**Hydrology and
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Discussions**

Food consumption patterns and their effect on water requirement in China

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Abstract

It is widely recognized that food consumption patterns significantly impact water requirements. The aim of this paper is to quantify how food consumption patterns influence water requirements in China. The findings show that per capita water requirement for food (CWRF) has increased from $250\,\mathrm{m^3\,cap^{-1}\,y^{-1}}$ in 1961 to $780\,\mathrm{m^3\,cap^{-1}\,y^{-1}}$ in 2003, largely due to an increase in the consumption of animal products in recent decades. Although steadily increasing, the CWRF of China is still much lower than that of many developed countries. The total water requirement for food (TWRF) has been determined as $1023\,\mathrm{km^3\,y^{-1}}$ in 2003. Three scenarios are proposed to project future TWRF, representing low, medium, and high levels of modernization (S1, S2, and S3, respectively). Analysis of these three scenarios indicates that TWRF will reach a maximum between 2020 and 2025, after which it is expected to decline. According to S2, the shift in food consumption patterns together with population growth may lead to an additional amount of required water of $114\,\mathrm{km^3\,y^{-1}}$ in 2025, even after taking technological advances into consideration. This will undoubtedly put high pressure on China's already scarce water resources. China needs to strengthen "green water" management and to take advantage of "virtual water" import to meet the additional TWRF.

1 Introduction

Besides population growth and externalities of uncontrolled economic growth, water scarcity is more and more recognized as a major threat to sustainable development (Koudstaal et al., 1992; Postel et al., 1996; Vörösmarty et al., 2000; Oki and Kanae, 2006). While water stress is often a direct result of population growth and economic development, this paper shows that changing consumption patterns may potentially become the main cause of water scarcity. Currently, approximately one third of the world's population lives in countries suffering water stress (Oki and Kanae, 2006). Many au-

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thors have projected that a large share of the world's population – up to two-thirds – will be affected by water scarcity over the next decades (Shiklomanov, 1991; Raskin et al., 1997; Seckler et al., 1998; Alcamo et al., 2000; Vörösmarty et al., 2000; Oki and Kanae, 2006).

5   The problem of water scarcity, in essence, originates from insufficient water for the production of food. Almost 90% of an individual's water requirement is needed for food production (Savenije, 2000). As a general rule, about 1-2 m^3 of water is required to produce 1 kg of cereal (Allan, 1998; Yang et al., 2003). More water is needed to produce one kilogram of meat. For example, it takes about 13.5 m^3 of water to produce 1 kg of

10   beef in California (Rijsberman, 2006). This means that the water requirement for consuming 1 kg of beef is equivalent to almost three-fourths of the recommended human's annual basic water requirement for drinking, human hygiene, sanitation, and modest household needs for preparing food (i.e. 50 liters $cap^{-1} d^{-1}$ per d, or 18 $m^3 cap^{-1} y^{-1}$) (Gleick, 1996).

15   A human being "eats" thousands of liters of water each day; however, the exact amount largely depends on food consumption patterns. Renault and Wallender (2000) estimated that a typical American diet requires twice as much water as a vegetarian diet with the same nutritional intake. Unraveling the effects of various food consumption patterns on water requirement help formulate appropriate water and food policies.

20   This paper aims to quantitatively examine the effects of food consumption patterns on water requirements in China. China has been selected for three reasons. First, with a population of about 1.3 billion, China feeds the largest number of consumers in the world; second, the constraint of water scarcity on food production has led to growing concerns regarding China's food production, food security, and their impacts on the

25   global food market (Liu et al., 2007b); third, China has experienced fast economic growth with an annual GDP growth rate of 8% over the past two decades; the highest rate in recent world history. Consumers' incomes have risen substantially, resulting in a rapid dietary change towards more meat consumption (FAO, 2006; Du et al., 2004). The shift in food consumption patterns will undoubtedly have profound effects on water

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requirements, but in-depth analysis on these effects is rarely found in literature.

2   Materials and methods

2.1   Food requirements at three scale levels

In this paper, food requirements are classified into three levels of scale: the basic level, the subsistence level and the cultural level, as suggested by Gerbens-Leenes and Nonhebel (2002). At the basic level, food requirements are only sufficient to prevent starvation, but one may suffer from malnutrition in the long run because many essential nutrients are lacking. At this level, the main purpose of food intake is to provide enough energy for basic survival and physical activity. At the subsistence level, food requirements are based on a selected number of nutrient-dense foods recommended that enable one to lead a healthy life over an entire life span. At the cultural level, food requirements correspond to the actual consumption pattern, which is embedded in different types and quantities of food and their combination in different dishes or meals. In order to analyze food requirements at the cultural level, food items have been grouped in six categories: (1) cereals and starchy roots (including rice, wheat, maize, other cereals, potatoes and other starchy roots); (2) sugar and sweeteners; (3) oil crops and vegetable oils; (4) vegetables and fruits; (5) alcoholic beverages; and (6) animal products (including beef, pork, poultry, mutton and goat, fish and seafood, eggs, milk, animal fats). In 2003, these foods accounted for 98% of both the total food consumption in weight and the total calorie intake (FAO, 2006).

