Country Policy Support Program (CPSP)

Water Supply, Water Demand and Agricultural Water Scarcity in China: A Basin Approach

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Summary

Over the past 50 years, China has remained largely self-sufficient in food supply even as her population grew and per capita consumption expanded to unprecedented levels. However, there are continuing questions as to China's ability to continue its food production success. A large part of this concern surrounds perceptions of growing scarcity in the water available to support agricultural output. This paper uses a "basin" approach to quantitatively analyze the current status of water supply and demand in China at national and sub-national scales so as to provide a basis for discussing China's water and agricultural future. To undertake the analysis, a Chinese river basin classification scheme and corresponding data is combined with a new spatially consistent data set to calculate basin scale water balances.

On the supply side, estimates show that water availability varies significantly between Northern (Sonhlieohe, Haihe, Huaihe and Yellow river) and Southern basins (Yangtze, Southeast, Southwest). Southern basins, covering 28 percent of area, contain 52 percent of the population and account for 60 percent of the total renewable water resources. Northern basins, also covering 28 percent of total area, contain 44 percent of the population but account for only 14 percent of the total water resources. The remaining basins (Inland and Southwest), though accounting for 26 percent of the total water resources, play a minor role in China's agriculture economy due to low population densities and climatic conditions.

Demand estimates were made for three categories of use: Agriculture, Industry and Domestic. Agriculture has by far the largest withdrawals (71 percent) of the developed water resources. Three quarters of the total water demand in Northern basins are for agriculture while the figure for Southern basins is 64 percent. Most agricultural water is obtained from surface supplies. However, groundwater is used to meet 40 percent of irrigation demand in Northern basins though playing almost no role in the South. The Industrial sector accounts for the next largest share of use, making up 21 percent of the total water demand. Domestic use accounts for the remaining 8 percent.

The supply and demand estimates were then used to create accounts for basin level total renewable water resources. Resulting water accounting parameters were used to define indicators of degree of water development, depletion fraction of developed water, groundwater abstraction rates and grain and non-grain production surplus or deficits. These indictors were then used to classify basins into one of four categories: Water Scarce/Food Deficit, Water Scarce/Food Surplus, Water Surplus/Food Deficit, and Water Surplus/Food Surplus.

Of the four northern basins, the Yellow and Songliao are classified as water scarce and food deficit while the Hei and Huai are water scarce but food surplus. The Yellow, Hei and Huai basins appear to already be so physically water scarce that they will not have enough water resources to meet future demand of all sectors even if the highest possible increases in water productivity occur. The Yangtze, Pearl, Southeast and Southeast basins are classified as water scarce but with large food production deficits. These basins can be considered as economically water scarce as they may need substantial investments in water resources development to meet future demand. The Inland basin, with its low population and hence low demand, falls in the final category as neither water nor food scarce.

The results of the analysis are in some ways not surprising-China's northern basins tend to show high degrees of water scarcity while water surplus is the norm in the south. It is also shown that China's internal agricultural surpluses or deficits, at least at the basin scale, do not tend to be correlated with water scarcity indicators at present. However, water scarcity in the northern basins where most of the grains including wheat and maize are now produced is likely to have a significant impact in meeting additional future food demand.

The implications of this finding are discussed along with other considerations for understanding China's agricultural and water future. The key variables such as population growth and urbanization, increasing consumption and changes in consumption patterns with income growth, the contribution of irrigation for crop yield and cropping intensity growth, unsustainable groundwater use in the northern basins, changes in cropping patterns, increasing productivity of rainfed agriculture, irrigation efficiency increase and the water demand for environment and pollution controls needs to be considered in estimating future water demand.

1.   Introduction

China is one of the world's largest producers and consumers of agricultural products and so has the potential to have major impacts on global food markets. The threat of growing Chinese imports on world food prices has long been highlighted (e.g. Brown 1995) but, despite such concerns, China continues to import only a small fraction of its food requirements. China's ability to maintain near self-sufficiency in agricultural products has stemmed from two factors. First, government policy has, until recently, kept markets relatively closed, thus almost by definition ensuring that the country is self-sufficient. Second and more importantly, China has been remarkably successful in increasing its food output over the last half century. As China continues to open to the outside world and China's economy continues to expand, the question now is whether past trends will continue or whether China will soon become a major food importer with all that portends for global food security.

