30%	10%
Iran	572,454	2,426	0.57	5.12	0.24	5.94	237	2113	97	2447	100%	0%	0%
Iraq	91,900	142	0.03	1.57	0.01	1.61	201	11097	97	11395	100%	0%	0%
Italy	219,223	1,342	0.66	1.04	0.13	1.82	491	772	97	1360	100%	0%	0%
Japan	1,723,400	11,101	9.69	3.06	0.67	13.42	873	276	61	1209	100%	0%	0%
Kazakhstan	72,307	217	0.05	0.93	0.02	1.00	208	4300	97	4605	100%	0%	0%
Korea, DPR	570,771	2,105	3.37	1.21	0.20	4.79	1603	577	97	2277	81%	19%	0%
Korea, Republic of	1,058,181	6,868	5.48	1.26	0.58	7.33	798	184	85	1067	74%	26%	0%
Laos	744,629	2,286	3.22	0.14	0.06	3.42	1407	63	27	1497	10%	58%	32%
Liberia	133,440	147	0.60	0.00	0.01	0.61	4063	12	97	4172	2%	0%	98%
Madagascar	1,212,974	2,623	6.75	0.88	0.01	7.63	2571	337	2	2910	49%	5%	46%
Malaysia	682,998	2,145	2.99	0.65	0.29	3.93	1395	302	136	1833	84%	1%	15%
Mali	382,428	811	1.11	1.89	0.08	3.08	1374	2334	97	3806	63%	0%	37%
Mexico	66,068	295	0.21	0.15	0.04	0.40	720	508	121	1349	34%	0%	66%
Mozambique	175,389	156	0.77	0.01	0.02	0.79	4930	45	97	5072	2%	9%	89%
Myanmar	6,366,958	21,663	23.54	3.16	0.67	27.36	1086	146	31	1263	31%	65%	4%
Nepal	1,546,422	4,161	6.10	0.53	0.40	7.03	1466	127	97	1690	33%	61%	6%
Nicaragua	83,645	254	0.42	0.00	0.01	0.43	1635	0	41	1676	0%	0%	100%
Nigeria	2,180,400	3,074	8.51	1.27	0.05	9.84	2769	413	17	3200	18%	0%	82%
Pakistan	2,338,360	6,950	5.51	13.48	0.61	19.59	792	1939	88	2819	100%	0%	0%
Panama	109,493	252	0.50	0.00	0.02	0.52	1982	0	97	2079	0%	0%	100%
Paraguay	27,606	110	0.11	0.09	0.00	0.21	1032	816	31	1879	66%	0%	34%
Peru	306,662	2,025	1.00	1.04	0.20	2.23	494	511	97	1103	38%	0%	62%
Philippines	4,031,215	12,780	16.86	6.49	0.87	24.22	1319	508	68	1895	66%	30%	4%
Portugal	24,995	147	0.03	0.27	0.01	0.31	207	1817	97	2121	100%	0%	0%
Russia	149,060	494	0.24	1.19	0.05	1.48	480	2413	97	2990	100%	0%	0%
Senegal	86,633	211	0.35	0.08	0.02	0.45	1638	403	97	2138	55%	0%	45%
Sierra Leone	198,254	240	1.03	0.00	0.02	1.05	4272	1	97	4370	0%	0%	100%
Spain	115,141	844	0.14	1.31	0.08	1.53	170	1549	97	1816	100%	0%	0%
Sri Lanka	839,774	2,869	2.78	3.33	0.44	6.55	970	1160	152	2282	87%	13%	0%
Surinam	46,742	177	0.20	0.06	0.02	0.27	1116	338	97	1551	69%	0%	31%
Tanzania	413,562	686	1.70	0.64	0.02	2.36	2479	934	24	3438	40%	12%	48%
Thailand	10,033,590	25,927	37.11	5.52	2.80	45.44	1431	213	108	1752	12%	86%	2%
Turkey	61,400	356	0.08	0.52	0.03	0.63	214	1459	97	1771	100%	0%	0%
United States of America	1,300,807	9,281	3.44	9.11	0.93	13.48	371	982	100	1452	100%	0%	0%
Uruguay	172,960	1,083	0.61	1.23	0.07	1.91	564	1138	64	1766	100%	0%	0%
Uzbekistan	104,180	230	0.05	1.27	0.02	1.33	200	5494	97	5791	100%	0%	0%
Venezuela	142,615	701	0.57	0.00	0.10	0.67	820	4	137	961	1%	0%	99%
Viet Nam	7,553,820	33,010	28.25	11.01	3.91	43.17	856	333	118	1308	60%	36%	4%
Total	150,934,129	590,339	594.74	264.26	57.29	916.30	-	-	-	-	-	-	-
Average	-	-	-	-	-	-	1007	448	97	1552	-	-	-
Other	662,593	1,498	1.51	0.67	0.15	2.33	-	-	-	-	-	-	-
World	151,596,722	591,837	596.25	264.93	57.44	918.62	-	-	-	-	-	-	-

Period 1999 – 2003

* Source: FAO (2007a)

Appendix I: Different methodologies

Country	Area* (ha)	Production* (kton year^{-1})	Mom (2007)			Hoekstra and Chapagain (2007a)				
			CWU (m^3 ha^{-1})	Volume of water use** (km^3 $year^{-1}$)	Virtual water content** (m^3 ton^{-1})	CWR (m^3 ha^{-1})	SP is depleted		SP is not depleted	
							Volume of water use*** (km^3 $year^{-1}$)	Virtual water content**** (m^3 ton^{-1})	Volume of water use*** (km^3 $year^{-1}$)	Virtual water content**** (m^3 ton^{-1})
Afghanistan	144,200	286	12,918	1.86	6513	13,130	1.89	6620	1.46	5108
Argentina	177,238	970	9,711	1.72	1774	7,120	1.26	1300	0.73	752
Australia	130,367	1,153	12,012	1.57	1359	8,980	1.17	1016	0.78	676
Bangladesh	10,754,034	37,002	5,122	55.08	1489	8,950	96.25	2601	63.99	1729
Bolivia	152,755	296	4,341	0.66	2240	9,880	1.51	5097	1.05	3549
Brazil	3,387,586	10,755	6,211	21.04	1956	9,000	30.49	2835	20.33	1890
Cambodia	2,039,915	4,140	4,611	9.41	2272	9,170	18.71	4518	12.59	3040
Chad	93,279	121	4,215	0.39	3255	13,850	1.29	10695	1.01	8378
Chile	25,045	124	10,450	0.26	2104	5,950	0.15	1198	0.07	594
China	29,274,307	181,634	6,571	192.37	1059	8,300	242.98	1338	155.15	854
Colombia	481,863	2,413	4,378	2.11	874	9,000	4.34	1797	2.89	1198
Congo, DR	435,241	329	3,690	1.61	4887	9,640	4.20	12768	2.89	8795
Costa Rica	56,637	244	5,255	0.30	1218	10,030	0.57	2326	0.40	1630
Cote d'Ivoire	340,917	634	3,631	1.24	1951	8,960	3.05	4814	2.03	3202
Cuba	191,520	624	7,673	1.47	2355	10,730	2.06	3293	1.48	2372
Dominican Republic	133,572	642	5,115	0.68	1065	11,020	1.47	2294	1.07	1669
Ecuador	347,581	1,292	5,639	1.96	1517	8,590	2.99	2310	1.94	1503
Egypt	632,261	5,865	10,013	6.33	1079	13,870	8.77	1495	6.87	1172
France	18,936	108	11,975	0.23	2096	9,010	0.17	1577	0.11	1052
Ghana	119,270	250	3,673	0.44	1750	9,730	1.16	4635	0.80	3206
Greece	21,854	158	9,286	0.20	1286	11,300	0.25	1565	0.18	1149
Guinea	509,700	817	4,676	2.38	2916	9,970	5.08	6217	3.55	4347
Guyana	126,710	491	5,647	0.72	1459	10,700	1.36	2764	0.98	1989
Haiti	53,540	113	3,579	0.19	1690	10,320	0.55	4872	0.39	3456
India	43,694,400	128,319	5,206	227.48	1773	8,520	372.28	2901	241.19	1880
Indonesia	11,650,945	51,370	6,280	73.17	1424	9,320	108.59	2114	73.63	1433
Iran	572,454	2,426	9,957	5.70	2350	13,060	7.48	3082	5.76	2374
Iraq	91,900	142	17,408	1.60	11298	18,360	1.69	11916	1.41	9969
Italy	219,223	1,342	7,730	1.69	1263	10,190	2.23	1664	1.58	1174
Japan	1,723,400	11,101	7,400	12.75	1149	7,910	13.63	1228	8.46	762
Kazakhstan	72,307	217	13,525	0.98	4508	10,890	0.79	3630	0.57	2630
Korea, DPR	570,771	2,105	8,040	4.59	2180	8,220	4.69	2229	2.98	1416
Korea, Republic of	1,058,181	6,868	6,375	6.75	982	8,720	9.23	1344	6.05	881
Laos	744,629	2,286	4,513	3.36	1470	9,000	6.70	2931	4.47	1954
Liberia	133,440	147	4,487	0.60	4075	9,280	1.24	8427	0.84	5703
Madagascar	1,212,974	2,623	6,289	7.63	2908	9,200	11.16	4254	7.52	2867
Malaysia	682,998	2,145	5,329	3.64	1696	8,900	6.08	2833	4.03	1878
Mali	382,428	811	7,861	3.01	3709	15,900	6.08	7501	4.93	6086
Mexico	66,068	295	5,476	0.36	1228	9,540	0.63	2139	0.43	1467
Mozambique	175,389	156	4,414	0.77	4975	9,960	1.75	11224	1.22	7843
Myanmar	6,366,958	21,663	4,193	26.70	1232	8,730	55.58	2566	36.48	1684
Nepal	1,546,422	4,161	4,287	6.63	1593	7,070	10.93	2628	6.29	1513
Nicaragua	83,645	254	4,970	0.42	1635	10,490	0.88	3451	0.63	2464
Nigeria	2,180,400	3,074	4,487	9.78	3183	10,470	22.83	7426	16.29	5298
Pakistan	2,338,360	6,950	8,118	18.98	2731	11,820	27.64	3977	20.62	2968
Panama	109,493	252	4,569	0.50	1982	9,430	1.03	4090	0.70	2789
Paraguay	27,606	110	7,371	0.20	1848	9,570	0.26	2399	0.18	1647
Peru	306,662	2,025	6,640	2.04	1006	8,740	2.68	1324	1.76	869
Philippines	4,031,215	12,780	5,792	23.35	1827	9,260	37.33	2921	25.24	1975
Portugal	24,995	147	11,884	0.30	2024	9,650	0.24	1643	0.17	1132
Russia	149,060	494	9,578	1.43	2893	7,250	1.08	2190	0.63	1284
Senegal	86,633	211	4,963	0.43	2041	15,230	1.32	6263	1.06	5030
Sierra Leone	198,254	240	5,178	1.03	4273	8,540	1.69	7046	1.10	4571
Spain	115,141	844	12,607	1.45	1719	10,830	1.25	1477	0.90	1068
Sri Lanka	839,774	2,869	7,276	6.11	2130	10,770	9.04	3153	6.53	2275
Surinam	46,742	177	5,513	0.26	1454	10,030	0.47	2645	0.33	1854
Tanzania	413,562	686	5,659	2.34	3413	10,020	4.14	6044	2.90	4235
Thailand	10,033,590	25,927	4,249	42.64	1644	9,450	94.82	3657	64.72	2496
Turkey	61,400	356	9,716	0.60	1674	11,370	0.70	1959	0.51	1442
United States of America	1,300,807	9,281	9,647	12.55	1352	8,630	11.23	1210	7.32	789
Uruguay	172,960	1,083	10,654	1.84	1702	6,960	1.20	1112	0.68	633
Uzbekistan	104,180	230	12,595	1.31	5694	12,940	1.35	5850	1.04	4494
Venezuela	142,615	701	4,048	0.58	823	10,200	1.45	2075	1.03	1465
Viet Nam	7,553,820	33,010	5,197	39.26	1189	9,230	69.72	2112	47.06	1426
Total	150,934,129	590,339	-	859.00	-	-	1,344.81	-	892.01	-
Average	-	-	-	-	1455	-	-	2278	-	1511

Period 1999 – 2003

* source: FAO (2007a)
** exclusive of the grey component
*** $CWR \times \text{area}$
**** $CWR \times \frac{\text{production}}{\text{area}}$