2.2   Virtual water content (VWC)

VWC can be defined as the volume of water used to produce a unit of a product at the place where the product was actually produced, or it can also be defined as the volume of water that would have been required to produce the product in the place where the

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product is consumed (Chapagain and Hoekstra, 2004). In China, food consumption mainly originates from domestic food production. Food imports are marginal compared to domestic production. For example, in 2003, the imports of cereals and meats were only equivalent to about 3% of the domestic production in weight (FAO, 2006). Due to the small share of food imports, the VWC values are determined on the basis of China's specific production conditions. The VWC of cereals, soybean, vegetables and fruits is obtained from Liu et al. (2007b), who estimated VWC based on yields and evaporation in the major producing regions in China. The VWC of meats, eggs, milk, sugar and sweeteners, vegetable oils, and alcoholic beverages has been taken from Chapagain and Hoekstra (2004). The VWC of fish and seafood is from Zimmer and Renault (2003).

2.3 Energy water productivity

Energy water productivity is defined as the caloric energy produced by one unit of water, and is calculated by dividing energy content by VWC. The data on energy content have been taken from FAO Food Balance Sheets for China's food consumption in 2003 (FAO, 2006).

2.4 Per capita water requirement for food (CWRF)

CWRF is defined as the amount of water used to produce certain food requirements on a per capita basis. The CWRF is calculated by multiplying the food requirements per food item by the VWC of the corresponding food item and then summing the results for the food categories. Three levels of CWRF (basic CWRF, subsistence CWRF, and cultural CWRF) have been estimated based on the three scale levels of food requirements. The basic CWRF is determined based on two considerations. First, the caloric energy requirements are hypothesized to be met only by the consumption of wheat (Gerbens-Leenes and Nonhebel, 2002); second, according to the Chinese Nutrition Society (CNS), at least 2400 and 2100 $\text{kcal cap}^{-1}\text{d}^{-1}$ of energy is required for

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male and female Chinese adults, respectively, to carry out light physical activities under healthy live conditions. Thus, the average of 2250 kcal cap^{-1} d^{-1} has been used as the recommended energy intake at the basic level. The calculation of subsistence CWRF is based on the recommended daily amounts of food intake from the food guide
5 pagoda of the CNS (http://www.cnsoc.org). The food guide pagoda is available in the supporting information SI (http://www.hydrol-earth-syst-sci-discuss.net/5/27/2008/ hessd-5-27-2008-supplement.pdf) Fig. 5. According to CNS, 100 g of milk and milk products are equivalent to 200 g of fresh milk, and 50 g bean and bean products are equivalent to 40 g of soybean. These equivalences are used in the calculation of sub-
10 sistence CWRF. Further, the consumption ratio of different cereals (in weight) and meat has been assumed identical to the cereal consumption pattern in 2003. The cultural CWRF is calculated based on actual food consumption patterns. Annual consumption of various food items over 1961–2003 is obtained from FAOSTAT (FAO, 2006).

In order to assess regional variation, cultural CWRF values have been estimated in
15 different regions based on the food consumption patterns in 2003 and the VWC values shown in Table 1. The regions analyzed are the European Union (the 15 member countries as a whole prior to the accession of the candidate countries on 1 May 2004, termed as EU15 here), USA, Japan, South Korea, developing countries as a whole (Developing), developed countries as a whole (Developed), and the world as a whole
20 (World). Developed and developing countries have been distinguished according to the classification by the Food and Agriculture Organization of the United Nations (FAO, 2006).

2.5 Total water requirement for food (TWRF)

TWRF is the total amount of water consumed to produce certain food requirements
25 for all the individuals in a country. It was calculated for China by multiplying CWRF by the population. Historical population data have been obtained from FAO (2006) for the period of 1961–2003. TWRF at the basic and subsistence levels have not been calculated, because these two levels are purely hypothetical situations which do not

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provide any information on the current and future water requirement situation.

The future levels of TWRF largely depend on food consumption patterns and future population. In addition, technological changes can also have a profound impact on TWRF via their influence on VWC. Accurate estimation of future food consumption pat-
5 terns is very difficult. Several studies presented estimates of future meat consumption, such as 30–50 kg cap^{-1} y^{-1} for 2025 (Heilig, 1999), 51.3 kg cap^{-1} y^{-1} for 2020 (World Bank, 1997), and 63 kg cap^{-1} y^{-1} for 2020 (Christopher et al., 1998). In 2003, meat consumption reached 55 kg cap^{-1} y^{-1} (FAO, 2006) showing that the first two studies notably underestimated actual consumption. Hence, future CWRF estimation based
10 on these cited projections may lead to large errors. In this paper, future CWRF values have been determined based on the general trend of historical CWRF values.