The answer to this question will depend fundamentally on China's water and how it is used (Zexhen et al 1992, Huang et al 2000, Brown 2001, Rosegrant 2002, Xuetao et al 2002, Song 2004). Much of the China's agricultural achievement since the founding of the People's Republic in 1949 can in fact be attributed to the development of water resources. Nationally, irrigated area increased from 15.4 million hectares in 1949 to 52.2 million hectares today, and 67 percent of grain output is now derived from irrigated land. Regionally, irrigation has transformed landscapes and economies, for example converting northern China from its historic status as a grain consumer to its present status as supplier of grain to the nation. However, China's water supplies are neither infinite nor distributed in proportion to demand. Falling groundwater tables in the North China Plain are notorious, and one of China's great rivers, the Yellow, is subject to virtual if not actual desiccation on an annual basis. At the same time, water resources seem so abundant in some areas of the south that the Chinese government is engaged in massive engineering projects to export supplies hundreds or even thousands of kilometers.

Clearly, China's current water situation, the role of water in agricultural output, and the problems in understanding China's agricultural water future are complex. The main objective of this paper is to develop and present a "basin" scale framework to assist in understanding this complexity. In so doing, the paper has two primary goals: first, to establish a spatially disaggregated picture of China's current water situation for those wishing to understand the present state of water development and its connection with agriculture; second, to provide a point of departure from which China's water and agricultural future can be discussed. The paper is also designed to complement efforts to update country policy papers for the International Committee

on Irrigation and Drainage (ICID 2000) in developing future water supply and demand scenarios for China using the PODIUM China river basin model (IWMI 2003).

In meeting its goals, the paper begins with a description of the Chinese system of basin classification. Water supply and demand estimates are then presented and used to calculate basin level water accounts. From the water accounts, a typology is developed for classifying each of China's basins into one of four categories based on its degree of water stress and its agricultural surplus/deficit status. The implications of the categorization are then discussed along with the key critical variables which need to be considered in understanding the potential directions of China's water and agricultural future.

2.   Evaluating China's Water Resources: A "basin" approach

From a hydrologic standpoint, the river basin forms a logical unit of analysis, since it establishes the boundary of the most important fluvial processes and functions for a given river system. Unfortunately though, hydrologic boundaries tend not to conform to the boundaries which meaningfully contain the economic, political and social activities which determine how a basin's water resources are used. As such, little data outside of hydrology is collected on a basin basis, and analysis of the interaction between hydrologic and social phenomena and their variation across space is difficult. Within China, recent efforts have been made to partially redress this problem through the division of the country into 9 major river "basins" as shown in **Figure 1** (Wang et al. 2000). This paper takes those basins, corresponding Chinese data, and additional data customized to basin definitions as the starting point for analysis. All data used in the analysis is available publicly at www.iwmi.org and necessary procedures and assumptions used in calculation and transformation are included in the appendix.

While the move to a basin system is a major step in improving our ability to analysis water issues in China, it should be noted that the 9 "basins" as shown in figure 1 deviate from strict hydrologic definitions. Instead, they are sometimes amalgamations of basins as, for example, the name Songliaohe (meaning the Song and the Liao Rivers) indicates. Further, it should be remembered that the meaning of "basin" in many parts of China, especially the flat north China plain, is blurred by the extensive anthropogenic change which has taken place over the last 2,000 or more years. Despite these limitations, the categorization still forms the best effort to date at moving to the basin approach for water analysis in China and provides a meaningful departure point from which to discuss spatial variation in the nation's water supply and demand.

In providing a general description of the variation of water resources and their use in China, it is convenient to divide the basins into three regional groupings-Northern, Southern and Inland-based on climatic, population and other characteristics. Four basins (Songliao, Hai, Huai and Yellow) make up the Northern Region (Table 1), which covers some 28 percent of total area and contains 44 percent of China's population. The Southern Region contains three basins (The Yangtze, Southeast, and Pearl) and accounts for 28 percent of total area and 52 percent of the population. The remaining Inland Region, contains two "basins" (Inland and Southwest) and is the largest in terms of physical area (44 percent of total) but, with a low population (4 percent of total), plays a minor role in China's overall water economy.