Appendix J: Virtual water content of rice products

Country	paddy rice				brown rice				white / broken rice			
	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	grey (m^3 ton^{-1})	total (m^3 ton^{-1})	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	grey (m^3 ton^{-1})	total (m^3 ton^{-1})	blue (m^3 ton^{-1})	green (m^3 ton^{-1})	grey (m^3 ton^{-1})	total (m^3 ton^{-1})
Afghanistan	6,204	309	97	6,610	7,756	386	121	8,263	9,545	475	149	10,169
Argentina	1,135	638	33	1,807	1,419	798	41	2,258	1,747	982	51	2,779
Australia	1,211	147	97	1,456	1,514	184	121	1,819	1,682	204	135	2,022
Bangladesh	572	916	105	1,593	715	1,145	131	1,991	854	1,368	156	2,378
Bolivia	0	2,240	10	2,250	0	2,800	13	2,812	0	3,199	15	3,214
Brazil	641	1,316	44	2,000	801	1,644	55	2,501	942	1,935	65	2,942
Cambodia	359	1,913	13	2,284	448	2,391	16	2,855	569	3,037	20	3,626
Chad	167	3,089	97	3,352	208	3,861	121	4,190	241	4,476	141	4,858
Chile	1,876	228	97	2,200	2,345	285	121	2,750	2,886	351	149	3,385
China	352	707	117	1,176	440	884	146	1,470	503	1,010	167	1,680
Colombia	0	874	108	982	0	1,093	135	1,228	0	1,345	166	1,511
Congo, DR	0	4,886	97	4,984	0	6,108	121	6,230	1	8,144	162	8,306
Costa Rica	0	1,218	162	1,381	0	1,523	203	1,726	0	1,875	250	2,124
Cote d'Ivoire	55	1,896	97	2,048	69	2,370	121	2,560	86	2,962	152	3,200
Cuba	1,057	1,298	97	2,452	1,321	1,622	121	3,065	1,605	1,970	147	3,722
Dominican Republic	0	1,065	112	1,177	0	1,331	140	1,471	0	1,638	173	1,811
Ecuador	5	1,511	81	1,597	7	1,889	101	1,997	9	2,519	134	2,662
Egypt	1,040	40	64	1,144	1,300	50	80	1,429	1,552	59	96	1,707
France	1,681	415	97	2,193	2,101	519	121	2,741	2,586	639	149	3,374
Ghana	40	1,709	97	1,847	50	2,137	121	2,308	60	2,551	145	2,756
Greece	1,088	198	97	1,383	1,360	247	121	1,728	1,727	314	154	2,195
Guinea	140	2,776	50	2,966	175	3,469	62	3,707	216	4,270	77	4,563
Guyana	337	1,122	97	1,556	421	1,403	121	1,945	511	1,704	147	2,362
Haiti	0	1,690	97	1,787	0	2,112	121	2,234	0	2,816	162	2,978
India	458	1,315	86	1,859	572	1,644	108	2,324	683	1,963	129	2,775
Indonesia	400	1,024	107	1,531	500	1,280	134	1,914	588	1,506	158	2,252
Iran	2,113	237	97	2,447	2,641	296	121	3,058	3,201	359	147	3,707
Iraq	11,097	201	97	11,395	13,871	251	121	14,244	16,562	300	145	17,007
Italy	772	491	97	1,360	964	614	121	1,700	1,152	733	145	2,029
Japan	276	873	61	1,209	345	1,091	76	1,512	378	1,196	83	1,657
Kazakhstan	4,300	208	97	4,605	5,375	260	121	5,756	6,529	315	147	6,991
Korea, DPR	577	1,603	97	2,277	722	2,004	121	2,847	837	2,323	141	3,301
Korea, Republic of	184	798	85	1,067	230	998	106	1,334	256	1,109	118	1,482
Laos	63	1,407	27	1,497	79	1,758	34	1,871	105	2,344	45	2,494
Liberia	12	4,063	97	4,172	15	5,079	121	5,215	19	6,772	162	6,953
Madagascar	337	2,571	2	2,910	421	3,214	3	3,638	526	4,018	3	4,547
Malaysia	302	1,395	136	1,833	377	1,743	170	2,291	472	2,179	213	2,863
Mali	2,334	1,374	97	3,806	2,918	1,718	121	4,757	3,537	2,082	147	5,766
Mexico	508	720	121	1,349	635	900	151	1,687	758	1,075	181	2,014
Mozambique	45	4,930	97	5,072	56	6,162	121	6,339	67	7,358	145	7,570
Myanmar	146	1,086	31	1,263	182	1,358	39	1,579	235	1,752	50	2,037
Nepal	127	1,466	97	1,690	159	1,833	121	2,113	189	2,189	145	2,523
Nicaragua	0	1,635	41	1,676	0	2,043	51	2,095	0	2,515	63	2,578
Nigeria	413	2,769	17	3,200	517	3,462	21	4,000	626	4,196	26	4,848
Pakistan	1,939	792	88	2,819	2,424	991	110	3,524	2,894	1,183	131	4,208
Panama	0	1,982	97	2,079	0	2,477	121	2,598	0	2,958	145	3,103
Paraguay	816	1,032	31	1,879	1,020	1,290	39	2,349	1,218	1,541	47	2,805
Peru	511	494	97	1,103	639	618	121	1,378	741	716	141	1,598
Philippines	508	1,319	68	1,895	634	1,649	85	2,369	781	2,030	105	2,916
Portugal	1,817	207	97	2,121	2,271	259	121	2,651	2,795	318	149	3,263
Russia	2,413	480	97	2,990	3,016	600	121	3,737	3,712	738	149	4,600
Senegal	403	1,638	97	2,138	504	2,047	121	2,672	620	2,520	149	3,289
Sierra Leone	1	4,272	97	4,370	1	5,340	121	5,462	1	7,120	162	7,283
Spain	1,549	170	97	1,816	1,937	212	121	2,270	2,352	258	147	2,757
Sri Lanka	1,160	970	152	2,282	1,450	1,213	190	2,853	1,705	1,427	224	3,356
Surinam	338	1,116	97	1,551	423	1,395	121	1,939	537	1,771	154	2,462
Tanzania	934	2,479	24	3,438	1,168	3,099	30	4,297	1,394	3,701	36	5,131
Thailand	213	1,431	108	1,752	266	1,789	135	2,191	323	2,169	164	2,655
Turkey	1,459	214	97	1,771	1,824	268	121	2,214	2,245	330	149	2,724
United States of America	982	371	100	1,452	1,227	463	125	1,815	1,402	529	143	2,074
Uruguay	1,138	564	64	1,766	1,423	705	80	2,208	1,626	806	91	2,523
Uzbekistan	5,494	200	97	5,791	6,868	250	121	7,239	8,342	303	147	8,793
Venezuela	4	820	137	961	5	1,025	172	1,201	6	1,261	211	1,478
Viet Nam	333	856	118	1,308	417	1,070	148	1,635	513	1,317	182	2,012
Average	*448*	*1,007*	*97*	*1,552*	*560*	*1,259*	*121*	*1,940*	*680*	*1,530*	*147*	*2,357*

Period 1999 – 2003

Appendix K: Water productivity

Country	irrigated lowland											
	first season						second season					
	$yield_{irrigated}$ (kg ha^{-1})	IWP_T (kg m^{-3})	IWP_{ET} (kg m^{-3})	$yield_{rainfed}$ (kg ha^{-1})	RWP_T (kg m^{-3})	RWP_{ET} (kg m^{-3})	$yield_{irrigated}$ (kg ha^{-1})	IWP_T (kg m^{-3})	IWP_{ET} (kg m^{-3})	$yield_{rainfed}$ (kg ha^{-1})	RWP_T (kg m^{-3})	RWP_{ET} (kg m^{-3})
Afghanistan	6,156	0.60	0.49	65	0.31	0.11	-	-	-	-	-	-
Argentina	7,976	1.22	1.13	948	0.50	0.27	-	-	-	-	-	-
Australia	6,449	0.69	0.59	111	0.38	0.09	-	-	-	-	-	-
Bangladesh	5,046	1.47	1.17	4,223	1.40	0.95	7,576	1.51	1.34	1,005	0.75	0.44
Bolivia	-	-	-	-	-	-	-	-	-	-	-	-
Brazil	7,694	1.25	1.19	1,694	0.81	0.44	-	-	-	-	-	-
Cambodia	6,456	2.16	2.00	4,652	1.40	1.00	7,694	1.39	1.18	89	0.18	0.10
Chad	8,456	2.96	2.70	3,319	1.10	0.81	3,517	0.35	0.29	4	0.02	0.01
Chile	3,521	0.43	0.34	381	0.81	0.34	-	-	-	-	-	-
China	6,742	1.79	1.59	2,903	0.98	0.66	8,014	2.86	2.70	3,115	1.06	0.74
Colombia	-	-	-	-	-	-	-	-	-	-	-	-
Costa Rica	-	-	-	-	-	-	-	-	-	-	-	-
Cuba	8,764	1.84	1.73	2,791	1.02	0.66	-	-	-	-	-	-
Dominican Republic	-	-	-	-	-	-	-	-	-	-	-	-
Ecuador	8,191	1.40	1.36	592	0.24	0.14	-	-	-	-	-	-
Egypt	5,347	0.68	0.54	131	1.19	0.36	-	-	-	-	-	-
France	4,608	0.52	0.44	423	0.43	0.18	-	-	-	-	-	-
Ghana	7,253	2.79	2.51	4,273	1.58	1.11	7,265	1.42	1.26	1,278	0.92	0.51
Greece	6,493	0.99	0.81	112	0.18	0.08	-	-	-	-	-	-
Guinea	7,797	1.82	1.62	6,177	1.68	1.23	8,360	1.25	1.08	720	0.90	0.47
Guyana	7,907	1.96	2.14	3,400	1.23	0.78	-	-	-	-	-	-
Haiti	-	-	-	-	-	-	-	-	-	-	-	-
India	6,324	2.00	1.76	2,728	0.99	0.68	6,248	1.05	0.92	418	0.33	0.21
Indonesia	8,702	2.24	2.18	5,613	1.39	1.03	8,838	1.74	1.60	1,580	0.87	0.55
Iran	5,883	0.75	0.61	391	0.84	0.39	-	-	-	-	-	-
Iraq	4,260	0.33	0.25	0	0.00	0.00	-	-	-	-	-	-
Italy	4,584	0.93	0.78	893	0.53	0.30	-	-	-	-	-	-
Ivory Coast	7,246	2.89	2.56	3,977	1.49	1.05	8,997	1.84	1.59	1,568	1.12	0.68
Japan	5,203	1.28	1.12	3,215	0.84	0.57	-	-	-	-	-	-
Kazakhstan	7,253	0.67	0.56	32	0.32	0.05	-	-	-	-	-	-
Laos	7,482	3.14	2.64	6,682	1.84	1.37	9,261	1.84	1.66	900	0.73	0.40
Liberia	6,982	2.52	2.56	5,648	1.54	1.12	-	-	-	-	-	-
Madagascar	10,379	2.10	1.89	7,551	1.77	1.32	-	-	-	-	-	-
Malaysia	7,515	3.09	2.89	4,355	1.31	0.97	7,647	2.66	2.54	4,681	1.56	1.11
Mali	4,629	0.60	0.51	626	0.54	0.27	7,691	1.15	1.02	302	0.49	0.18
Mexico	7,829	1.08	0.98	1,356	1.07	0.52	-	-	-	-	-	-
Mozambique	8,428	2.23	2.17	4,026	1.27	0.88	-	-	-	-	-	-
Myanmar (Burma)	6,332	3.54	2.96	5,585	1.79	1.31	8,715	1.81	1.52	20	0.05	0.03
Nepal	6,782	3.27	2.89	3,783	1.27	0.91	-	-	-	-	-	-
Nicaragua	-	-	-	-	-	-	-	-	-	-	-	-
Nigeria	7,581	2.16	1.97	3,533	1.15	0.82	6,872	0.93	0.79	381	0.58	0.27
North Korea	6,976	1.51	0.99	4,396	1.05	0.76	-	-	-	-	-	-
Pakistan	5,041	1.04	0.81	382	0.29	0.16	-	-	-	-	-	-
Panama	-	-	-	-	-	-	-	-	-	-	-	-
Paraguay	9,528	1.71	1.67	1,255	0.56	0.32	-	-	-	-	-	-
Peru	7,565	0.95	0.83	284	0.34	0.17	-	-	-	-	-	-
Philippines	7,749	2.30	2.27	5,827	1.54	1.13	8,787	1.99	1.80	1,164	0.74	0.46
Portugal	5,666	0.61	0.50	297	0.76	0.24	-	-	-	-	-	-
Russia	3,184	0.44	0.38	178	0.27	0.11	-	-	-	-	-	-
Senegal	7,322	1.83	1.55	4,549	1.49	1.09	8,227	1.29	1.14	431	0.60	0.23
Sierra Leone	6,897	1.26	1.05	6,499	1.45	1.09	-	-	-	-	-	-
South Korea	6,845	2.17	1.82	3,896	1.08	0.77	-	-	-	-	-	-
Spain	5,803	0.60	0.50	164	0.45	0.13	-	-	-	-	-	-
Sri Lanka	7,880	2.04	1.96	1,280	0.51	0.34	6,791	1.14	1.01	432	0.42	0.21
Suriname	7,342	1.91	2.00	3,646	1.30	0.86	-	-	-	-	-	-
Tanzania, United Republic of	8,947	1.82	1.75	2,174	0.95	0.58	-	-	-	-	-	-
Thailand	6,818	2.30	2.12	4,353	1.48	1.04	7,636	1.43	1.22	299	0.43	0.27
Turkey	3,736	0.49	0.41	224	0.43	0.18	-	-	-	-	-	-
United States	5,872	0.88	0.78	397	0.30	0.15	-	-	-	-	-	-
Uruguay	6,800	0.94	0.85	743	0.39	0.21	-	-	-	-	-	-
Uzbekistan	7,407	0.73	0.61	37	0.35	0.08	-	-	-	-	-	-
Venezuela	8,459	2.82	2.90	2,831	0.96	0.65	7,967	2.32	2.27	1,669	0.72	0.47
Vietnam	6,683	2.13	1.88	3,482	1.25	0.89	7,061	1.69	1.51	2,157	1.14	0.71
Zaire	8,166	2.04	1.89	2,504	0.92	0.62	-	-	-	-	-	-