The projection of China's future population has been collected from the latest re-leased World Population Prospects: The 2006 Revision (United Nation, 2006). Tech-nological changes will likely lead to a decrease in VWC values. Shi and Lu (2001)
15 forecasted that, to meet China's food demand, crop water productivity needs to be im-proved by 56% for the option of food self-sufficiency and 66% for the option of balanced agricultural water supply and demand over the next three decades. To meet these pre-dictions, the VWC would need to decrease by −1.2% y^{-1} and −1.3% y^{-1}, respectively. These two rates have been used for the slow and fast modernization scenarios. The
20 average rate or −1.25% y^{-1} has been used for the medium modernization scenario.

In this paper, the period prior to 2030 has been selected for the scenario analysis. According to the medium variant of the UN's projection, China's population may reach the maximum in 2030 and then decline. Thus, in the nearest future China will face its greatest challenge in meeting the domestic food demand.

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3   Results and discussion

3.1   Virtual water content and energy water productivity

Table 1 shows the VWC values for the main food items in China. Generally, animal products, oil crops and vegetable oils have relatively high VWC values compared to other food items. Particularly, beef has the highest VWC of 12.6 $m^3 kg^{-1}$ among all food items. In contrast, vegetables and fruits have the lowest VWC. The VWC of cereals are between 0.84 and 1.3 $m^3 kg^{-1}$.

Cereals and starchy roots have the highest energy water productivity, ranging between 2200 $kcal\,m^{-3}$ and 3400 $kcal\,m^{-3}$ (Table 1). Animal products generally have much lower energy water productivity than plant products. For instance, beef needs 17 times more water than wheat to supply the same amounts of energy. If the average energy requirement of 2250 $kcal\,cap^{-1}\,d^{-1}$ is covered by wheat, then 0.8 $m^3\,cap^{-1}\,d^{-1}$ of water is required. However, if this amount of energy is covered by beef 14 $m^3\,cap^{-1}\,d^{-1}$ is needed.

3.2   Historical food consumption patterns

Chinese diets have shifted towards animal products, particularly meat. Meat used to be luxury food in China, and its consumption remained at low levels prior to 1980. However, meat consumption has risen rapidly, by a factor of 3.7, from 1980 to 2003. The large increase in meat consumption is mainly due to the rapid increase in per capita income, urbanization, and market expansion (Hsu et al., 2002; Huang et al., 1999). In the past four decades, the consumption of rice and wheat increased gradually until it peaked in the late 1990s. Since then, cereal consumption has dropped. The consumption of maize changed little over time, with only a slight decline in recent years. The consumption of starchy roots steadily declined until 1995, and then bounced back in the early 2000s. Another remarkable change was the significant increase in vegetable and fruit consumption. On average, the consumption of fruits and vegetables

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reached $320\,kg\,cap^{-1}\,y^{-1}$ in 2003, which is a four fold increase compared to that in 1961, and is now the most abundantly eaten food type in weight. The consumption of sugar and sweeteners, oil crops and vegetable oils and alcoholic beverages is also increasing. The historical food consumption of various food items over time is available

5   as supporting information SI (http://www.hydrol-earth-syst-sci-discuss.net/5/27/2008/ hessd-5-27-2008-supplement.pdf) Table 2.

3.3   Per capita water requirement for food

Basic CWRF is estimated to lie around $300\,m^3\,cap^{-1}\,y^{-1}$. Subsistence CWRF ranges from 480 to $680\,m^3\,cap^{-1}\,y^{-1}$. These two numbers correspond to low and high sub-

10   sistence levels respectively. CWRF at the high subsistence level is more than double the basic CWRF. Figure 1 presents the estimated cultural CWRF from 1961 to 2003, indicating the basic and subsistence CWRF levels.

    The cultural CWRF in the early 1960s was lower than the basic CWRF (Fig. 1). The year 1961 is the last year of the so-called "three bad years", which contained a series

15   of calamities that resulted in the deaths of tens of millions directly caused by starvation. In 1961, the Chinese government started to introduce a series of new economic policies known as "readjustment, consolidation, filling-out, and raising standards" to boost agricultural production. Consequently, cereal consumption (particularly wheat and rice consumption) rose steadily, which led to an increase in CWRF from 1961 to 1965.

20   Afterwards, the Cultural Revolution, 1966–1976, which involved devastating social turmoil, had adverse effects on agricultural production. Over this period, cultural CWRF remained close to the basic level. After the Cultural Revolution, China abandoned collective agriculture and in 1978 assigned most agricultural land to families under the household responsibility system. The adoption of this system contributed to technolog-

25   ical changes, which played an important role in driving productivity, particularly in the 1980s (Liu and Yin, 2004). Between 1978 and 1984, the rise of cultural CWRF was largely due to higher consumption of cereals and starchy roots and animal products.