Figure 1. River basins and provincial boundaries
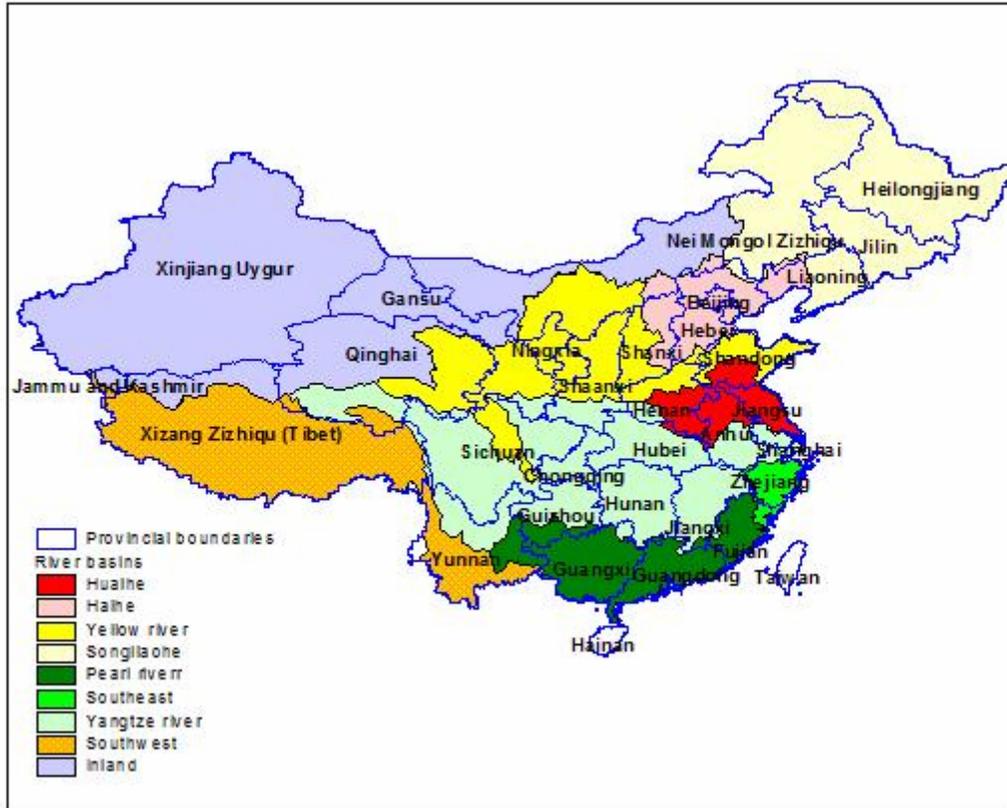
Table 1. Area and population of river basins

River Basin	Total area 1000 km²	Population in 1995		
		Total Millions	Density Number/km²	Urban-% of total %
Huaihe	329	200	609	23
Haihe	318	130	407	31
Yellow river	795	114	144	31
Songliaohe	1,248	122	98	43
Northern	2,690	566	210	31
Southeast	240	72	299	28
Pearl river	581	152	261	25
Yangtze river	1,809	442	245	32
Southern	2,630	666	253	30
Southwest	851	22	25	13
Inland	3,374	29	9	27
Inland	4,225	50	12	21
All basins	9,545	1,282	134	30

Data Source: Changming and Zhikai 2001

Together the Northern and Southern Regions form what is often termed the core area or "heartland" of China. Within the core area, the Northern Region is generally typified as China's wheat growing region while the Southern Region is known for rice production. The differences in cropping between the two regions are explained largely by differences in rainfall patterns with the northern basins generally receiving less rainfall than the southern. The remaining Inland Region contains large areas of desert, high plateau and mountains and, with some exceptions, is largely non-agricultural.