Country	rainfed lowland			rainfed upland		
	$yield_{rainfed}$ (kg ha^{-3})	RWP_T (kg m^{-3})	RWP_{ET} (kg m^{-3})	$yield_{rainfed}$ (kg ha^{-3})	RWP_T (kg m^{-3})	RWP_{ET} (kg m^{-3})
Afghanistan	-	-	-	-	-	-
Argentina	-	-	-	3,123	1.19	0.60
Australia	-	-	-	-	-	-
Bangladesh	2,666	1.26	0.71	2,328	1.55	0.74
Bolivia	-	-	-	2,460	1.20	0.57
Brazil	-	-	-	3,277	1.64	0.74
Cambodia	3,243	1.25	0.78	3,107	1.55	0.74
Chad	-	-	-	2,960	1.35	0.74
Chile	-	-	-	-	-	-
China	3,523	1.15	0.74	2,989	1.35	0.72
Colombia	-	-	-	2,314	1.01	0.53
Costa Rica	-	-	-	4,176	1.47	0.79
Cuba	-	-	-	-	-	-
Dominican Republic	-	-	-	2,270	0.88	0.44
Ecuador	-	-	-	2,556	0.93	0.45
Egypt	-	-	-	-	-	-
France	-	-	-	-	-	-
Ghana	-	-	-	2,836	1.70	0.79
Greece	-	-	-	-	-	-
Guinea	-	-	-	3,508	1.62	0.79
Guyana	-	-	-	2,925	1.49	0.68
Haiti	-	-	-	2,213	1.13	0.62
India	3,198	1.20	0.76	2,673	1.44	0.78
Indonesia	3,930	1.15	0.76	3,403	1.35	0.73
Iran	-	-	-	-	-	-
Iraq	-	-	-	-	-	-
Italy	-	-	-	-	-	-
Ivory Coast	-	-	-	2,859	1.66	0.82
Japan	-	-	-	-	-	-
Kazakhstan	-	-	-	-	-	-
Laos	4,020	1.42	0.91	3,911	1.82	0.91
Liberia	-	-	-	3,293	1.51	0.74
Madagascar	5,355	1.58	1.00	4,926	1.75	0.91
Malaysia	4,085	1.39	0.92	3,708	1.72	0.83
Mali	-	-	-	2,460	1.46	0.64
Mexico	-	-	-	1,959	1.28	0.56
Mozambique	3,439	1.17	0.73	2,921	1.38	0.67
Myanmar (Burma)	3,743	1.52	0.98	3,811	1.77	0.97
Nepal	3,359	1.30	0.85	2,390	1.45	0.87
Nicaragua	-	-	-	3,108	1.39	0.63
Nigeria	-	-	-	2,772	1.34	0.70
North Korea	5,031	1.09	0.79	4,626	1.41	0.97
Pakistan	-	-	-	-	-	-
Panama	-	-	-	3,407	1.51	0.75
Paraguay	-	-	-	2,484	1.14	0.56
Peru	-	-	-	2,680	1.28	0.63
Philippines	3,851	1.24	0.81	3,636	1.53	0.82
Portugal	-	-	-	-	-	-
Russia	-	-	-	2,138	0.74	0.49
Senegal	-	-	-	3,117	1.60	0.83
Sierra Leone	-	-	-	3,118	1.29	0.60
South Korea	4,570	1.14	0.83	3,281	1.38	0.92
Spain	-	-	-	-	-	-
Sri Lanka	2,463	0.74	0.50	-	-	-
Suriname	-	-	-	2,904	1.48	0.70
Tanzania, United Republic of	2,387	1.14	0.59	2,558	1.31	0.58
Thailand	3,206	1.34	0.82	3,034	1.72	0.79
Turkey	-	-	-	-	-	-
United States	-	-	-	-	-	-
Uruguay	-	-	-	-	-	-
Uzbekistan	-	-	-	-	-	-
Venezuela	-	-	-	2,606	1.24	0.65
Vietnam	3,161	1.18	0.76	2,800	1.42	0.74
Zaire	-	-	-	3,116	1.65	0.84

Appendix L: Trade in rice products

Country	Paddy rice		Brown rice		White rice		Broken rice	
	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})
Afhanistan	0	0	0	0	29,389	2,368	1,121	0
Albania	1,882	0	9,983	0	10,612	0	640	0
Algeria	3,555	0	4,736	0	52,481	20	8,394	0
Andorra	0	0	0	0	350	0	0	0
Angola	40	0	177	0	29,104	0	552	0
Anguilla	0	0	0	0	140	0	0	0
Antigua and Barbuda	0	0	1,908	0	749	0	0	0
Argentina	0	182,309	476	34,425	6,574	209,666	8,644	13,228
Armenia	1,681	0	8,161	0	387	0	0	0
Aruba*	0	0	0	0	0	0	0	0
Australia	71	68,268	293	45,392	53,265	233,194	5,746	28,947
Austria	1,829	41	3,228	67	18,430	792	7,281	578
Azerbaijan, Republic of	7,684	246	1,357	0	9,790	0	64	0
Bahamas	1,206	0	1,697	0	6,188	1,135	1,086	0
Bahrain	0	0	0	154	22,107	291	0	0
Bangladesh	2,618	0	148	148	602,661	380	332	0
Barbados	0	0	3,663	84	4,488	0	0	29
Belarus	207	0	6,544	0	21,698	1,156	928	0
Belgium	3,117	1,021	154,932	5,162	40,744	67,489	53,780	12,495
Belize	159	3	105	60	2,315	84	225	73
Benin	0	0	2,047	0	118,589	1,333	8,942	0
Bermuda	0	0	0	0	314	0	0	0
Bhutan	0	0	7,819	0	11,251	30	0	0
Bolivia	367	0	294	0	10,535	617	1,510	0
Bosnia and Herzegovina	0	0	10	0	3,359	23	0	0
Botswana	166	0	0	0	5,466	0	124	573
British Virgin Islands*	0	0	0	0	0	0	0	0
Brazil	386,005	330	231,697	3,375	305,867	14,221	6,498	17,218
Brunei Darussalam	235	0	158	0	27,143	60	4	75
Bulgaria	5,486	349	16,704	345	16,054	391	108	1,905
Burkina Faso	12	0	1,097	158	5,909	79	4,431	109
Burundi	0	0	0	0	1,242	0	0	0
Cambodia	130	0	7,286	2,724	8,188	1,913	15,838	360
Cameroon	0	0	519	0	29,564	0	640	0
Canada	199	6	23,471	283	165,986	1,158	9,606	85
Cape Verde	2,146	0	0	0	18,208	0	446	0
Cayman Islands	0	0	166	0	264	200	0	0
Central African Republic	0	0	0	0	353	0	0	0
Chad	0	0	0	0	50	0	0	0
Chile	1,228	0	137	0	81,275	150	19,595	0
China	318	18,015	687	161,121	234,204	2,233,507	918	232,759
Cocos Islands	0	0	0	0	90	0	0	0
Colombia	3,137	99	1,966	120	64,129	907	7,507	0
Comoros	100	0	7,703	0	12,021	0	824	0
Congo, Republic of	0	0	1,371	0	16,709	0	1,382	0
Congo, Dem Republic of	0	0	0	0	4,392	0	1,062	0
Cook Islands*	0	0	0	0	0	0	0	0
Costa Rica	95,605	156	233	0	984	2,775	140	3,472
Côte d'Ivoire	2,438	0	4,557	0	887,867	194	104,018	496
Croatia	0	0	127	0	17,492	583	0	0
Cuba	18,720	0	3,705	0	147,080	0	257,082	0
Cyprus*	0	0	0	0	0	0	0	0
Czech Republic	690	0	2,895	507	52,786	5,386	786	25
Denmark	115	64	3,133	404	27,040	3,642	3,642	481
Djibouti	0	0	100	760	18,909	1,391	877	330
Dominica	0	0	1,138	0	201	0	37	0
Dominican Republic	0	0	1,690	3,984	31,994	1,057	954	1,190
Timor-Leste	0	0	0	0	0	0	0	0
Ecuador	1,408	83	681	0	193	36,449	1,036	2,282
Egypt	0	8,267	2,429	87,722	19,737	162,665	0	23,031
El Salvador	60,581	69	620	174	4,817	496	1,972	156
Equatorial Guinea	0	0	0	0	1,575	0	0	0
Estonia	126	48	127	0	3,196	0	0	0
Ethiopia	0	0	2,438	0	7,253	0	1,197	0
Faroe Islands	0	0	0	0	71	0	0	0
Fiji Islands	2,140	0	18,590	0	9,031	0	603	0
Finland	0	0	9,446	250	15,660	768	1,426	0
French Guiana	0	0	0	0	0	0	0	0
French Polynesia	0	0	0	0	8,889	0	0	0
France	7,657	34,777	145,076	5,895	197,905	44,950	78,090	4,317
Gabon	0	23	0	0	79,771	24	250	0
Gambia	5,692	0	934	0	8,712	0	31,701	112
Georgia	483	0	90	0	517	0	0	0
Germany	5,637	4,791	125,520	4,083	119,332	42,852	30,622	6,359
Ghana	0	0	304	0	162,084	626	32,683	272
Gibraltar	0	0	0	0	152	0	0	0
Greece	1,059	2,528	2,521	38,016	12,976	16,456	83	7,539
Greenland	0	0	0	0	190	0	0	0
Grenada	223	0	1,198	0	342	0	137	0
Guatemala	47,830	73	726	133	1,144	669	2,354	0
Guinea	35	130	256	0	107,422	0	75,715	0
Guinea-Bissau	0	0	0	0	9,946	0	210	0
Guyana	0	1,890	0	179,152	0	49,235	0	22,486
Haiti	7,339	0	12,341	0	264,436	0	3,692	0
Honduras	40,417	288	1,849	0	8,621	32	322	1,338
Hong Kong*	0	0	0	0	0	0	0	0
Hungary	7,012	0	19	0	42,373	241	837	0
Iceland	31	0	35	0	785	0	0	46
India	282	21,402	1,598	202,848	8,472	2,383,349	6,977	195,211
Indonesia	9,359	211	229,992	1,468	1,141,304	5,915	608,923	1,656

Country	Paddy rice		Brown rice		White rice		Broken rice	
	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})
Iran, Islamic Rep of	6,373	2,679	44	7,999	950,142	1,331	0	0
Iraq	0	0	0	0	284,101	12,557	0	0
Ireland	5,700	242	3,644	118	9,517	2,622	3,933	40
Israel	0	0	1,212	0	63,675	106	144	0
Italy	29,567	20,145	43,934	50,255	12,434	554,215	5,034	50,031
Jamaica	22,601	0	56,506	0	11,899	1	5,713	0
Japan	129	5,186	104,980	188,566	466,437	39,540	93,059	6,217
Jordan	0	0	2,840	0	109,956	1,529	658	409
Kazakhstan	0	2,582	2,521	202	11,933	2,949	0	6,597
Kenya	1,036	69	1,429	0	90,970	600	19,305	18
Kiribati	0	0	0	0	319	0	0	0
Korea, Dem People's Rep	214	0	106,014	0	164,081	0	593	0
Korea, Republic of	2,613	0	144,763	0	4,378	854	0	0
Kuwait	0	0	0	0	99,870	491	0	0
Kyrgyzstan	130	0	1,884	0	1,734	0	80	0
Laos	0	0	0	0	4,849	90	1,048	0
Latvia	0	0	48	0	6,539	4,971	0	0
Lebanon	63	0	4,475	100	44,025	2,505	190	48
Liberia	130	0	0	0	26,952	400	561	0
Libyan Arab Jamahiriya	0	0	0	0	75,160	0	0	0
Lithuania	0	0	35	0	10,612	1,677	72	0
Luxembourg	0	0	198	0	1,006	35	518	0
Macau*	0	0	0	0	0	0	0	0
Macedonia,The Fmr Yug Rp	42	0	151	34	867	1,508	0	0
Madagascar	0	0	2,481	0	141,480	511	10,480	0
Malawi	773	82	0	0	1,878	2,052	40	0
Malaysia	2,008	0	3,817	1,956	485,058	20,393	31,608	11,771
Maldives	0	0	0	0	15,775	0	100	0
Mali	74	0	391	0	17,788	0	28,733	0
Malta	91	0	0	0	1,182	0	486	0
Marshall Islands	0	0	0	0	1,207	0	0	0
Mauritania	0	0	262	0	5,630	0	3,260	0
Mauritius	111	0	105	0	68,917	328	381	0
Mexico	599,368	100	3,454	87	55,880	365	3,386	1,909
Micronesia, Fed States of	0	0	124	0	5,800	0	0	0
Moldova, Republic of	0	0	471	0	8,025	58	729	0
Mongolia	0	0	445	0	10,356	0	0	343
Montserrat	0	0	0	0	41	0	0	0
Morocco	967	0	0	0	1,583	28	345	0
Mozambique	227	0	1,742	0	71,014	107	363	3,915
Myanmar	74	853	1,154	2,424	5,472	62,400	671	53,260
New Caledonia	0	0	5,085	0	2,290	0	0	0
New Mariana	0	0	0	0	595	0	0	0
Namibia	271	0	38	0	885	53	2,822	278
Nepal	607	0	0	0	28,915	161	647	0
Netherlands Antilles	0	0	4,989	195	9,107	8,031	1,276	1,529
Netherlands	3,582	2,087	105,477	36,838	68,981	54,161	50,055	35,983
New Zealand	0	0	164	0	29,507	83	3,367	0
Nicaragua	51,131	0	1,255	125	14,654	318	2,807	460
Niger	84	0	756	0	110,870	571	3,033	0
Nigeria	3,450	0	1,000	0	835,961	482	36,353	0
Norway	175	0	578	0	15,817	7	177	49
Oman	113	0	0	0	94,056	1,635	133	185
Pakistan	18	6,409	0	82,617	2,888	777,166	0	82,162
Palau	0	0	286	0	1,124	0	0	0
Panama	10,586	0	817	204	2,605	82	0	0
Papua New Guinea*	0	0	0	0	0	0	0	0
Paraguay	117	9,485	352	0	1,952	1,665	1,381	0
Peru	3,243	0	17,089	0	52,901	0	0	1,036
Philippines	119	0	334	91	755,080	98	16,450	0
Poland	43	0	1,687	0	90,605	1,531	8,117	34
Portugal	31,542	352	63,371	216	27,338	965	2,624	5,432
Qatar	627	0	813	0	37,918	172	83	0
Réunion	0	0	0	0	0	0	0	0
Romania	2,660	0	79,498	227	5,954	719	181	0
Russian Federation	2,620	7,340	5,317	6,470	422,809	6,243	10,454	7,836
Rwanda	530	0	883	0	13,492	0	826	0
Saint Vincent/Grenadines	0	117	8,314	2,017	7,472	4,099	570	0
Samoa	0	0	0	0	465	0	0	0
Sao Tome and Principe	0	0	392	0	1,846	0	0	0
Saudi Arabia	5,998	44	4,560	520	757,218	782	1,727	110
Senegal	0	0	1,913	0	15,853	1,178	767,821	7,550
Seychelles*	0	0	0	0	0	0	0	0
Sierra Leone	0	0	0	100	7,078	0	5,210	0
Singapore	2,424	0	2,090	641	379,810	10,724	27,335	9,509
Slovakia	266	33	664	81	32,771	1,356	0	0
Slovenia	0	160	0	1,762	8,899	1,133	236	0
Solomon Islands	0	0	0	0	60	0	3,791	0
Somalia	2,400	0	0	0	46,153	1,000	604	0
South Africa	1,610	1,369	1,202	25	508,655	24,292	11,480	4,834
Spain	35,384	19,788	32,770	180,618	44,921	109,919	11,087	51,961