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After 1984, consumption of cereals and starchy roots showed a slight decline. The increase in cultural CWRF was mainly caused by higher consumption of animal products, oil crops and vegetable oils, and vegetables and fruits. Cultural CWRF reached low subsistence CWRF in the late 1980s, and then arrived at high subsistence CWRF in the middle 1990s. In 2003, the cultural CWRF reached $780\,\mathrm{m}^3\,\mathrm{cap}^{-1}\,\mathrm{y}^{-1}$, which is about 15% higher than the CWRF at the high subsistence level. This is mainly due to meat and fish consumption being higher than the CNS recommended amount by about 50%. The contribution of animal products to CWRF has increased from 18% to 50% from 1961 to 2003. The contribution of cereals and starchy roots decreased from 61% to 25% during the same time span. Water requirement for the consumption of both vegetables and fruits and oil crops and vegetable oils steadily increased over time, contributing to 20% of CWRF in 2003.

Per capita water requirement for animal products has increased by about $3.3\%\,\mathrm{y}^{-1}$ since 1996. In contrast, water requirement for the consumption of non-animal products almost leveled off over this period. Increasing water requirement for vegetables and fruits and oil crops and vegetable oils is almost compensated by decreasing water requirement for cerealsand starchy roots.

Water requirements for the consumption of specific food items or categories depend not only on food consumption in weight but also on the VWC of these foods. For instance, even though animal products accounted for only 16% of total food consumption in weight in 2003, their production required over half the cultural CWRF (Fig. 2). In contrast, vegetables and fruits accounted for 44% of the total food consumption in weight, but their consumption only resulted in about 10% of CWRF. The VWC of animal products generally has much higher values than that of vegetables and fruits, as shown in Table 1. As a result, some food items take a disproportional share of the water requirements. Similarly, some food groups have a disproportional share of the dietary energy intake and cultural CWRF (Fig. 2). in this regard, the energy water productivity plays a key role.

It should be pointed out that the VWC values used in this study (Table 1) are based

on estimations for the years around 2000. VWC values fluctuate. For example, Xu and Zhao (2001) report that VWC of rice decreased from $4.3\,\mathrm{m^3\,kg^{-1}}$ in 1949 to $1.1\,\mathrm{m^3\,kg^{-1}}$ in 1996 in Fengqiu County in China. This decrease in VWC is mainly caused by technological innovations including the establishment of water conservation facilities, bet-
5 ter soil management, extension of new crop varieties, and a continuous increase in fertilizer application (Xu and Zhao, 2001). Annual VWC values of various food items in China are, unfortunately, rarely available. However, this should not influence the presented analysis, as its main objective is to demonstrate the effect of consumption patterns alone on CWRF, while holding all other variables constant. Therefore, the in-
10 fluence of technological changes has not been included. However, it will be taken into account in the scenario analysis of the future TWRF below.

3.4 Cultural CWRF and energy intake

Cultural CWRF and energy intake has changed at almost equal annual growth rates between 1961 and 1984 (see supporting information SI (http:
15 //www.hydrol-earth-syst-sci-discuss.net/5/27/2008/hessd-5-27-2008-supplement.pdf) Fig. 6). They both increased at a rate of $5\%\,\mathrm{y^{-1}}$ from 1961 to 1965, remained almost zero from 1966 to 1976, and increased again at a rate of about $4\%\,\mathrm{y^{-1}}$ from 1977 to 1984. Over the period 1961–1984, consumption of animal products hardly varied; and energy intake from animal products remained relatively constant. The variation in
20 total energy intake was mainly caused by changes in the consumption of cereal crops and starchy roots (FAO, 2006). Cereals and starchy roots have similar energy water productivity, resulting in the similar increase rates of cultural CWRF and energy intake.
   From 1985 to 1997, however, the CWRF increased much faster than total energy intake. Growth rates of CWRF and total energy intake were $5\%\,\mathrm{y^{-1}}$ and $1\%\,\mathrm{y^{-1}}$, re-
25 spectively. The main reason for the faster growth of CWRF was the increase in the consumption of food items with low energy water productivity (e.g. animal products) and less consumption of the food items with high energy water productivity (e.g. starchy roots). Although total energy intake from non-animal products only increased slightly,

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consumption of various plant products changed. Consumption of cereals and starchy roots declined, while consumption of vegetables and fruits increased significantly, thus causing a further growth of CWRF.

Since 1997, energy intake has slightly declined. The decrease in energy intake from cereals and starchy roots outweighed the increase in energy intake from animal products. Lower energy water productivity of animal products led to a further increase in CWRF.

3.5 Comparison with other regions

Cultural CWRF values vary significantly among regions (Fig. 3). The largest value is for the USA ($3074\,\mathrm{m^3\,cap^{-1}\,y^{-1}}$), and the smallest for the developing countries ($658\,\mathrm{m^3\,cap^{-1}\,y^{-1}}$). The CWRF of China is similar to that of the world average, but is much lower than that of developed countries, particularly EU15 and the USA (Fig. 3). Two other Asian countries, Japan and South Korea, have a cultural CWRF value of about one-third higher than China. The relatively low CWRF of China is mainly due to lower consumption of animal products. For example, in the USA, the consumption of animal products corresponds to almost $900\,\mathrm{m^3\,cap^{-1}\,y^{-1}}$ of water, of which $465\,\mathrm{m^3\,cap^{-1}\,y^{-1}}$ is due to beef consumption. This volume alone is much larger than the CWRF of China. Additionally, developed countries also consume more sugar and sweeteners and alcoholic beverages than China. Water requirements for the consumption of cereals and starchy roots hardly vary among regions.