3. Water Supply

Chinese statistics place long term average (1956-1979) precipitation at about 6,200 km[3] per year (Zhengying 1994, Wang et al. 2000). Some 44 percent of this precipitation flows as runoff to which is added another 56 km[3] of water from glacial melt and 17 km[3] as inflow from other countries. In total then, annual average surface water resources are approximately 2,712 km[2]. In addition, groundwater generated from natural recharge provides 829 km[3] of water. However, much of the groundwater is seepage from surface supplies, and groundwater itself often contributes to river flow. Thus surface and groundwater supplies must be adjusted to account for an "overlap" which has been estimated at 728 km[3] per year (FAO 2003). Subtracting this overlap, China's Total Renewable Water Resources (TRWR) are estimated at about 2,813 km[3] per year.

In aggregate, these figures show that China has abundant overall water resources. However, these resources vary substantially by location, generally increasing from the northwest to the southeast in conjunction with rainfall patterns. As a result, the Northern Basins contribute only 14 percent of total supplies while Southern Basins provide more than 60 percent. The Yangtze Basin alone supplies some 35 percent of China's total supplies (Table 2).

Table 2. Water resources of China

| River Basin	Rainfall Mm	Renewable Water Resources				Potentially Utilizable Water Resources		
		Surface water	Ground water	Overlap	Total (TRWR)	Surface water	Ground water	Total
		Km[3]	Km[3]	Km[3]	Km[3]	Km[3]	Km[3]	Km[3]
Huaihe	860	74	39	17	96	42	24	65
Haihe	560	29	26	13	42	10	20	30
Yellow river	464	66	41	32	74	37	11	48
Songliaohe	511	165	63	35	193	65	30	95
Northern	**546**	**334**	**169**	**98**	**405**	**154**	**85**	**238**
Southeast	1757	256	61	58	259	48	3	50
Pearl river	1543	468	112	109	471	124	7	130
Yangtze river	1070	951	246	236	961	348	12	360
Southern	**1237**	**1,675**	**419**	**403**	**1,691**	**519**	**21**	**540**
Southwest	1098	585	154	154	585	28	2	30
Inland basin	158	116	86	72	130	50	15	65
Inland region	**347**	**702**	**241**	**227**	**716**	**78**	**17**	**95**
All Basins	**648**	**2,712**	**829**	**728**	**2,813**	**751**	**123**	**873**

Data Source: Changming and Zhikai 2001

Furthermore, even with substantial resources, China's large population means that per capita annual availability is only some 2,000 m[3] as compared to a global average of over 7,000 m[3]. Again however, average availability figures mask significant variation between basins

(Figure 2). At the extreme ends of the scale, the Haihe Basin in the north has less 325 m^3 of water per capita per year while the Southwest Basin has more than 20,000 m^3.

In addition to spatial variation, water supplies in China also show significant temporal variation. China is dominated by a continental monsoon climate with 60 to 80 percent of the water resources of northern China generated in the five months between July and November. Similarly, 60 to 70 percent of the water resources in southern river basins are generated between April and July. Because of both the spatial and temporal variation of rainfall and also due to limitations of possible storage sites in water abundant regions, only a portion of total renewable water resources can be captured for human utilization. In fact, the Potentially Utilizable Water Resources of China are estimated to be only 30 percent of the total renewable water resources (Table 2). However, the percentage of total waters potentially utilizable is itself not equal across space. Only one-quarter of total renewable water resources of the Southern Region is potentially utilizable while the figure for the Northern Region is nearly 60 percent, somewhat equalizing the apparent disparity between the north and the south.

Figure 2. Per capita water availability in 2000
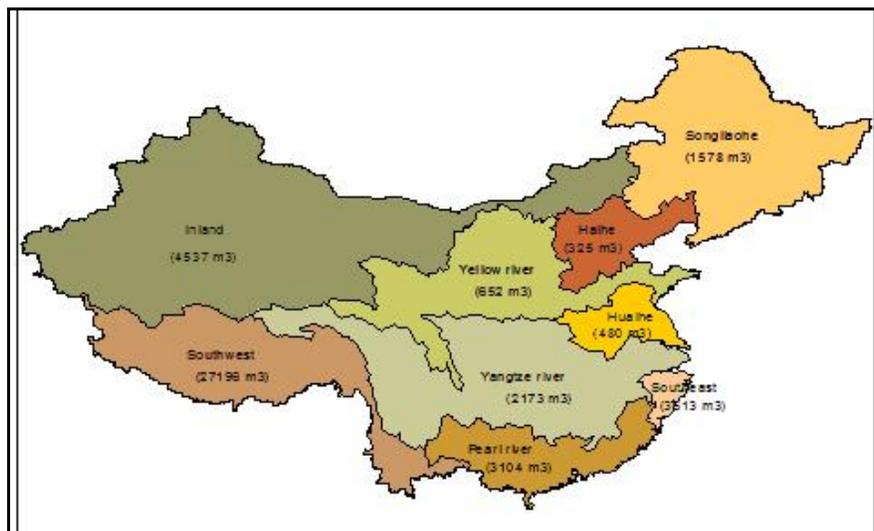
4. Water Demand