Country	Paddy rice		Brown rice		White rice		Broken rice	
	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})	import (ton year^{-1})	export (ton year^{-1})
Sri Lanka	3,903	0	707	244	68,006	1,466	3,854	0
Saint Helena	0	0	0	0	0	0	0	0
Saint Kitts and Nevis	0	0	573	0	550	0	9	0
Saint Lucia	0	0	11,542	27	689	0	89	0
Sudan	2,896	0	16,875	0	6,735	217	0	0
Suriname	0	0	542	28,902	251	4,796	0	3,431
Swaziland	712	0	25	0	7,178	238	266	67
Sweden	454	0	8,066	390	36,867	768	2,258	41
Switzerland	707	0	23,432	181	24,346	4,525	33,028	2,866
Syrian Arab Republic*	0	0	0	0	0	0	0	0
Taiwan*	0	0	0	0	0	0	0	0
Tajikistan	0	0	0	202	2,087	4,385	0	77
Tanzania, United Rep of	5,703	2,894	894	638	55,371	6,169	74,336	2,208
Thailand	50	12,937	39	175,279	4,989	4,202,084	0	1,173,147
Togo	375	0	14,325	0	23,534	2,793	16,278	502
Tonga	0	0	0	0	0	125	260	0
Trinidad and Tobago	1,023	0	26,949	882	19,762	191	1,668	0
Tunisia	0	0	0	0	15,720	21	1,355	0
Turkey	228,104	441	11,930	61	155,338	465	411	2,701
Turkmenistan	0	0	0	0	423	68	0	0
Turks and Caicos Is	0	227	313	0	815	640	0	0
Uganda	246	59	0	0	22,105	848	25,511	554
Ukraine	33	567	2,081	0	44,517	208	3,576	0
United Arab Emirates	167	536	174	1,153	296,317	170,819	879	4,511
United Kingdom	8,645	3,309	257,026	3,848	146,280	44,114	75,888	11,368
Uruguay	459	80,455	402	203,199	100	398,331	392	35,677
United States of America	507	1,308,641	27,979	463,354	347,495	1,368,010	5,357	102,080
Uzbekistan	0	0	0	0	24,342	0	0	0
Vanuatu	0	0	0	0	204	0	0	0
Venezuela,Bolivar Rep of	7,768	3,381	0	1,862	9,498	13,372	61	5,366
Viet Nam	8,951	3,986	0	86,464	510	1,259,687	991	579,672
Yemen	0	0	0	0	141,679	0	0	0
Serbia and Montenegro	252	0	594	0	8,804	9	0	0
Zambia	653	0	0	0	7,124	0	3,859	0
Zimbabwe	82	0	0	0	6,579	41	139	189
World	1,842,042	1,842,042	2,310,190	2,310,190	14,738,159	14,738,159	2,847,198	2,847,198

Period 1999 – 2003

Source: ITC (2006)
* no trade data was taken into account for these countries

Detailed trade data can be found on the DVD-R (`\Afstuderen\Statistics\Trade\PC-TAS HS\Merged\<product>\*.xls`)

Appendix M: Virtual water import

Country	VWI paddy rice (km³ year⁻¹)				VWI brown rice (km³ year⁻¹)				VWI white rice (km³ year⁻¹)				VWI broken rice (km³ year⁻¹)				VWI total (km³ year⁻¹)			
	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total
Afhanistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.03	0.00	0.12	0.00	0.00	0.00	0.00	0.09	0.04	0.00	0.13
Albania	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.04
Algeria	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.05	0.06	0.01	0.12	0.00	0.01	0.00	0.02	0.06	0.08	0.01	0.15
Andorra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Angola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.07	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.07
Anguilla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antigua and Barbuda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Argentina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.01	0.01	0.00	0.02	0.02	0.02	0.00	0.04
Armenia	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.03
Aruba*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Australia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.01	0.15	0.00	0.01	0.00	0.02	0.04	0.12	0.01	0.17
Austria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.04	0.01	0.01	0.00	0.02	0.03	0.03	0.00	0.06
Azerbaijan, Republic of	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.05
Bahamas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Bahrain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.08	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.08
Bangladesh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	1.18	0.08	1.67	0.00	0.00	0.00	0.00	0.41	1.19	0.08	1.68
Barbados	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Belarus	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.02	0.03	0.00	0.06	0.00	0.00	0.00	0.00	0.05	0.04	0.00	0.09
Belgium	0.00	0.00	0.00	0.01	0.24	0.07	0.02	0.34	0.04	0.06	0.01	0.10	0.06	0.06	0.01	0.13	0.35	0.20	0.03	0.57
Belize	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Benin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.23	0.02	0.32	0.00	0.02	0.00	0.02	0.08	0.24	0.02	0.34
Bermuda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bhutan	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.05
Bolivia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.03
Bosnia and Herzegovina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Botswana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
British Virgin Islands*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brazil	0.41	0.21	0.02	0.65	0.33	0.17	0.02	0.51	0.48	0.28	0.03	0.79	0.01	0.01	0.00	0.02	1.23	0.66	0.07	1.96
Brunei Darussalam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.07	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.07
Bulgaria	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.03	0.01	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.03	0.03	0.01	0.06
Burkina Faso	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.03
Burundi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cambodia	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.02	0.01	0.03	0.00	0.04	0.02	0.05	0.00	0.08
Cameroon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.08	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.08
Canada	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.04	0.18	0.18	0.02	0.39	0.01	0.01	0.00	0.02	0.23	0.20	0.03	0.45
Cape Verde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04
Cayman Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Central African Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.11	0.01	0.22	0.02	0.03	0.00	0.05	0.12	0.14	0.01	0.27
China	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.51	0.04	0.62	0.00	0.00	0.00	0.00	0.08	0.51	0.04	0.63
Cocos Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Colombia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.01	0.16	0.00	0.01	0.00	0.01	0.02	0.15	0.01	0.18
Comoros	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.06
Congo, Republic of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.05	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.05
Congo, Dem Republic of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Cook Islands*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costa Rica	0.09	0.04	0.01	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.04	0.01	0.14
Côte d'Ivoire	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.46	0.98	0.15	1.58	0.04	0.21	0.02	0.27	0.51	1.19	0.16	1.87
Croatia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03
Cuba	0.02	0.01	0.00	0.03	0.00	0.00	0.00	0.01	0.09	0.15	0.02	0.26	0.13	0.30	0.04	0.48	0.24	0.46	0.07	0.77
Cyprus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Czech Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.07	0.01	0.12	0.00	0.00	0.00	0.00	0.05	0.07	0.01	0.13
Denmark	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.00	0.06	0.00	0.00	0.00	0.01	0.03	0.04	0.00	0.08
Djibouti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.05	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.05
Dominica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dominican Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.07	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.07
Timor-Leste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ecuador	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Egypt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.05	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.05
El Salvador	0.06	0.02	0.01	0.09	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.07	0.03	0.01	0.10
Equatorial Guinea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estonia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ethiopia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03
Faroe Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fiji Islands	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.07
Finland	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.02	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.06
French Guiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
French Polynesia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02
France	0.01	0.00	0.00	0.01	0.15	0.14	0.02	0.30	0.22	0.20	0.03	0.45	0.07	0.11	0.01	0.19	0.44	0.45	0.06	0.95
Gabon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.17	0.01	0.21	0.00	0.00	0.00	0.00	0.03	0.17	0.01	0.21
Gambia	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.03	0.05	0.00	0.08	0.04	0.07	0.01	0.11
Georgia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Germany	0.00	0.00	0.00	0.01	0.16	0.08	0.02	0.26	0.13	0.12	0.02	0.27	0.02	0.05	0.00	0.08	0.32	0.25	0.04	0.61
Ghana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.20	0.02	0.37	0.01	0.07	0.01	0.09	0.17	0.27	0.03	0.46
Gibraltar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Greece	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.04
Greenland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grenada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guatemala	0.04	0.02	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.02	0.01	0.08
Guinea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.14	0.02	0.25	0.05	0.11	0.01	0.16	0.15	0.24	0.03	0.42
Guinea-Bissau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Guyana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haiti	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.02	0.38	0.15	0.04	0.57	0.00	0.00	0.00	0.01	0.40	0.17	0.04	0.61
Honduras	0.04	0.02	0.00	0.06	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.06	0.02	0.01	0.08
Hong Kong*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.05	0.04	0.01	0.09	0.00	0.00	0.00	0.00	0.05	0.05	0.01	0.11
Iceland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
India	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	0.01	0.00	0.03	0.03	0.02	0.00	0.05
Indonesia	0.00	0.01	0.00	0.02	0.10	0.28	0.03	0.40	0.69	1.64	0.19	2.52	0.31	1.04	0.10	1.45	1.10	2.97	0.32	4.39

Country	VWI paddy rice (km^3 year^{-1})				VWI brown rice (km^3 year^{-1})				VWI white rice (km^3 year^{-1})				VWI broken rice (km^3 year^{-1})				VWI total (km^3 year^{-1})			
	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total
Iran, Islamic Rep of	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	1.09	1.58	0.13	2.80	0.00	0.00	0.00	0.00	1.10	1.58	0.13	2.81
Iraq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.50	0.05	0.67	0.00	0.00	0.00	0.00	0.12	0.50	0.05	0.67
Ireland	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.03	0.01	0.00	0.00	0.01	0.03	0.02	0.00	0.05
Israel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.09	0.01	0.16	0.00	0.00	0.00	0.00	0.06	0.09	0.01	0.16
Italy	0.04	0.01	0.00	0.05	0.04	0.06	0.01	0.11	0.01	0.02	0.00	0.03	0.01	0.00	0.00	0.01	0.10	0.09	0.01	0.20
Jamaica	0.02	0.01	0.00	0.03	0.03	0.07	0.01	0.11	0.01	0.01	0.00	0.03	0.01	0.00	0.00	0.01	0.07	0.09	0.01	0.18
Japan	0.00	0.00	0.00	0.00	0.13	0.05	0.01	0.19	0.48	0.44	0.07	0.99	0.09	0.11	0.01	0.21	0.69	0.60	0.10	1.39
Jordan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.16	0.05	0.01	0.23	0.00	0.00	0.00	0.00	0.17	0.05	0.01	0.23
Kazakhstan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Kenya	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.11	0.01	0.29	0.05	0.02	0.00	0.07	0.22	0.14	0.02	0.37
Kiribati	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Korea, Dem People's Rep	0.00	0.00	0.00	0.00	0.04	0.11	0.01	0.16	0.07	0.25	0.03	0.35	0.00	0.00	0.00	0.00	0.11	0.37	0.04	0.52
Korea, Republic of	0.00	0.00	0.00	0.00	0.08	0.13	0.02	0.23	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.08	0.14	0.02	0.25
Kuwait	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.17	0.01	0.30	0.00	0.00	0.00	0.00	0.11	0.17	0.01	0.30
Kyrgyzstan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Laos	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Latvia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Lebanon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.03	0.01	0.09	0.00	0.00	0.00	0.00	0.06	0.04	0.01	0.10
Liberia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.06	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.06
Libyan Arab Jamahiriya	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.01	0.14	0.00	0.00	0.00	0.00	0.05	0.07	0.01	0.14
Lithuania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03
Luxembourg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macau*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macedonia,The Fmr Yug Rp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Madagascar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.23	0.18	0.02	0.44	0.02	0.01	0.00	0.03	0.25	0.20	0.02	0.47
Malawi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Malaysia	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.28	0.82	0.08	1.18	0.04	0.05	0.00	0.10	0.33	0.88	0.08	1.29
Maldives	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04
Mali	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04	0.02	0.05	0.00	0.07	0.03	0.08	0.01	0.12
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marshall Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mauritania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.02
Mauritius	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.10	0.01	0.21	0.00	0.00	0.00	0.00	0.10	0.10	0.01	0.21
Mexico	0.59	0.22	0.06	0.87	0.00	0.00	0.00	0.01	0.08	0.03	0.01	0.12	0.00	0.00	0.00	0.01	0.68	0.26	0.07	1.01
Micronesia, Fed States of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Moldova, Republic of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Mongolia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Montserrat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Morocco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Mozambique	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.12	0.01	0.19	0.00	0.00	0.00	0.00	0.06	0.12	0.01	0.20
Myanmar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02
New Caledonia	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
New Mariana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Namibia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01
Nepal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.00	0.08	0.00	0.00	0.00	0.00	0.02	0.06	0.00	0.08
Netherlands Antilles	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03
Netherlands	0.00	0.00	0.00	0.01	0.11	0.10	0.01	0.23	0.07	0.08	0.01	0.16	0.04	0.07	0.01	0.12	0.23	0.26	0.03	0.52
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.00	0.07	0.00	0.00	0.00	0.01	0.05	0.03	0.00	0.08
Nicaragua	0.05	0.02	0.01	0.07	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.03	0.00	0.01	0.00	0.01	0.07	0.04	0.01	0.12
Niger	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.15	0.02	0.27	0.00	0.00	0.00	0.01	0.11	0.15	0.02	0.28
Nigeria	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.41	1.62	0.13	2.16	0.02	0.07	0.01	0.10	0.43	1.70	0.14	2.27
Norway	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04
Oman	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.13	0.01	0.33	0.00	0.00	0.00	0.00	0.19	0.13	0.01	0.33
Pakistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Palau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panama	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.02
Papua New Guinea*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paraguay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Peru	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.03	0.08	0.04	0.01	0.13	0.00	0.00	0.00	0.00	0.11	0.05	0.01	0.17
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	1.16	0.13	1.72	0.01	0.03	0.00	0.04	0.44	1.19	0.13	1.76
Poland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.14	0.01	0.22	0.01	0.01	0.00	0.02	0.08	0.15	0.02	0.25
Portugal	0.05	0.01	0.00	0.06	0.05	0.07	0.01	0.13	0.03	0.03	0.00	0.07	0.00	0.00	0.00	0.01	0.13	0.12	0.02	0.27
Qatar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.05	0.00	0.15	0.00	0.00	0.00	0.00	0.09	0.05	0.01	0.15
Réunion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Romania	0.00	0.00	0.00	0.00	0.08	0.02	0.01	0.11	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.09	0.03	0.01	0.13
Russian Federation	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.28	0.51	0.07	0.86	0.04	0.01	0.00	0.05	0.34	0.52	0.07	0.93
Rwanda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.05	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.06
Saint Vincent/Grenadines	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.03
Samoa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sao Tome and Principe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saudi Arabia	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.77	1.25	0.10	2.12	0.00	0.00	0.00	0.00	0.78	1.27	0.10	2.14
Senegal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.34	1.51	0.12	1.97	0.35	1.53	0.13	2.00
Seychelles*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sierra Leone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.01	0.02	0.00	0.03
Singapore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.71	0.06	0.94	0.01	0.05	0.00	0.06	0.18	0.77	0.06	1.01
Slovakia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.07	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.07
Slovenia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Solomon Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01
Somalia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.01	0.13	0.00	0.00	0.00	0.00	0.03	0.10	0.01	0.13
South Africa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.95	0.08	1.33	0.01	0.02	0.00	0.03	0.32	0.97	0.08	1.37
Spain	0.03	0.01	0.00	0.05	0.03	0.03	0.00	0.06	0.04	0.06	0.01	0.11	0.02	0.01	0.00	0.03	0.13	0.11	0.02	0.25