In the near future, dietary changes in China, directed towards higher consumption of animal products, will continue to bear on water requirements. If China shifts towards the American level of animal product consumption, the cultural CWRF will rise by almost 400%. Similarly, if consumption patterns in developing countries would shift towards the affluent diets of western countries, the CWRF values would rise up to a three fold increase. Such a change in food consumption pattern would play a much greater role in increasing water requirements than population growth.

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3.6 Total water requirement for food (TWRF): present and future

The TWRF has been estimated at $1023\,km^3\,y^{-1}$ in China in 2003. To analyze the TWRF in the period of 2004–2030, three scenarios have been developed.

Slow modernization scenario (S1). The per capita water requirement for animal products increases with an annual growth rate of $1.6\%\,y^{-1}$, half that of recent years. Per capita water requirement for non-animal products remains at the consumption level of 2003. Population growth follows the high variant of the UN population projection. Technological innovation decreases the VWC by $-1.2\%\,y^{-1}$.

Medium modernization scenario (S2). The current growth rates of per capita water requirement for animal products ($3.3\%\,y^{-1}$) and non-animal products ($0.2\%\,y^{-1}$) will remain constant until 2030. Population growth follows the medium variant of the UN population projection. Technological innovation decreases the VWC by $-1.25\%\dot{y}^{-1}$, the average of S1 and S3.

High modernization scenario (S3). Food consumption in 2030 will reach the average level of developed countries. Consumption of each food item changes linearly over 2004–2030. Population growth follows the low variant of the UN population projection. Technological innovation decreases the VWC by $-1.3\%\,y^{-1}$.

The results of future TWRF scenarios S1–S3 are presented in Fig. 4. Under S1, a peak in TWRF will occur around 2020. During this period, the shift in food consumption patterns alone will result in 14% more TWRF compared to that in 2003, while population growth alone will lead to 13% more TWRF. Both factors combined increase the TWRF by 28% over 2003–2020. Technological changes decrease the VWC by about 20%. As a result, TWRF reaches $1044\,km^3\,y^{-1}$ in 2020, about 2% higher than in 2003. Afterwards, the TWRF will decrease.

Under S2, TWRF will reach a maximum in 2025 (Fig. 4). Around this time the shift in food consumption and population growth will lead to a 39% and 10% increase compared to 2003, respectively (all other factors remaining equal). Both factors combined will increase the TWRF by 53%. Technological innovation alone will decrease the VWC

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by 28%. As a result, TWRF arrives at 1137 km^3 y^{-1} in 2025, 11% higher than in 2003.

Under S3, TWRF will reach a maximum in 2020 (Fig. 4). The shift in food consumption patterns and population growth will result in 44% and 4% increase compared to 2003, respectively, whereas both factors combined increase the TWRF by 50%.

5　Technological innovation decreases the VWC by 22%. As a result, TWRF arrives at 1189 km^3 y^{-1} in 2020, about 16% higher than in 2003.

The TWRF will most likely reach a peak between 2020 and 2025. Before that, an additional amount of water ranging between 21 and 166 km^3 y^{-1} will be required. This is a substantial increase, which amounts to 10–74% of current consumptive irrigation

10　water use (MWR, 2005). The analysis also suggests that the shift in food consumption pattern will contribute more to the growth of the TWRF than population growth, especially under S2 and S3.

4　Conclusions

There are three sources of water that can be managed to meet the additional TWRF

15　requirements. The first source is blue water, which is defined as the water in rivers, lakes, reservoirs, ponds and aquifers (Falkenmark, 2003). For food production, blue water means irrigation. However, increasing water scarcity and competition from other sectors have put agricultural blue water use under great pressure. There has been a reallocation of irrigation water to industrial and domestic sectors, and environmental

20　water needs are give more and more weight (Yang and Zehnder, 2001). In China, irrigation water use declined by 15% over 1997–2003 (MWR, 2005). It is difficult to allocate more blue water to future domestic agricultural production.