Like water supply, water demand and its various components also show significant spatial variation. Total water demand in 2000 was estimated to be about 545 km^3 (Table 3) with Northern Basins accounting for 38 percent, Southern Basins 54 percent and Inland Basins 8 percent. In the Northern and Inland Basins, groundwater accounts for a significant amount of total water used (45 and 23 percent respectively) while in the Southern Basins almost all demand is met with surface water.

Water demand can be broken down into four main categories of use: Agricultural, Domestic, Industrial and Environmental. However, while environmental use is now explicitly considered in China, environmental water accounting has yet to enter statistics (See **Zhu et al., 2003 and Zhu et al., 2004** for discussions). Of the remaining three categories, agriculture is by far the largest consumer user of water, accounting for over 70% of total use.

Table 3. Water demand (2000)

River Basin	Total Water Demand		Distribution of Total Water Demand		
	Total Km^3	% from ground water %	Agriculture %	Domestic %	Industrial %
Huaihe	73	36	80	7	14
Haihe	42	64	75	10	16
Yellow river	34	39	74	9	17
Songliaohe	59	46	68	7	25
Northern	208	45	75	8	18
Southeast	34	2	68	8	25
Pearl river	69	3	65	12	23
Yangtze river	181	3	63	9	28
Southern	284	3	64	10	26
Southwest	10	2	87	7	7
Inland basin	43	29	95	2	4
Inland region	53	23	93	3	4
All basins	545	21	71	8	21

Source: Authors estimate using PODIUM China 2004 (see www.iwmi.org , www.icid.org for the model and annexes for brief description of demand estimation)

Within the agricultural sector, water use can be divided into two components, rainfed and irrigated. Rainfed agricultural uses water supplies before they reach the river (i.e. consume part of the 56 percent of rainfall which does not contribute to runoff) and so does not form part of the demand examined here (but see section seven for additional discussion). Irrigated agriculture covers 56 percent of total arable land and provides about 67 percent of China's total grain output. Table 4 gives details of irrigated area by basin. The majority of equipped area (net irrigated area) is located in the Northern Basins. However, overall lower water availability holds cropping intensity on irrigated land to only 135 percent (i.e. on average each hectare of irrigated land provides 1.35 harvests per year). In Southern Basins with their more abundant water resources, cropping intensity on irrigated land reaches almost 200 percent. As a result, the gross irrigated area (area of crops actually irrigated within a year) in southern basins is nearly equal to gross area in northern and inland basins.

The irrigation requirement (difference between evapotranspiration and effective rainfall) averages about 217 mm in the Northern Region, about 15 percent higher than in the Southern Region (see **Annex A** for method of estimation). However, due to high efficiencies in groundwater irrigated areas and the large area irrigated with groundwater in the north, the total irrigation water demand in the northern basins(155 km^3) is 15 percent less than the irrigation demand in southern basins (181 km^3).

After agriculture, industry is the next largest user of water and accounts for 21 percent of total water demand, a figure which has increased by 50 percent in less than a decade (**Table 5**). The Southeast, Pearl and Yangtze Basins in the south and Songliao in the north account more than 75 percent of the total industrial water demand and most of the recent increase. Each of these basins is the home of major manufacturing and industry which has expanded substantially since China's economic reforms began in the late 1970s and early 1980s.