Country	VWI paddy rice ($km^3\ year^{-1}$)				VWI brown rice ($km^3\ year^{-1}$)				VWI white rice ($km^3\ year^{-1}$)				VWI broken rice ($km^3\ year^{-1}$)				VWI total ($km^3\ year^{-1}$)			
	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total
Sri Lanka	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.12	0.10	0.01	0.23	0.01	0.01	0.00	0.01	0.13	0.12	0.01	0.25
Saint Helena	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saint Kitts and Nevis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saint Lucia	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.02
Sudan	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.05
Suriname	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Swaziland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Sweden	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.03	0.05	0.01	0.09	0.00	0.00	0.00	0.01	0.04	0.07	0.01	0.11
Switzerland	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.04	0.02	0.03	0.00	0.06	0.02	0.06	0.00	0.08	0.07	0.10	0.01	0.18
Syrian Arab Republic*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Taiwan*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tajikistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tanzania, United Rep of	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.06	0.01	0.12	0.06	0.11	0.01	0.18	0.11	0.18	0.02	0.30
Thailand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Togo	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.02	0.03	0.00	0.06	0.01	0.03	0.00	0.04	0.04	0.08	0.01	0.13
Tonga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trinidad and Tobago	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.05	0.02	0.02	0.00	0.05	0.00	0.00	0.00	0.00	0.04	0.06	0.01	0.11
Tunisia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.05
Turkey	0.25	0.07	0.02	0.34	0.01	0.00	0.00	0.02	0.20	0.07	0.02	0.29	0.00	0.00	0.00	0.00	0.46	0.15	0.04	0.65
Turkmenistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turks and Caicos Is	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Uganda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.06	0.03	0.04	0.00	0.08	0.06	0.07	0.01	0.13
Ukraine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.01	0.10	0.01	0.00	0.00	0.01	0.06	0.05	0.01	0.11
United Arab Emirates	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.54	0.04	0.91	0.00	0.00	0.00	0.00	0.33	0.54	0.04	0.92
United Kingdom	0.01	0.00	0.00	0.01	0.27	0.29	0.03	0.58	0.18	0.14	0.02	0.35	0.12	0.05	0.01	0.18	0.58	0.49	0.06	1.13
Uruguay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United States of America	0.00	0.00	0.00	0.00	0.03	0.04	0.00	0.07	0.17	0.66	0.05	0.89	0.00	0.01	0.00	0.01	0.21	0.71	0.06	0.98
Uzbekistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.05	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.05
Vanuatu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Venezuela,Bolivar Rep of	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.03
Viet Nam	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Yemen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.28	0.02	0.39	0.00	0.00	0.00	0.00	0.09	0.28	0.02	0.39
Serbia and Montenegro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Zambia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.01	0.02	0.00	0.03
Zimbabwe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Global flow	*1.87*	*0.80*	*0.17*	*2.84*	*2.26*	*2.06*	*0.26*	*4.58*	*12.34*	*21.66*	*2.20*	*36.20*	*1.90*	*4.63*	*0.45*	*6.98*	*18.36*	*29.15*	*3.08*	*50.60*

Period 1999 – 2003
* no trade data was taken into account for these countries

The total virtual water flow can found directly by multiplying total import/ export (see Appendix L) with the export averaged virtual water content of the product traded (see Table M-1)

	paddy rice				brown rice				white rice				broken rice			
	blue ($m^3\ ton^{-1}$)	green ($m^3\ ton^{-1}$)	grey ($m^3\ ton^{-1}$)	total ($m^3\ ton^{-1}$)	blue ($m^3\ ton^{-1}$)	green ($m^3\ ton^{-1}$)	grey ($m^3\ ton^{-1}$)	total ($m^3\ ton^{-1}$)	blue ($m^3\ ton^{-1}$)	green ($m^3\ ton^{-1}$)	grey ($m^3\ ton^{-1}$)	total ($m^3\ ton^{-1}$)	blue ($m^3\ ton^{-1}$)	green ($m^3\ ton^{-1}$)	grey ($m^3\ ton^{-1}$)	total ($m^3\ ton^{-1}$)
Export average VWC	1,015	436	91	1,542	977	890	114	1,982	837	1,470	149	2,456	667	1,627	157	2,451

Table M-1: export average virtual water content of rice products

Detailed virtual water flows can be found on the DVD-R (`\Afstuderen\Statistics\VWF\vwf_2.xls`)

Appendix N: Virtual water export

Country	VWE paddy rice (km^3 year^{-1})				VWE brown rice (km^3 year^{-1})				VWE white rice (km^3 year^{-1})				VWE broken rice (km^3 year^{-1})				VWE total (km^3 year^{-1})			
	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total
Afhanistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02
Albania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Algeria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Andorra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Angola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anguilla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Antigua and Barbuda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Argentina	0.21	0.12	0.01	0.33	0.05	0.03	0.00	0.08	0.37	0.21	0.01	0.58	0.02	0.01	0.00	0.04	0.65	0.36	0.02	1.03
Armenia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aruba*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Australia	0.08	0.01	0.01	0.10	0.07	0.01	0.01	0.08	0.39	0.05	0.03	0.47	0.05	0.01	0.00	0.06	0.59	0.07	0.05	0.71
Austria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Azerbaijan, Republic of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bahamas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bahrain	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bangladesh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barbados	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Belarus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Belgium	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.05	0.10	0.01	0.16	0.01	0.02	0.00	0.03	0.06	0.13	0.01	0.20
Belize	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bermuda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bhutan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bolivia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bosnia and Herzegovina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Botswana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
British Virgin Islands*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brazil	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.03	0.00	0.04	0.02	0.03	0.00	0.05	0.03	0.07	0.00	0.10
Brunei Darussalam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulgaria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Burkina Faso	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Burundi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cambodia	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02
Cameroon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cape Verde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cayman Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Central African Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
China	0.01	0.01	0.00	0.02	0.07	0.14	0.02	0.24	1.12	2.26	0.37	3.75	0.12	0.24	0.04	0.39	1.32	2.65	0.44	4.40
Cocos Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Colombia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Comoros	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Congo, Republic of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Congo, Dem Republic of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cook Islands*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costa Rica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01
Côte d'Ivoire	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Croatia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cuba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cyprus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Czech Republic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Denmark	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Djibouti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Dominica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dominican Republic	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Timor-Leste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ecuador	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.10	0.00	0.01	0.00	0.01	0.00	0.10	0.01	0.10
Egypt	0.01	0.00	0.00	0.01	0.11	0.00	0.01	0.13	0.25	0.01	0.02	0.28	0.04	0.00	0.00	0.04	0.41	0.02	0.03	0.45
El Salvador	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Equatorial Guinea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Estonia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethiopia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Faroe Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fiji Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Finland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
French Guiana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
French Polynesia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
France	0.06	0.01	0.00	0.08	0.01	0.00	0.00	0.02	0.12	0.03	0.01	0.15	0.01	0.00	0.00	0.01	0.20	0.05	0.01	0.26
Gabon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gambia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Georgia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Germany	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.03	0.07	0.01	0.10	0.00	0.01	0.00	0.01	0.04	0.09	0.01	0.13
Ghana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gibraltar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Greece	0.00	0.00	0.00	0.00	0.05	0.01	0.00	0.07	0.03	0.01	0.00	0.04	0.01	0.00	0.00	0.02	0.10	0.02	0.01	0.12
Greenland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grenada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guatemala	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guinea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guinea-Bissau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guyana	0.00	0.00	0.00	0.00	0.08	0.25	0.02	0.35	0.03	0.08	0.01	0.12	0.01	0.04	0.00	0.05	0.11	0.38	0.03	0.52
Haiti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Honduras	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hong Kong*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iceland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
India	0.01	0.03	0.00	0.04	0.12	0.33	0.02	0.47	1.63	4.68	0.31	6.61	0.13	0.38	0.03	0.54	1.89	5.42	0.36	7.67
Indonesia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02

Country	VWE paddy rice (km^3 year^{-1})				VWE brown rice (km^3 year^{-1})				VWE white rice (km^3 year^{-1})				VWE broken rice (km^3 year^{-1})				VWE total (km^3 year^{-1})			
	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total
Iran, Islamic Rep of	0.01	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.04
Iraq	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.21
Ireland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Israel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Italy	0.02	0.01	0.00	0.03	0.05	0.03	0.01	0.09	0.64	0.41	0.08	1.12	0.06	0.04	0.01	0.10	0.76	0.48	0.10	1.34
Jamaica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Japan	0.00	0.00	0.00	0.01	0.07	0.21	0.01	0.29	0.01	0.05	0.00	0.07	0.00	0.01	0.00	0.01	0.08	0.26	0.02	0.37
Jordan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kazakhstan	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.04	0.00	0.00	0.05	0.07	0.00	0.00	0.08
Kenya	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kiribati	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Korea, Dem People's Rep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Korea, Republic of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kuwait	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kyrgyzstan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laos	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Latvia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Lebanon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Liberia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Libyan Arab Jamahiriya	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lithuania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Luxembourg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macau*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Macedonia,The Fmr Yug Rp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Madagascar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malawi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malaysia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.06	0.01	0.03	0.00	0.03	0.02	0.07	0.01	0.10
Maldives	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mali	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marshall Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mauritania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mauritius	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mexico	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Micronesia, Fed States of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moldova, Republic of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mongolia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Montserrat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Morocco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mozambique	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03
Myanmar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.11	0.00	0.13	0.01	0.09	0.00	0.11	0.03	0.21	0.01	0.24
New Caledonia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New Mariana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Namibia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nepal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Netherlands Antilles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Netherlands	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.07	0.04	0.08	0.01	0.13	0.02	0.06	0.01	0.08	0.08	0.19	0.02	0.29
New Zealand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nicaragua	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Niger	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nigeria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Norway	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oman	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pakistan	0.01	0.01	0.00	0.02	0.20	0.08	0.01	0.29	2.25	0.92	0.10	3.27	0.24	0.10	0.01	0.35	2.70	1.10	0.12	3.93
Palau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Panama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Papua New Guinea*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Paraguay	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Peru	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philippines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Portugal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.02	0.00	0.00	0.02
Qatar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Réunion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Romania	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Russian Federation	0.02	0.00	0.00	0.02	0.02	0.00	0.00	0.02	0.02	0.00	0.00	0.03	0.03	0.01	0.00	0.04	0.09	0.02	0.00	0.11
Rwanda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saint Vincent/Grenadines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Samoa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sao Tome and Principe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saudi Arabia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Senegal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.01	0.02	0.00	0.03
Seychelles*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sierra Leone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Singapore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.01	0.01	0.00	0.02	0.01	0.03	0.00	0.05
Slovakia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Slovenia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Solomon Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Somalia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
South Africa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.06	0.00	0.01	0.00	0.01	0.02	0.05	0.00	0.07
Spain	0.03	0.00	0.00	0.04	0.35	0.04	0.02	0.41	0.26	0.03	0.02	0.30	0.12	0.01	0.01	0.14	0.76	0.08	0.05	0.89

Country	VWE paddy rice ($km^3\ year^{-1}$)				VWE brown rice ($km^3\ year^{-1}$)				VWE white rice ($km^3\ year^{-1}$)				VWE broken rice ($km^3\ year^{-1}$)				VWE total ($km^3\ year^{-1}$)			
	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total	blue	green	grey	total
Sri Lanka	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Saint Helena	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saint Kitts and Nevis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saint Lucia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sudan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Suriname	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.06	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.02	0.05	0.00	0.08
Swaziland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sweden	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Switzerland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.02
Syrian Arab Republic*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Taiwan*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tajikistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Tanzania, United Rep of	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.00	0.01	0.00	0.01	0.02	0.04	0.00	0.06
Thailand	0.00	0.02	0.00	0.02	0.05	0.31	0.02	0.38	1.36	9.11	0.69	11.16	0.38	2.54	0.19	3.11	1.78	11.99	0.90	14.68
Togo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Tonga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trinidad and Tobago	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tunisia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turkey	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01
Turkmenistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Turks and Caicos Is	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Uganda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
United Arab Emirates	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.26	0.03	0.40	0.00	0.01	0.00	0.01	0.12	0.27	0.03	0.42
United Kingdom	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.03	0.07	0.01	0.10	0.01	0.02	0.00	0.03	0.04	0.09	0.01	0.14
Uruguay	0.09	0.05	0.01	0.14	0.29	0.14	0.02	0.45	0.65	0.32	0.04	1.01	0.06	0.03	0.00	0.09	1.09	0.54	0.06	1.69
United States of America	1.28	0.48	0.13	1.90	0.57	0.21	0.06	0.84	1.92	0.72	0.20	2.84	0.14	0.05	0.01	0.21	3.91	1.48	0.40	5.79
Uzbekistan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanuatu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Venezuela,Bolivar Rep of	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.03	0.00	0.03
Viet Nam	0.00	0.00	0.00	0.01	0.04	0.09	0.01	0.14	0.65	1.66	0.23	2.53	0.30	0.76	0.11	1.17	0.98	2.52	0.35	3.85
Yemen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serbia and Montenegro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zambia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zimbabwe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Global flow	*1.87*	*0.80*	*0.17*	*2.84*	*2.26*	*2.06*	*0.26*	*4.58*	*12.34*	*21.66*	*2.20*	*36.20*	*1.90*	*4.63*	*0.45*	*6.98*	*18.36*	*29.15*	*3.08*	*50.60*

Period 1999 – 2003

* no trade data was taken into account for these countries

The total virtual water flow can found directly by multiplying total import/ export (see Appendix L) with the export averaged virtual water content of the product traded (see Table M-1 Appendix M).