The second source of water is green water. Green water refers to the water coming from precipitation, stored in unsaturated soil, and taken up by plants as transpiration

25　(Savenije, 2000). Green water accounts for 73% of the consumptive water use for do-

mestic crop production in China (Liu et al., 2007c[1]), and likely constitutes the majority of water used for the production of animal products. In particular grazing production systems use mostly green water, in which water has almost zero opportunity cost. Although important, green water is often ignored by water managers, largely due to
5 the difficulty to assess or manage it and its low opportunity cost (Liu et al., 2007c). Capturing more green water can be achieved by expanding agricultural land areas, water conservation and by more effectively utilizing local rainfall. Expanding agricultural land areas will not likely be feasible in China. Recent land use trends show a reallocation of agricultural land to other uses (Tan et al., 2005). Effective rainfall man-
10 agement seems a more feasible option to increase the future water supply. Rockström et al. (2003) demonstrated that rainwater harvesting is a promising approach for green water management in the semi-arid tropics of Asia and Africa. Rainfall harvesting has been adopted in the past by many households in the semiarid areas in China to provide water storage for both irrigation and household usage (Zhao et al., 1995). So far, it has
15 been practiced in 15 provinces, mainly in the North, Northwest, and Southwest China. The potential of additional water supply through rainwater harvesting has never been quantitatively assessed for China.

The third source of water is virtual water. Virtual water describes the amount of water consumed in the production process of a product (Allan, 1998). The concept of virtual
20 water implies that water scarce countries could mitigate water scarcity by importing water intensive food (Chapagain et al., 2006; Hoekstra and Hung, 2005; Yang et al., 2003; Liu et al., 2007a). Based on the food items looked at in this study, it is estimated that China had a total net virtual water import of $81\,\mathrm{km}^3\,\mathrm{y}^{-1}$ in 2003, equivalent to 8% of the TWRF. The virtual water strategy has not been consciously used by the
25 Chinese government, largely due to its emphasis on the principle of self-sufficiency in food supply (Liu et al., 2007b). With intensified water scarcity, China's decision makers may have to consider loosening its stance on the self-sufficiency principle and, thereby,

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taking advantage of virtual water through the trade of water-intensive foods.

To conclude, the additional TWRF triggered by the shift of food consumption patterns and population growth will impose high pressure on China's finite water resources. Amongst the other options, two seem feasible to meet the additional water required for food consumption, namely effectively rainfall management and increased virtual water imports. Both options need further study to provide realistic estimates of their potential contribution to China's water supply. Since the requirement of additional water largely depends on food consumption patterns, it is theoretically possible to reduce the additional water requirement by consuming lower amounts of food items with high VWC, such as animal products. Fish could serve as an alternative to meat as a source of protein. Production of sea fish does not require freshwater; hence, replacement of part of meat with sea fish can also save freshwater. Although food consumption patterns are closely related to increasing affluence, awareness-raising may play a role in affecting the food preference of China's population. Currently, China's meat consumption has exceeded the recommended amounts by the CNS. In addition, some authors have argued that the contemporary Chinese diet shifts may be detrimental to health, by introducing higher incidence of diet-related diseases (Du et al., 2004). Raising public awareness and encouragement of the CNS diet may help mitigate the future water scarcity problem in China.

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Table 1. Virtual water content and energy water productivity for mostly consumed food items.

Foot Items	Virtual water content ($m^3\,kg^{-1}$)	Energy content ($kcal\,kg^{-1}$)	Energy water productivity ($kcal\ m^{-3}$)
Cereals and Roots			
Rice	1.31	3625	2770
Wheat	0.98	2633	2701
Maize	0.84	2872	3403
Other cereals [†]	1.24	2709	2185
potatoes and other starchy roots[‡]	0.23	699	3107
Sugar and Sweeteners[§]	1.02	3481	3423
Oil crops and Vegetables oils			
Soybeans and other oil crops[‖]	3.20	3314	1035
Vegetable oils[¶]	5.08	8720	1715
Vegetables and Fruits			
Vegetables[#]	0.19	188	995
Fruits[††]	0.50	413	834
Animal Products			
Beef	12.56	2021	161
Pork	2.21	3500	1583
Poultry	2.39	1708	715
Mutton and goat meat[‡‡]	4.50	2005	446
Fish and sea food	5.00	497	99
Eggs	3.55	1455	410
Milk	1.00	670	670
Animal fats	4.00	7080	1770
Alcoholic beverages[§§]	0.18	490	2768