Table 4. Irrigated area and irrigation water demand

River Basin	Net Irrigated area	Irrigation Intensity	Gross Irrigated Area	Irrigation requirem-ent	Irrigation efficie-ncy	Irrigation demand	% from ground-water
	c_1 m ha	$c_2 = (c_3/c_1)$ %	C_3 m ha	C_4 mm	$c_5 = (c_6/c_4 /c_3)$ %	c_6 km^3	c_7 %
Huaihe	8.9	183	16.3	201	57	58.0	33
Haihe	7.5	112	8.4	204	54	31.6	60
Yellow	5.1	134	6.8	162	44	25.1	27
Songliaohe	5.1	106	5.4	354	48	40.4	38
Northern Basins	26.6	139	36.9	217	52	155.0	39
Southeast	1.9	227	4.4	236	45	23.0	1
Pearl river	4.2	200	8.4	240	45	44.9	0
Yangtze	14.9	193	28.8	167	42	113.6	2
Southern Basins	21.0	198	41.6	189	43	181.5	1
Southwest	0.8	225	1.7	235	45	8.8	0
Inland basin	4.3	126	5.4	396	53	40.2	27
Inland region	5.0	141	7.1	357	52	49.1	22
All basins	52.7	163	85.6	215	41	385.5	19

Source: PODIUM China 2004 (www.iwmi.org for PODIUM Model and data) and Yongsong 2003 (for generating data at basin level).

Table 5. Domestic and industrial water demand

River Basin	Domestic Sector			Industrial sector	
	Per capita water demand		Total Km^3	Total Km^3	Growth since 1993 %
	Rural l/pc/day	Urban l/pc/day			
Huaihe	44	138	4.8	10.0	4
Haihe	44	182	4.1	6.6	-2
Yellow	39	145	3.0	5.6	-4
Songliaohe	58	141	4.2	14.5	84
Northern Basins	45	150	16.1	36.7	22
SouthEast	73	177	2.7	8.4	82
Pearl river	95	326	8.5	15.9	22
Yangtze	57	207	16.8	50.6	70
Southern Basins	68	227	28.0	74.9	58
Southwest	71	212	0.7	0.7	124
Inland	42	125	0.7	1.6	18
Inland basins	55	148	1.4	2.3	36
All basins	57	190	45.5	113.9	50

Data Source: Yongsong 2003

The final category of demand, domestic, includes both human and livestock use and accounted for 8 percent of China's total water demand in 2000 (Tables 3). The urban domestic sector consists of household and public consumption along with water use for the urban environment, businesses and construction. Rural domestic demand consists of household and livestock demand. Per capita domestic use varies substantially between urban and rural areas with figures in cities roughly double those in the countryside (Table 5), an important factor in future

water demand as China continues to urbanize. Per capita demand in Southern Basins is about 25 percent higher than in Northern basins.

5.   Water Accounting

With basic estimates of water supply and demand, it is possible to construct water accounts for China as a whole and by basin. Water accounting is a framework for understanding the sources and uses of water in a given geographic location and can help, for example, in identifying emerging water scarcities and opportunities for improving water productivity. Water accounting here begins with Total Renewable Water Resources which is adjusted for potential utilization to arrive at Potentially Utilizable Water Resources (PUWR) as described above. PUWR are then adjusted for transfers to arrive at net PUWR which can be further divided into three components: Process evaporation, non-process evaporation and outflow (to the sea, a downstream country or an internal sink). *Process evaporation* consists of evapotranspiration from irrigated fields and evaporation from the domestic and industrial sectors. *Non-process evaporation* consists of depletion by other factors, such as through homesteads, bare soil, swamps, reservoir surfaces, canals, and rivers, for which the withdrawals are not intended. *Outflows,* consist of two parts: the utilizable outflows are the water which either leaves the system (basin) and flows to another country or the sea, and theun-utilizable outflows are the water which enters an internal "sink" where quality is degraded to such an extent that the water is no longer useful.

Figure 3 show the water accounts for northern and southern basins in the year 2000, while Table 6 gives details by basin. The figure and table bring up a number of issues of note. First, most water in China is in fact not utilizable, especially in the south as exemplified by the Southwest Basin where the figure is 95 percent. Second, process evaporation accounts for less than one-quarter of the potentially utilizable flow. This shows that for the country as a whole, there are still substantial water resources available for increasing process evaporation either through recycling structures or through new infrastructure developments. Finally, outflow accounts for about two-thirds of the potentially utilizable flow, 50 percent of that in the north and more than 75 percent in the south.