Detailed virtual water flows can be found on the DVD-R (`\Afstuderen\Statistics\VWF\vwf_2.xls`)

Appendix O: Virtual water flows in and between regions

Blue virtual water flows (km^3 $year^{-1}$)

	Africa	Asia	Central America and Caribbean	Europe	Middle East	North America	Oceania	South America	Total VWE
Africa	0.11	0.01	0.00	0.15	0.20	0.00	0.00	0.00	0.46
Asia	2.70	3.15	0.21	0.63	2.05	0.20	0.06	0.03	9.01
Central America and Caribbean	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02
Europe	0.27	0.04	0.02	1.63	0.11	0.01	0.00	0.01	2.08
Middle East	0.01	0.03	0.00	0.01	0.33	0.00	0.00	0.00	0.37
North America	0.35	0.76	0.86	0.49	0.39	0.84	0.01	0.21	3.92
Oceania	0.01	0.21	0.00	0.05	0.22	0.04	0.06	0.00	0.59
South America	0.06	0.00	0.11	0.11	0.30	0.02	0.00	1.29	1.90
Total VWI	3.49	4.20	1.21	3.06	3.60	1.11	0.14	1.54	18.36

Green virtual water flows (km^3 $year^{-1}$)

	Africa	Asia	Central America and Caribbean	Europe	Middle East	North America	Oceania	South America	Total VWE
Africa	0.17	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.19
Asia	7.73	9.31	0.47	1.41	4.23	0.83	0.19	0.14	24.32
Central America and Caribbean	0.00	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.06
Europe	0.18	0.02	0.01	0.92	0.04	0.01	0.00	0.00	1.20
Middle East	0.01	0.01	0.00	0.00	0.27	0.00	0.00	0.00	0.29
North America	0.13	0.29	0.32	0.19	0.15	0.32	0.01	0.08	1.48
Oceania	0.00	0.03	0.00	0.01	0.03	0.01	0.01	0.00	0.07
South America	0.04	0.00	0.21	0.28	0.16	0.01	0.01	0.83	1.54
Total VWI	8.28	9.66	1.04	2.84	4.88	1.17	0.22	1.06	29.15

Grey virtual water flows (km^3 $year^{-1}$)

	Africa	Asia	Central America and Caribbean	Europe	Middle East	North America	Oceania	South America	Total VWE
Africa	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.03
Asia	0.71	0.88	0.07	0.12	0.33	0.06	0.02	0.01	2.21
Central America and Caribbean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Europe	0.03	0.00	0.00	0.17	0.01	0.00	0.00	0.00	0.22
Middle East	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03
North America	0.04	0.08	0.09	0.05	0.04	0.09	0.00	0.02	0.40
Oceania	0.00	0.02	0.00	0.00	0.02	0.00	0.01	0.00	0.05
South America	0.00	0.00	0.02	0.02	0.01	0.00	0.00	0.07	0.13
Total VWI	0.80	0.98	0.18	0.38	0.46	0.16	0.02	0.10	3.08

Total virtual water flows (km^3 $year^{-1}$)

	Africa	Asia	Central America and Caribbean	Europe	Middle East	North America	Oceania	South America	Total VWE
Africa	0.29	0.01	0.00	0.16	0.22	0.00	0.00	0.00	0.69
Asia	11.15	13.34	0.75	2.16	6.61	1.09	0.27	0.18	35.55
Central America and Caribbean	0.00	0.00	0.04	0.03	0.00	0.00	0.00	0.00	0.08
Europe	0.48	0.07	0.04	2.72	0.17	0.01	0.00	0.01	3.50
Middle East	0.02	0.04	0.00	0.01	0.62	0.00	0.00	0.00	0.70
North America	0.51	1.13	1.27	0.73	0.58	1.25	0.02	0.32	5.80
Oceania	0.01	0.25	0.00	0.06	0.26	0.05	0.08	0.00	0.71
South America	0.10	0.01	0.34	0.42	0.47	0.04	0.01	2.19	3.58
Total VWI	12.57	14.85	2.43	6.28	8.93	2.44	0.38	2.71	50.60

Appendix P: Global water savings

Country	Global water saving ($km^3\ year^{-1}$)			
	blue	green	grey	total
Afghanistan	0.21	-0.02	0.00	0.18
Argentina	0.01	-0.01	0.00	0.00
Australia	0.06	-0.10	0.00	-0.05
Bangladesh	0.10	-0.36	0.02	-0.24
Bolivia	-0.02	0.02	0.00	0.01
Brazil	-0.50	0.83	-0.02	0.31
Cambodia	0.00	0.04	0.00	0.03
Chad	0.00	0.00	0.00	0.00
Chile	0.18	-0.11	0.00	0.07
China	0.04	-0.27	0.00	-0.23
Colombia	-0.02	-0.05	0.00	-0.06
Congo, DR	0.00	0.02	0.00	0.01
Costa Rica	-0.10	0.08	0.01	-0.01
Cote d'Ivoire	-0.42	1.76	-0.01	1.33
Cuba	0.43	0.37	-0.01	0.79
Dominican Republic	-0.05	0.04	0.00	-0.01
Ecuador	0.00	0.00	0.00	0.00
Egypt	0.02	-0.04	0.00	-0.02
France	0.52	-0.16	0.00	0.36
Ghana	-0.15	0.23	0.00	0.08
Greece	0.00	-0.01	0.00	0.00
Guinea	-0.11	0.54	-0.01	0.41
Haiti	-0.40	0.62	0.01	0.23
India	-0.02	0.01	0.00	-0.01
Indonesia	0.05	-0.03	-0.01	0.01
Iran	1.58	-1.07	0.01	0.52
Iraq	4.58	-0.42	-0.01	4.16
Italy	-0.02	-0.03	0.00	-0.05
Japan	-0.45	0.18	-0.04	-0.31
Kazakhstan	0.08	-0.01	0.00	0.07
Korea, DPR	0.10	0.23	0.00	0.33
Korea, Republic of	-0.05	0.01	-0.01	-0.05
Laos	0.00	0.00	0.00	0.00
Liberia	-0.04	0.17	0.00	0.13
Madagascar	-0.17	0.41	-0.02	0.22
Malaysia	-0.08	0.26	0.03	0.20
Mali	0.13	0.02	0.00	0.15
Mexico	-0.33	0.24	0.02	-0.07
Mozambique	-0.06	0.41	0.00	0.35
Myanmar	0.00	0.00	0.00	0.00
Nepal	-0.01	0.01	0.00	-0.01
Nicaragua	-0.07	0.09	-0.01	0.02
Nigeria	0.12	1.93	-0.11	1.94
Pakistan	0.00	0.00	0.00	0.00
Panama	-0.02	0.02	0.00	0.01
Paraguay	0.00	0.00	0.00	0.00
Peru	-0.06	0.00	0.00	-0.06
Philippines	0.16	0.38	-0.05	0.49
Portugal	0.15	-0.08	0.00	0.06
Russia	1.27	-0.19	-0.01	1.07
Senegal	0.14	0.45	-0.01	0.58
Sierra Leone	-0.01	0.06	0.00	0.06
Spain	0.11	-0.07	0.00	0.04
Sri Lanka	0.00	-0.01	0.01	0.00
Surinam	0.00	0.00	0.00	0.00
Tanzania	0.07	0.30	-0.01	0.36
Thailand	0.00	0.00	0.00	0.00
Turkey	0.24	-0.04	0.00	0.21
United States of America	0.00	0.00	0.00	0.00
Uruguay	0.32	-0.51	-0.01	-0.20
Uzbekistan	0.17	-0.01	0.00	0.16
Venezuela	-0.02	0.01	0.00	-0.01
Viet Nam	0.00	0.00	0.00	0.00
Global	7.70	6.15	-0.24	13.60

Period 1999 – 2003

Global water savings per product and country can be found on the DVD-R (`\Afstuderen\Statistics\Water Savings\global water savings.xls`)

Appendix Q: Global water footprint of rice consumption

Country	IWFP (km^3 $year^{-1}$)				EWFP (km^3 $year^{-1}$)				WFP	WFP_{cap}
	blue	green	grey	total	blue	green	grey	total	(km^3 $year^{-1}$)	(m^3 cap^{-1} $year^{-1}$)
Afhanistan	1.75	0.09	0.03	1.87	0.08	0.04	0.00	0.12	1.99	-
Albania	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.04	0.04	13.29
Algeria	0.00	0.00	0.00	0.00	0.06	0.08	0.01	0.15	0.15	4.90
Andorra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Angola	0.00	0.01	0.00	0.01	0.02	0.05	0.00	0.07	0.09	6.77
Anguilla	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.47
Antigua and Barbuda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	75.84
Argentina	0.47	0.27	0.01	0.75	0.01	0.01	0.00	0.02	0.77	20.48
Armenia	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.03	0.03	9.56
Aruba*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Australia	0.82	0.13	0.07	1.02	0.02	0.09	0.01	0.12	1.13	58.55
Austria	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.06	0.06	7.58
Azerbaijan, Republic of	0.01	0.02	0.00	0.03	0.02	0.02	0.00	0.05	0.08	9.35
Bahamas	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.02	57.74
Bahrain	0.00	0.00	0.00	0.00	0.04	0.03	0.00	0.08	0.08	109.52
Bangladesh	21.17	33.91	3.87	58.95	0.41	1.19	0.08	1.68	60.63	430.33
Barbados	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	64.70
Belarus	0.00	0.00	0.00	0.00	0.05	0.03	0.00	0.08	0.08	8.49
Belgium	0.00	0.00	0.00	0.00	0.29	0.07	0.02	0.37	0.37	36.44
Belize	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.02	98.96
Benin	0.02	0.05	0.00	0.08	0.08	0.24	0.02	0.34	0.42	65.97
Bermuda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.09
Bhutan	0.02	0.04	0.00	0.07	0.01	0.03	0.00	0.05	0.12	55.01
Bolivia	0.00	0.66	0.00	0.66	0.02	0.02	0.00	0.03	0.70	82.37
Bosnia and Herzegovina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	1.72
Botswana	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	6.92
British Virgin Islands*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Brazil	6.86	14.09	0.47	21.42	1.23	0.66	0.07	1.95	23.37	134.32
Brunei Darussalam	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.07	0.07	213.37
Bulgaria	0.01	0.02	0.00	0.02	0.02	0.03	0.00	0.06	0.08	10.24
Burkina Faso	0.04	0.10	0.01	0.15	0.01	0.01	0.00	0.03	0.18	14.49
Burundi	0.03	0.06	0.01	0.09	0.00	0.00	0.00	0.00	0.09	14.65
Cambodia	1.48	7.91	0.05	9.44	0.02	0.05	0.00	0.08	9.52	706.05
Cameroon	0.03	0.06	0.01	0.09	0.02	0.05	0.00	0.08	0.17	10.87
Canada	0.00	0.00	0.00	0.00	0.22	0.20	0.03	0.45	0.45	14.48
Cape Verde	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04	0.04	96.90
Cayman Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Central African Republic	0.01	0.03	0.00	0.04	0.00	0.00	0.00	0.00	0.04	10.63
Chad	0.02	0.37	0.01	0.40	0.00	0.00	0.00	0.00	0.41	49.96
Chile	0.23	0.03	0.01	0.27	0.12	0.14	0.01	0.27	0.54	35.30
China	62.64	125.77	20.79	209.21	0.08	0.50	0.04	0.61	209.82	162.37
Cocos Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Colombia	0.00	2.11	0.26	2.37	0.02	0.15	0.01	0.18	2.55	59.48
Comoros	0.01	0.02	0.00	0.03	0.02	0.04	0.00	0.06	0.08	114.26
Congo, Republic of	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.05	0.06	15.61
Congo, Dem Republic of	0.00	1.61	0.03	1.64	0.00	0.01	0.00	0.01	1.65	33.02
Cook Islands*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Costa Rica	0.00	0.29	0.04	0.33	0.10	0.04	0.01	0.14	0.47	116.43
Côte d'Ivoire	0.04	1.20	0.06	1.30	0.51	1.19	0.16	1.86	3.16	196.52
Croatia	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.03	0.03	7.53
Cuba	0.66	0.81	0.06	1.53	0.24	0.46	0.07	0.77	2.30	204.41
Cyprus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Czech Republic	0.00	0.00	0.00	0.00	0.04	0.07	0.01	0.12	0.12	11.24
Denmark	0.00	0.00	0.00	0.00	0.03	0.04	0.00	0.07	0.07	12.67
Djibouti	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.05	0.05	70.10
Dominica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.00
Dominican Republic	0.00	0.67	0.07	0.75	0.05	0.02	0.00	0.07	0.82	96.56
Timor-Leste	0.02	0.05	0.00	0.08	0.00	0.00	0.00	0.00	0.08	109.66
Ecuador	0.01	1.86	0.10	1.96	0.00	0.00	0.00	0.01	1.97	155.89
Egypt	5.69	0.22	0.35	6.26	0.01	0.03	0.00	0.05	6.31	91.19
El Salvador	0.02	0.04	0.00	0.06	0.07	0.03	0.01	0.10	0.16	25.81
Equatorial Guinea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.15
Estonia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	6.23
Ethiopia	0.00	0.01	0.00	0.01	0.01	0.02	0.00	0.03	0.04	0.61
Faroe Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.64
Fiji Islands	0.01	0.01	0.00	0.02	0.01	0.05	0.00	0.07	0.09	111.39
Finland	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.06	0.06	10.85
French Guiana	0.01	0.02	0.00	0.04	0.00	0.00	0.00	0.00	0.04	215.00
French Polynesia	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.02	76.28
France	0.12	0.04	0.01	0.17	0.30	0.41	0.05	0.76	0.93	15.61
Gabon	0.00	0.00	0.00	0.00	0.03	0.17	0.01	0.21	0.22	168.48
Gambia	0.01	0.03	0.00	0.04	0.04	0.07	0.01	0.11	0.16	116.58
Georgia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40
Germany	0.00	0.00	0.00	0.00	0.28	0.17	0.03	0.48	0.48	5.79
Ghana	0.01	0.43	0.02	0.46	0.17	0.27	0.03	0.46	0.92	45.94
Gibraltar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.70
Greece	0.09	0.02	0.01	0.11	0.01	0.01	0.00	0.02	0.13	12.27
Greenland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.68
Grenada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45.84
Guatemala	0.02	0.04	0.00	0.06	0.05	0.02	0.01	0.08	0.14	12.04
Guinea	0.11	2.27	0.04	2.42	0.15	0.24	0.03	0.42	2.84	345.06
Guinea-Bissau	0.04	0.09	0.01	0.13	0.01	0.01	0.00	0.02	0.15	106.51
Guyana	0.05	0.17	0.02	0.24	0.00	0.00	0.00	0.00	0.24	318.40
Haiti	0.00	0.19	0.01	0.20	0.40	0.17	0.04	0.61	0.81	99.89
Honduras	0.01	0.01	0.00	0.02	0.05	0.02	0.01	0.08	0.10	14.75
Hong Kong*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Hungary	0.00	0.01	0.00	0.01	0.05	0.05	0.01	0.11	0.12	12.28
Iceland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.46
India	56.83	163.34	10.74	230.91	0.03	0.02	0.00	0.05	230.96	223.56
Indonesia	20.54	52.61	5.50	78.65	1.10	2.97	0.32	4.39	83.04	387.43