[†] based on data for sorghum [‡] based on data for potatoes
[§] based on data for refined sugars [‖] based on data for soybeans
[¶] based on data for soybean oil [#] based on data for tomatoes
[††] based on data for apples [‡‡] based on average data for goat meat and sheep meat
[§§] based on data for beer
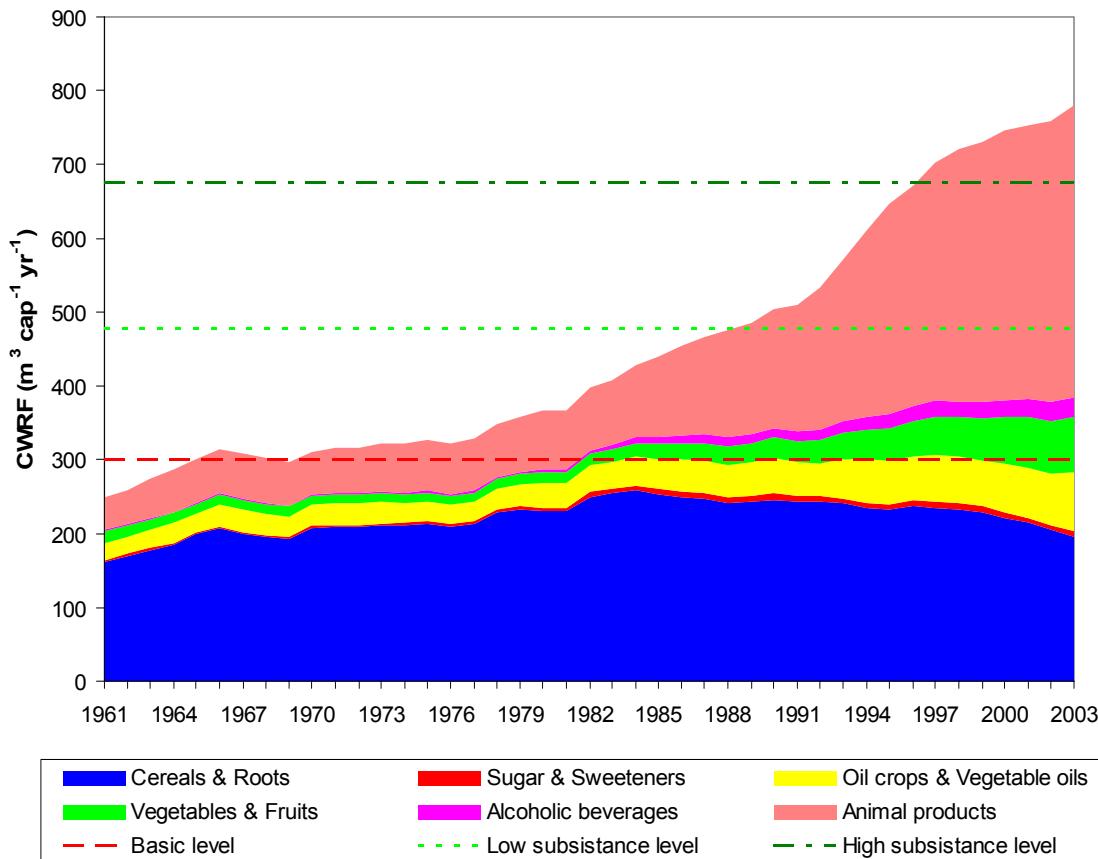
**Fig. 1.** The per capita water requirement for food (CWRF) at the basic, subsistence and cultural levels.