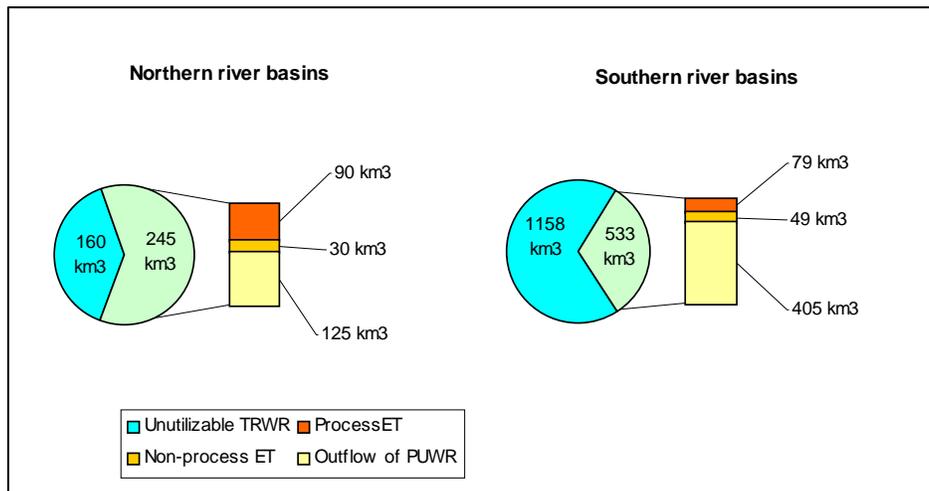**Figure 3.** Water accounting of southern and northern river basins

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Table 6. Components of water accounting across basins

River Basins	Total renew-able water resources (TRWR) Average 1956-1979	Potentiall y utili-zeble TRWR	Net water transfers	Potentially utilizable water resources			
				Total	Proce ss evap.	Non-process evap.	Outflow
	Km^3	Km^3	Km^3	Km^3	Km^3	Km^3	Km^3
Huaihe	96	65	10	75	33	10	32
Haihe	42	30	4	34	22	5	7
Yellow	74	48	-7	41	14	7	20
Songliaohe	193	95	0	95	21	9	64
Northern Basins	405	238	7	245	90	30	124
SouthEast	259	50	0	50	10	7	33
Pearl river	471	130	0	130	18	12	100
Yangtze	961	360	-7	353	51	30	272
Southern Basins	1,691	540	(7)	533	79	49	405
Southwest	130	65	0	65	22	5	38
Inland	585	30	0	30	3	2	25
Inland basins	716	95	0	95	26	7	63
All basins	2,813	873	(0)	873	195	86	592

Source: Authors estimate using PODIUM China 2004 (www.iwmi.org for Podium model)

6.   Water scarcity and crop production surplus and deficit

One of the biggest concerns for Chinese industrialization, modernization and food security is the growing threat of water scarcity. Many of the predictions of impending water crises in China are based on analysis of agriculture in northern China or the problems of industrial depletion of groundwater. But are the threats real and, if so, do they apply to China as a whole or only to particular regions? What does the spatial pattern of water supply, demand and scarcity suggest for China's future development, both agriculturally and over all? To help answer these questions, the water accounts developed in the previous sections are combined here with additional data so as to provide a basis for analyzing spatial variability in China's water scarcity and it impact on agriculture. To perform the analysis, current water scarcity and abundance is assessed based on five indicators: the degree of development, the depletion fraction, the groundwater abstraction ratio and the crop production surplus or deficit. The degree of development and the grain production deficits or surpluses are the basis of an IWMI index of water and food scarcity (Seckler et al 1998, IWMI 2000). The three additional indicators are added to assess the severity of present water scarcity and linkages to agriculture production.