Country	IWFP (km^3 $year^{-1}$)				EWFP (km^3 $year^{-1}$)				WFP	WFP_{cap}
	blue	green	grey	total	blue	green	grey	total	(km^3 $year^{-1}$)	(m^3 cap^{-1} $year^{-1}$)
Iran, Islamic Rep of	5.10	0.57	0.23	5.91	1.09	1.58	0.13	2.81	8.71	129.53
Iraq	1.38	0.03	0.01	1.42	0.11	0.50	0.04	0.65	2.07	-
Ireland	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.05	0.05	11.82
Israel	0.00	0.00	0.00	0.00	0.06	0.09	0.01	0.16	0.16	25.76
Italy	0.34	0.23	0.04	0.62	0.03	0.03	0.00	0.07	0.69	12.00
Jamaica	0.00	0.00	0.00	0.00	0.07	0.09	0.01	0.18	0.18	69.20
Japan	3.00	9.44	0.66	13.09	0.68	0.58	0.10	1.36	14.45	113.55
Jordan	0.00	0.00	0.00	0.00	0.17	0.05	0.01	0.23	0.23	44.18
Kazakhstan	0.86	0.04	0.02	0.92	0.01	0.01	0.00	0.02	0.94	60.60
Kenya	0.02	0.05	0.00	0.07	0.22	0.14	0.02	0.37	0.45	14.37
Kiribati	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.72
Korea, Dem People's Rep	1.21	3.37	0.20	4.79	0.11	0.37	0.04	0.52	5.31	237.08
Korea, Republic of	1.26	5.48	0.58	7.33	0.08	0.14	0.02	0.25	7.58	160.78
Kuwait	0.00	0.00	0.00	0.00	0.11	0.17	0.01	0.30	0.30	126.42
Kyrgyzstan	0.01	0.02	0.00	0.03	0.00	0.00	0.00	0.01	0.03	6.91
Laos	0.14	3.22	0.06	3.42	0.00	0.01	0.00	0.01	3.44	635.76
Latvia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.05
Lebanon	0.00	0.00	0.00	0.00	0.06	0.03	0.01	0.09	0.09	26.79
Liberia	0.00	0.59	0.01	0.61	0.04	0.02	0.00	0.06	0.67	218.33
Libyan Arab Jamahiriya	0.00	0.00	0.00	0.00	0.05	0.07	0.01	0.14	0.14	25.46
Lithuania	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	7.09
Luxembourg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.65
Macau*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Macedonia,The Fmr Yug Rp	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.02	9.31
Madagascar	0.88	6.74	0.01	7.63	0.25	0.20	0.02	0.47	8.10	492.68
Malawi	0.04	0.09	0.01	0.13	0.00	0.00	0.00	0.01	0.14	12.01
Malaysia	0.64	2.94	0.29	3.86	0.32	0.86	0.08	1.27	5.13	218.35
Maldives	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04	0.04	148.24
Mali	1.89	1.11	0.08	3.08	0.03	0.08	0.01	0.12	3.20	261.07
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.10
Marshall Islands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.50
Mauritania	0.03	0.08	0.01	0.12	0.01	0.01	0.00	0.02	0.14	50.31
Mauritius	0.00	0.00	0.00	0.00	0.10	0.10	0.01	0.21	0.21	174.33
Mexico	0.15	0.21	0.04	0.40	0.68	0.26	0.07	1.00	1.40	13.93
Micronesia, Fed States of	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	116.42
Moldova, Republic of	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	4.79
Mongolia	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	6.91
Montserrat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Morocco	0.01	0.03	0.00	0.04	0.00	0.00	0.00	0.01	0.05	1.77
Mozambique	0.01	0.74	0.01	0.76	0.06	0.12	0.01	0.19	0.95	52.46
Myanmar	3.13	23.33	0.66	27.12	0.00	0.01	0.00	0.02	27.14	563.17
New Caledonia	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	69.10
New Mariana	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Namibia	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	4.76
Nepal	0.53	6.10	0.40	7.03	0.02	0.06	0.00	0.08	7.12	295.65
Netherlands Antilles	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	43.96
Netherlands	0.00	0.00	0.00	0.00	0.15	0.07	0.01	0.23	0.23	14.30
New Zealand	0.00	0.00	0.00	0.00	0.05	0.03	0.00	0.08	0.08	20.18
Nicaragua	0.00	0.41	0.01	0.42	0.07	0.04	0.01	0.12	0.54	103.59
Niger	0.03	0.07	0.01	0.11	0.11	0.15	0.02	0.28	0.39	35.10
Nigeria	1.27	8.51	0.05	9.83	0.43	1.70	0.14	2.26	12.10	102.68
Norway	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.04	0.04	9.37
Oman	0.00	0.00	0.00	0.00	0.19	0.13	0.01	0.33	0.33	121.04
Pakistan	10.78	4.41	0.49	15.67	0.00	0.00	0.00	0.01	15.68	107.16
Palau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	145.46
Panama	0.00	0.50	0.02	0.52	0.02	0.01	0.00	0.02	0.55	181.71
Papua New Guinea*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21
Paraguay	0.08	0.10	0.00	0.19	0.00	0.00	0.00	0.01	0.20	34.79
Peru	1.04	1.00	0.20	2.23	0.11	0.05	0.01	0.17	2.40	91.01
Philippines	6.49	16.86	0.87	24.22	0.44	1.19	0.13	1.76	25.98	336.75
Poland	0.00	0.00	0.00	0.00	0.08	0.15	0.02	0.24	0.24	6.33
Portugal	0.25	0.03	0.01	0.30	0.12	0.12	0.01	0.26	0.55	55.27
Qatar	0.00	0.00	0.00	0.00	0.09	0.05	0.01	0.15	0.15	252.33
Réunion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Romania	0.00	0.00	0.00	0.00	0.09	0.03	0.01	0.13	0.13	5.84
Russian Federation	1.12	0.23	0.05	1.40	0.32	0.51	0.07	0.90	2.30	15.87
Rwanda	0.01	0.02	0.00	0.03	0.02	0.03	0.00	0.06	0.08	10.38
Saint Vincent/Grenadines	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.02	157.95
Samoa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.52
Sao Tome and Principe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.08
Saudi Arabia	0.00	0.00	0.00	0.00	0.78	1.26	0.10	2.14	2.14	93.77
Senegal	0.08	0.34	0.02	0.45	0.35	1.51	0.12	1.98	2.42	251.84
Seychelles*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sierra Leone	0.00	1.03	0.02	1.05	0.01	0.02	0.00	0.03	1.08	235.03
Singapore	0.00	0.00	0.00	0.00	0.17	0.73	0.06	0.96	0.96	235.55
Slovakia	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.07	0.07	12.29
Slovenia	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	6.66
Solomon Islands	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.02	39.61
Somalia	0.00	0.01	0.00	0.01	0.03	0.10	0.01	0.13	0.14	-
South Africa	0.00	0.00	0.00	0.00	0.30	0.92	0.07	1.30	1.30	29.34
Spain	0.61	0.10	0.04	0.75	0.06	0.07	0.01	0.14	0.89	21.75

Country	IWFP ($km^3\ year^{-1}$)				EWFP ($km^3\ year^{-1}$)				WFP	WFP_{cap}
	blue	green	grey	total	blue	green	grey	total	($km^3\ year^{-1}$)	($m^3\ cap^{-1}\ year^{-1}$)
Sri Lanka	3.32	2.78	0.44	6.54	0.13	0.12	0.01	0.25	6.79	362.22
Saint Helena	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Saint Kitts and Nevis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	53.24
Saint Lucia	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.02	0.02	164.80
Sudan	0.00	0.01	0.00	0.02	0.03	0.01	0.00	0.05	0.06	1.94
Suriname	0.04	0.14	0.01	0.20	0.00	0.00	0.00	0.00	0.20	466.80
Swaziland	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	17.27
Sweden	0.00	0.00	0.00	0.00	0.04	0.07	0.01	0.11	0.11	12.65
Switzerland	0.00	0.00	0.00	0.00	0.06	0.09	0.01	0.16	0.16	22.70
Syrian Arab Republic*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Taiwan*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Tajikistan	0.02	0.05	0.00	0.08	0.00	0.00	0.00	0.00	0.08	13.05
Tanzania, United Rep of	0.63	1.66	0.02	2.31	0.10	0.17	0.02	0.30	2.61	73.31
Thailand	3.74	25.12	1.90	30.76	0.00	0.01	0.00	0.01	30.77	499.80
Togo	0.03	0.07	0.01	0.10	0.04	0.08	0.01	0.12	0.23	48.27
Tonga	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.88
Trinidad and Tobago	0.00	0.00	0.00	0.01	0.04	0.06	0.01	0.11	0.11	86.82
Tunisia	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.05	0.05	4.71
Turkey	0.52	0.08	0.03	0.63	0.46	0.15	0.04	0.64	1.27	18.33
Turkmenistan	0.03	0.06	0.01	0.09	0.00	0.00	0.00	0.00	0.09	19.19
Turks and Caicos Is	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.13
Uganda	0.05	0.11	0.01	0.17	0.06	0.07	0.01	0.13	0.31	12.66
Ukraine	0.03	0.08	0.01	0.12	0.06	0.05	0.01	0.11	0.23	4.70
United Arab Emirates	0.00	0.00	0.00	0.00	0.21	0.27	0.02	0.50	0.50	173.77
United Kingdom	0.00	0.00	0.00	0.00	0.54	0.39	0.05	0.98	0.98	16.62
Uruguay	0.15	0.07	0.01	0.23	0.00	0.00	0.00	0.00	0.23	68.16
United States of America	5.28	2.22	0.55	8.05	0.12	0.46	0.04	0.61	8.66	30.08
Uzbekistan	1.27	0.05	0.02	1.33	0.03	0.01	0.00	0.05	1.38	54.73
Vanuatu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.70
Venezuela,Bolivar Rep of	0.00	0.55	0.09	0.64	0.02	0.01	0.00	0.03	0.67	27.13
Viet Nam	10.02	25.74	3.56	39.32	0.00	0.01	0.00	0.01	39.34	496.54
Yemen	0.00	0.00	0.00	0.00	0.09	0.28	0.02	0.39	0.39	20.87
Serbia and Montenegro	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	1.90
Zambia	0.01	0.01	0.00	0.02	0.01	0.02	0.00	0.03	0.05	4.94
Zimbabwe	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.02	1.40
Global WFP	*247.49*	*568.62*	*54.52*	*870.64*	*17.44*	*27.63*	*2.92*	*47.99*	*918.62*	*151.15*

Period 1999 – 2003

* no trade data was taken into account for these countries

Appendix R: Water footprint of regions

Region	TWU (km^3 $year^{-1}$)		VWI (km^3 $year^{-1}$)		VWE (km^3 $year^{-1}$)		IWFP (km^3 $year^{-1}$)		EWFP (km^3 $year^{-1}$)		WFP (km^3 $year^{-1}$)	
Africa	11.50	27.91	3.49	8.28	0.46	0.19	11.07	27.81	3.46	8.19	14.53	36.00
	0.87	40.28	0.80	12.57	0.03	0.69	0.84	39.72	0.79	12.44	1.63	52.16
Asia	220.99	537.19	4.20	9.66	9.01	24.32	212.04	512.97	4.14	9.57	216.18	522.53
	53.40	811.59	0.98	14.85	2.21	35.55	51.20	776.21	0.97	14.68	52.17	790.89
Central America and Caribbean	0.71	3.01	1.21	1.04	0.01	0.06	0.71	2.98	1.20	1.01	1.91	3.99
	0.23	3.95	0.18	2.43	0.01	0.08	0.23	3.92	0.18	2.38	0.40	6.30
Europe	3.02	1.03	3.06	2.84	2.08	1.20	1.47	0.53	2.52	2.14	4.00	2.67
	0.26	4.31	0.38	6.28	0.22	3.50	0.13	2.13	0.30	4.96	0.42	7.09
Middle East	7.22	0.68	3.60	4.88	0.37	0.29	6.99	0.68	3.44	4.59	10.44	5.27
	0.28	8.18	0.46	8.93	0.03	0.70	0.28	7.95	0.43	8.46	0.71	16.42
North America	9.26	3.65	1.11	1.17	3.92	1.48	5.43	2.43	1.02	0.91	6.46	3.34
	0.96	13.87	0.16	2.44	0.40	5.80	0.59	8.45	0.13	2.07	0.72	10.52
Oceania	1.41	0.19	0.14	0.22	0.59	0.07	0.83	0.15	0.12	0.19	0.95	0.33
	0.11	1.71	0.02	0.38	0.05	0.71	0.07	1.05	0.02	0.33	0.09	1.37
South America	10.83	22.59	1.54	1.06	1.90	1.54	8.94	21.07	1.52	1.04	10.47	22.11
	1.32	34.74	0.10	2.71	0.13	3.58	1.19	31.20	0.10	2.67	1.29	33.87
Total	**264.93**	**596.25**	**18.36**	**29.15**	**18.36**	**29.15**	**247.49**	**568.62**	**17.44**	**27.63**	**264.93**	**596.25**
	57.44	**918.62**	**3.08**	**50.60**	**3.08**	**50.60**	**54.52**	**870.64**	**2.92**	**47.99**	**57.44**	**918.62**