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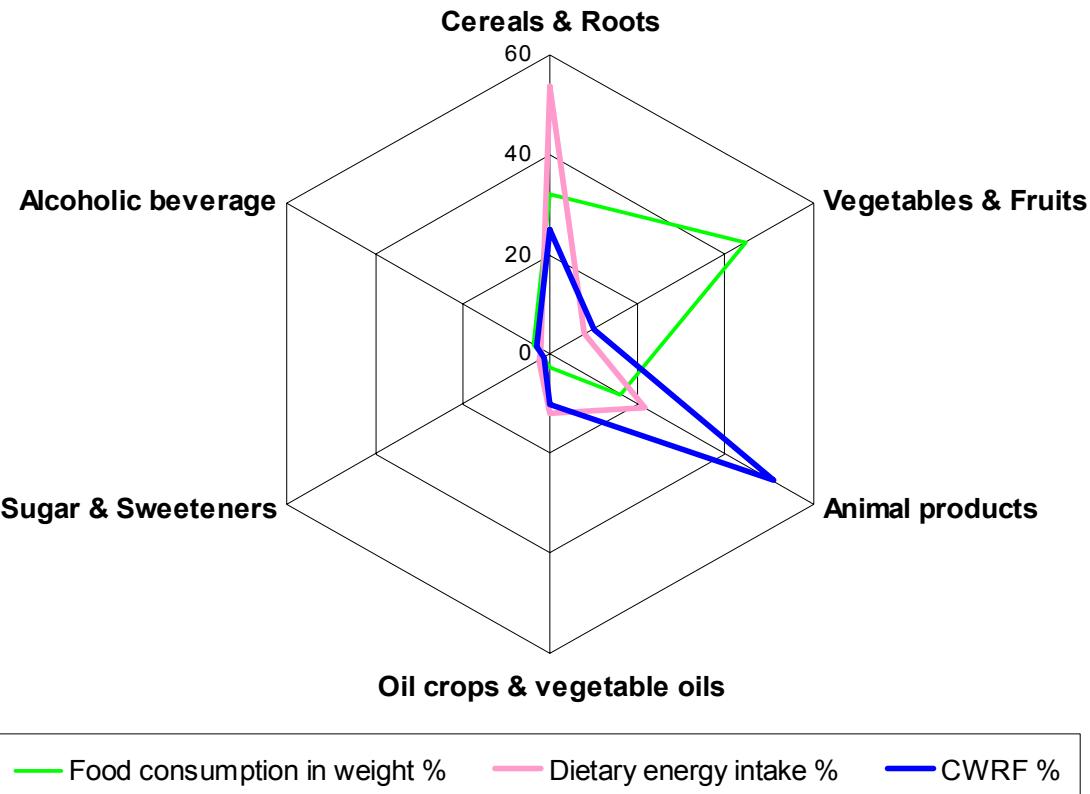
Fig. 2. Sources of food consumption in weight, dietary energy intake and CWRF. All are presented as the percentage of the total.
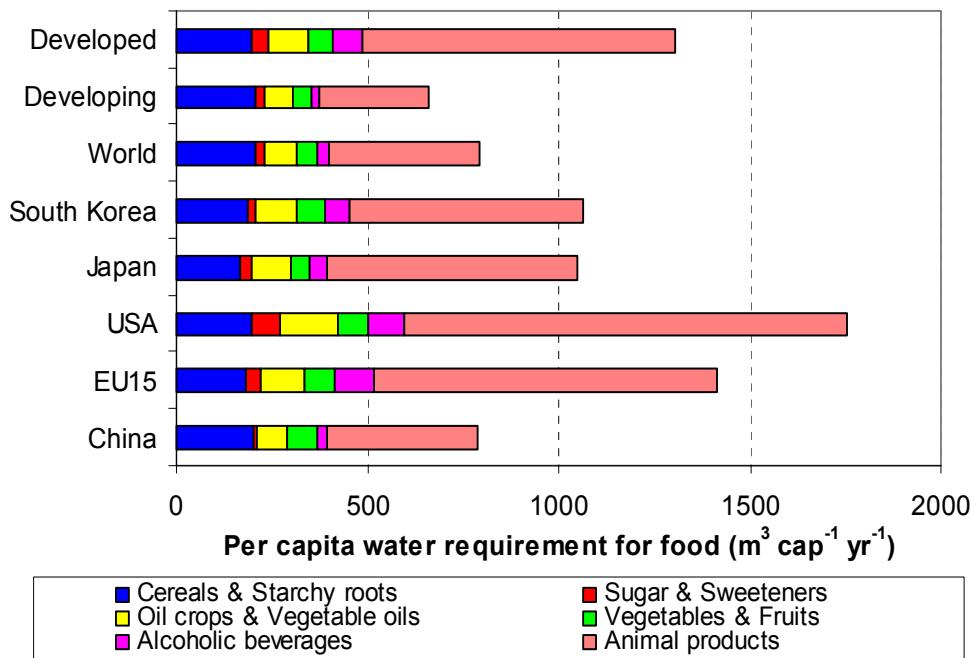
Fig. 3. Per capita water requirement for food (CWRF) at the cultural level in 2003 in different regions.

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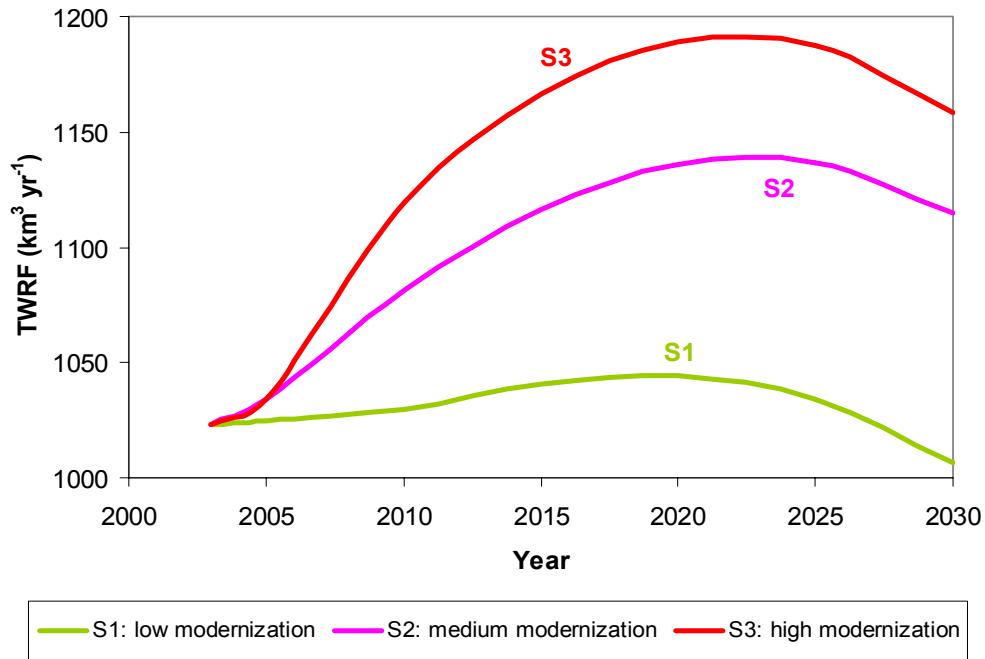
Fig. 4. Forecasted total water requirement for food (TWRF) in 2003–2030 under three scenarios.

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