Period 1999 – 2003

Appendix S: Top down vs. bottom up approach

Country	top down approach				bottom up approach			
	WFP_{blue} (km^3 $year^{-1}$)	WFP_{green} (km^3 $year^{-1}$)	WFP_{grey} (km^3 $year^{-1}$)	WFP_{total} (km^3 $year^{-1}$)	WFP_{blue} (km^3 $year^{-1}$)	WFP_{green} (km^3 $year^{-1}$)	WFP_{grey} (km^3 $year^{-1}$)	WFP_{total} (km^3 $year^{-1}$)
Albania	0.03	0.01	0.00	0.04	0.02	0.04	0.00	0.06
Algeria	0.06	0.08	0.01	0.15	0.07	0.17	0.02	0.26
Angola	0.02	0.06	0.01	0.09	0.05	0.11	0.01	0.17
Argentina	0.48	0.28	0.01	0.77	0.21	0.12	0.01	0.34
Armenia	0.02	0.00	0.00	0.03	0.01	0.02	0.00	0.04
Australia	0.85	0.21	0.07	1.13	0.31	0.04	0.02	0.37
Austria	0.03	0.03	0.00	0.06	0.03	0.07	0.01	0.11
Azerbaijan, Republic of	0.03	0.04	0.00	0.08	0.02	0.05	0.00	0.08
Bangladesh	21.58	35.09	3.95	60.63	18.52	29.66	3.39	51.57
Barbados	0.01	0.01	0.00	0.02	0.00	0.01	0.00	0.01
Belarus	0.05	0.03	0.00	0.08	0.02	0.03	0.00	0.05
Belgium	0.29	0.07	0.02	0.37	0.02	0.05	0.01	0.08
Belize	0.01	0.02	0.00	0.02	0.00	0.01	0.00	0.02
Benin	0.10	0.29	0.03	0.42	0.08	0.18	0.02	0.28
Bolivia	0.02	0.68	0.00	0.70	0.00	0.55	0.00	0.55
Bosnia and Herzegovina	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.02
Brazil	8.09	14.74	0.54	23.37	6.12	12.57	0.42	19.12
Brunei Darussalam	0.01	0.06	0.00	0.07	0.01	0.03	0.00	0.05
Bulgaria	0.03	0.04	0.01	0.08	0.02	0.05	0.00	0.07
Burkina Faso	0.05	0.11	0.01	0.18	0.17	0.37	0.04	0.57
Burundi	0.03	0.06	0.01	0.09	0.02	0.05	0.00	0.07
Cambodia	1.50	7.96	0.06	9.52	1.13	6.00	0.04	7.16
Cameroon	0.05	0.11	0.01	0.17	0.16	0.36	0.03	0.55
Canada	0.22	0.20	0.03	0.45	0.15	0.34	0.03	0.53
Cape Verde	0.01	0.03	0.00	0.04	0.02	0.04	0.00	0.06
Central African Republic	0.01	0.03	0.00	0.04	0.01	0.03	0.00	0.04
Chad	0.02	0.37	0.01	0.41	0.02	0.34	0.01	0.37
Chile	0.35	0.17	0.02	0.54	0.45	0.06	0.02	0.53
China	62.72	126.27	20.83	209.82	57.46	115.36	19.07	191.89
Colombia	0.02	2.26	0.27	2.55	0.00	1.72	0.21	1.93
Comoros	0.02	0.06	0.00	0.08	0.02	0.05	0.00	0.08
Congo, Dem Republic of	0.00	1.61	0.03	1.65	0.00	1.66	0.03	1.70
Congo, Republic of	0.03	0.03	0.00	0.06	0.03	0.08	0.01	0.12
Costa Rica	0.10	0.32	0.05	0.47	0.00	0.36	0.05	0.41
Côte d'Ivoire	0.54	2.39	0.23	3.16	0.06	2.12	0.11	2.29
Croatia	0.01	0.02	0.00	0.03	0.01	0.02	0.00	0.03
Cuba	0.90	1.27	0.13	2.30	1.02	1.26	0.09	2.37
Cyprus	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Czech Republic	0.04	0.07	0.01	0.12	0.03	0.07	0.01	0.11
Denmark	0.03	0.04	0.00	0.07	0.02	0.04	0.00	0.06
Dominica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dominican Republic	0.05	0.69	0.08	0.82	0.00	0.60	0.06	0.66
Ecuador	0.01	1.86	0.10	1.97	0.00	1.32	0.07	1.40
Egypt	5.70	0.25	0.35	6.31	4.25	0.16	0.26	4.67
El Salvador	0.08	0.07	0.01	0.16	0.04	0.09	0.01	0.14
Estonia	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.02
Ethiopia	0.01	0.03	0.00	0.04	0.01	0.03	0.00	0.05
Fiji Islands	0.02	0.07	0.01	0.09	0.03	0.06	0.01	0.09
Finland	0.03	0.02	0.00	0.06	0.02	0.05	0.00	0.07
France	0.42	0.45	0.06	0.93	0.85	0.21	0.05	1.11
French Polynesia	0.01	0.00	0.00	0.02	0.01	0.01	0.00	0.02
Gabon	0.03	0.17	0.01	0.22	0.04	0.09	0.01	0.14
Gambia	0.05	0.10	0.01	0.16	0.03	0.08	0.01	0.12
Georgia	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Germany	0.28	0.17	0.03	0.48	0.18	0.41	0.04	0.63
Ghana	0.18	0.69	0.05	0.92	0.02	0.90	0.05	0.97
Greece	0.10	0.03	0.01	0.13	0.12	0.02	0.01	0.15
Grenada	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Guatemala	0.07	0.06	0.01	0.14	0.04	0.10	0.01	0.15
Guinea	0.26	2.51	0.07	2.84	0.13	2.57	0.05	2.75
Guinea-Bissau	0.04	0.10	0.01	0.15	0.06	0.13	0.01	0.20
Guyana	0.05	0.17	0.02	0.24	0.03	0.11	0.01	0.16
Haiti	0.40	0.36	0.05	0.81	0.00	0.91	0.05	0.96
Honduras	0.06	0.03	0.01	0.10	0.03	0.07	0.01	0.11
Hungary	0.06	0.06	0.01	0.12	0.04	0.08	0.01	0.12
Iceland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
India	56.86	163.36	10.74	230.96	51.69	148.57	9.77	210.02
Indonesia	21.64	55.58	5.82	83.04	17.85	45.73	4.78	68.37

Country	top down approach				bottom up approach			
	WFP_{blue} (km^3 $year^{-1}$)	WFP_{green} (km^3 $year^{-1}$)	WFP_{grey} (km^3 $year^{-1}$)	WFP_{total} (km^3 $year^{-1}$)	WFP_{blue} (km^3 $year^{-1}$)	WFP_{green} (km^3 $year^{-1}$)	WFP_{grey} (km^3 $year^{-1}$)	WFP_{total} (km^3 $year^{-1}$)
Iran, Islamic Rep of	6.19	2.15	0.37	8.71	7.48	0.84	0.34	8.67
Ireland	0.03	0.02	0.00	0.05	0.01	0.03	0.00	0.05
Israel	0.06	0.09	0.01	0.16	0.04	0.10	0.01	0.15
Italy	0.38	0.27	0.05	0.69	0.39	0.25	0.05	0.69
Jamaica	0.07	0.09	0.01	0.18	0.05	0.12	0.01	0.18
Japan	3.67	10.02	0.75	14.45	3.06	9.69	0.67	13.43
Jordan	0.17	0.05	0.01	0.23	0.07	0.15	0.01	0.24
Kazakhstan	0.87	0.06	0.02	0.94	0.79	0.04	0.02	0.84
Kenya	0.24	0.18	0.02	0.45	0.13	0.29	0.03	0.44
Korea, Dem People's Rep	1.33	3.74	0.24	5.31	1.35	3.75	0.23	5.33
Korea, Republic of	1.35	5.63	0.60	7.58	1.19	5.18	0.55	6.92
Kyrgyzstan	0.01	0.02	0.00	0.03	0.01	0.02	0.00	0.04
Laos	0.15	3.23	0.06	3.44	0.10	2.33	0.04	2.48
Latvia	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.02
Lebanon	0.06	0.03	0.01	0.09	0.02	0.05	0.00	0.07
Liberia	0.04	0.61	0.02	0.67	0.00	0.91	0.02	0.93
Libyan Arab Jamahiriya	0.05	0.07	0.01	0.14	0.06	0.13	0.01	0.20
Lithuania	0.01	0.01	0.00	0.02	0.01	0.01	0.00	0.02
Macedonia,The Fmr Yug Rp	0.01	0.01	0.00	0.02	0.00	0.01	0.00	0.01
Madagascar	1.14	6.94	0.03	8.10	0.79	6.00	0.00	6.79
Malawi	0.04	0.09	0.01	0.14	0.04	0.09	0.01	0.13
Malaysia	0.96	3.80	0.37	5.13	0.78	3.62	0.35	4.75
Maldives	0.01	0.03	0.00	0.04	0.01	0.02	0.00	0.03
Mali	1.92	1.19	0.09	3.20	2.09	1.23	0.09	3.40
Malta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Mauritania	0.04	0.09	0.01	0.14	0.03	0.08	0.01	0.12
Mauritius	0.10	0.10	0.01	0.21	0.05	0.11	0.01	0.16
Mexico	0.83	0.47	0.10	1.40	0.45	0.64	0.11	1.20
Moldova, Republic of	0.01	0.01	0.00	0.02	0.01	0.01	0.00	0.02
Mongolia	0.01	0.01	0.00	0.02	0.01	0.03	0.00	0.04
Morocco	0.02	0.03	0.00	0.05	0.02	0.04	0.00	0.06
Mozambique	0.07	0.86	0.02	0.95	0.01	1.30	0.03	1.34
Myanmar	3.14	23.34	0.66	27.14	2.14	15.96	0.45	18.56
Nepal	0.55	6.16	0.41	7.12	0.43	4.92	0.33	5.68
Netherlands	0.15	0.07	0.01	0.23	0.05	0.12	0.01	0.19
New Zealand	0.05	0.03	0.00	0.08	0.02	0.05	0.00	0.08
Nicaragua	0.07	0.45	0.02	0.54	0.00	0.50	0.01	0.51
Niger	0.15	0.22	0.02	0.39	0.12	0.28	0.03	0.43
Nigeria	1.70	10.21	0.19	12.10	1.71	11.44	0.07	13.22
Norway	0.01	0.03	0.00	0.04	0.01	0.03	0.00	0.05
Pakistan	10.78	4.41	0.49	15.68	7.09	2.90	0.32	10.31
Panama	0.02	0.51	0.03	0.55	0.00	0.46	0.02	0.48
Paraguay	0.08	0.11	0.00	0.20	0.08	0.10	0.00	0.19
Peru	1.14	1.05	0.20	2.40	0.98	0.95	0.19	2.12
Philippines	6.93	18.05	1.00	25.98	6.10	15.87	0.82	22.79
Poland	0.08	0.15	0.02	0.24	0.05	0.12	0.01	0.18
Portugal	0.38	0.15	0.03	0.55	0.49	0.06	0.03	0.57
Romania	0.09	0.03	0.01	0.13	0.06	0.14	0.01	0.21
Russian Federation	1.44	0.74	0.12	2.30	2.64	0.52	0.11	3.27
Rwanda	0.03	0.05	0.00	0.08	0.02	0.04	0.00	0.06
Saint Lucia	0.01	0.02	0.00	0.02	0.00	0.00	0.00	0.00
Sao Tome and Principe	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Saudi Arabia	0.78	1.26	0.10	2.14	0.51	1.14	0.11	1.76
Senegal	0.43	1.85	0.15	2.42	0.42	1.72	0.10	2.24
Serbia and Montenegro	0.01	0.01	0.00	0.02	0.01	0.03	0.00	0.04
Seychelles	0.00	0.00	0.00	0.00	0.27	0.27	0.27	0.81
Slovakia	0.03	0.03	0.00	0.07	0.02	0.05	0.00	0.07
Slovenia	0.01	0.00	0.00	0.01	0.01	0.02	0.00	0.03
Solomon Islands	0.00	0.01	0.00	0.02	0.01	0.03	0.00	0.05
South Africa	0.30	0.93	0.07	1.30	0.36	0.80	0.08	1.24
Spain	0.67	0.17	0.05	0.89	0.75	0.08	0.05	0.88

Country	top down approach				bottom up approach			
	WFP_{blue} (km^3 $year^{-1}$)	WFP_{green} (km^3 $year^{-1}$)	WFP_{grey} (km^3 $year^{-1}$)	WFP_{total} (km^3 $year^{-1}$)	WFP_{blue} (km^3 $year^{-1}$)	WFP_{green} (km^3 $year^{-1}$)	WFP_{grey} (km^3 $year^{-1}$)	WFP_{total} (km^3 $year^{-1}$)
Sri Lanka	3.45	2.90	0.45	6.79	3.06	2.56	0.40	6.02
Sudan	0.03	0.02	0.00	0.06	0.02	0.06	0.01	0.08
Suriname	0.04	0.14	0.01	0.20	0.02	0.06	0.01	0.09
Sweden	0.04	0.07	0.01	0.11	0.03	0.06	0.01	0.10
Switzerland	0.06	0.09	0.01	0.16	0.03	0.07	0.01	0.11
Syrian Arab Republic	0.00	0.00	0.00	0.00	0.19	0.43	0.04	0.66
Tanzania, United Rep of	0.73	1.84	0.04	2.61	0.77	2.04	0.02	2.82
Thailand	3.74	25.13	1.90	30.77	1.92	12.88	0.97	15.77
Timor-Leste	0.02	0.05	0.00	0.08	0.04	0.09	0.01	0.14
Togo	0.07	0.14	0.01	0.23	0.06	0.14	0.01	0.21
Trinidad and Tobago	0.04	0.07	0.01	0.11	0.02	0.04	0.00	0.06
Tunisia	0.01	0.04	0.00	0.05	0.02	0.04	0.00	0.05
Turkey	0.97	0.22	0.08	1.27	1.08	0.16	0.07	1.30
Turkmenistan	0.03	0.06	0.01	0.09	0.02	0.05	0.00	0.08
Uganda	0.11	0.18	0.02	0.31	0.07	0.17	0.02	0.26
Ukraine	0.09	0.13	0.01	0.23	0.08	0.17	0.02	0.27
United Arab Emirates	0.21	0.27	0.02	0.50	0.09	0.20	0.02	0.30
United Kingdom	0.54	0.39	0.05	0.98	0.20	0.45	0.04	0.70
United States of America	5.40	2.67	0.59	8.66	3.82	1.44	0.39	5.66
Uruguay	0.15	0.07	0.01	0.23	0.03	0.01	0.00	0.04
Uzbekistan	1.30	0.06	0.03	1.38	1.49	0.05	0.03	1.57
Venezuela,Bolivar Rep of	0.02	0.55	0.09	0.67	0.00	0.43	0.07	0.50
Viet Nam	10.03	25.75	3.56	39.34	6.64	17.05	2.36	26.05
Yemen	0.09	0.28	0.02	0.39	0.23	0.51	0.05	0.78
Zimbabwe	0.01	0.01	0.00	0.02	0.01	0.03	0.00	0.05
World	260.77	593.04	57.19	911.01	225.19	511.25	49.21	785.65

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