The **Degree of Development** is the ratio of primary water supply to PUWR. The higher the degree of development, less opportunities there are for capturing any remaining potentially utilizable water resources for future use. The **Groundwater Abstraction Ratio** is defined as the ratio of groundwater withdrawals to available groundwater supply. Available groundwater is the sum of natural groundwater recharge from precipitation and the groundwater recharge from the return flows[1]. The ratio suggests the degree of sustainability in groundwater use with high ratios indicating potentially unsustainable overdraft. The **Depletion Fraction** is the ratio of total

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[1] Groundwater recharge varies from 50 to 70 percents in the irrigation and the domestic sectors and 10 percent in industrial sector return flows.

depletion[2] (process and non-process evaporation and outflows to a sink) to primary water supply. The depletion fraction indicates the extent of water depleted from developed water resources at the basin scale and hence the opportunities for increased water utilization through additional recycling. The *crop production Surplus/Deficit* is defined as the ratio of value of total grain and non-grain crop production to value of total grain and non-grain crop demand (see appendix B for the methods of estimation). The ratio indicates the extent to which a basin meets its internal crop demand. This indicator creates a linkage between water availability, food production and food demand so as to suggest the sustainability of current agricultural practices at the basin scale. The data for each of indicators is shown in **Table 7**.

Table 7. Degree of development, Depletion fraction, groundwater abstraction ratio and food production surplus/deficit

Basins	Degree of development	Depletion fraction	Ground water abstraction ratio	Production deficit/ surplus-% of demand			Scarcity group
				Grains	Non-grains	All crop	
	%	%	%	%	%	%	
Huaihe	72	87	62	11	5	7	
Haihe	96	89	92	-18	19	12	
Yellow	64	86	63	7	-28	-21	
Songliaohe	44	84	57	42	-52	-34	
Northern Basins	63	87	67	10	-11	-7	
SouthEast	56	72	5	-33	-23	-25	
Pearl river	41	69	6	-34	-7	-12	
Yangtze	40	70	10	-2	-25	-21	
Southern Basins	41	70	8	-13	-21	-19	
Southwest	26	73	3	-2	-5	-5	
Inland	45	95	42	27	46	42	
Inland basins	39	90	36	15	24	22	
All basins	47	78	41	-1	-14	-12	

Source: Authors estimate using Podium China model (see www.iwmi.org for the model)

In summary,

- the degree of development is estimated to be about 47 percent for China overall and varies from 26 percent in the Southwest Basin to 96 percent in the Hai. The Northern and Southern basins are estimated to have developed about 63 and 41 percent of their utilizable water resources respectively.

- China's depleted fraction is estimated to be about 78 percent. Of particular note, 87 percent of the primary water supply in the Northern Region is estimated to be depleted, indicating little room for increased recycling.

- the groundwater abstraction ratio is estimated to be about 40 percent for all of China. However, most of the usage is in northern basins, where current demand for groundwater is estimated to be about two-third of total available groundwater supply. The high ratio in

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[2] Non-process depletion includes evaporation from swamps, bare surfaces etc of irrigation withdrawals (25% of return flows), flows to sink (5-10 percents of the return flows), evaporation from reservoir surfaces (15% of the reservoir capacity).

thenorthern basins suggests unsustainable use in at least some areas. The Haihe basin uses almost all of its available groundwater supply.

- China's crop production deficit in 2000 was 11 percent of total consumption. Much of the deficit is related to oil seeds and, in the southern region, vegetables. At the same time, the southern basins have substantial rice surpluses while the northern basins have substantial wheat and maize surpluses (Table 8).

Using the indicators, cluster analysis (see annex C for details) was performed to separate China's basins into four categories based on their water utilization outcomes and food supply and demand characteristics. The results are shown in figure 4 while brief descriptions of the four clusters and their member basins are given below.

Cluster1: Water scarce-Food deficit: Basins in this group have a relatively high degree of water development, high groundwater abstraction ratios, and high depletion ratios and along with substantial crop production deficits. Two northern basins, the Yellow and Songliao, fall in this group. Though the Songliao basin has substantial grain surpluses, both basins have large overall agricultural deficits due to non-grain crop sector. As future demand for urban and industrial water increases, there will be extreme pressure to cut water supplies to agriculture in both basins. Any reduction in water supply to agriculture will almost certainly increase the overall crop production deficits. Of particular concern, it will reduce the two basins' contributions to grain supply, especially for wheat and maize, elsewhere in China. At present, production surpluses of wheat in the Yellow River basin and of maize in both basins meets, respectively, 28 and 78 percent of the total wheat and maize production shortfalls in production deficit basins (Table 8).

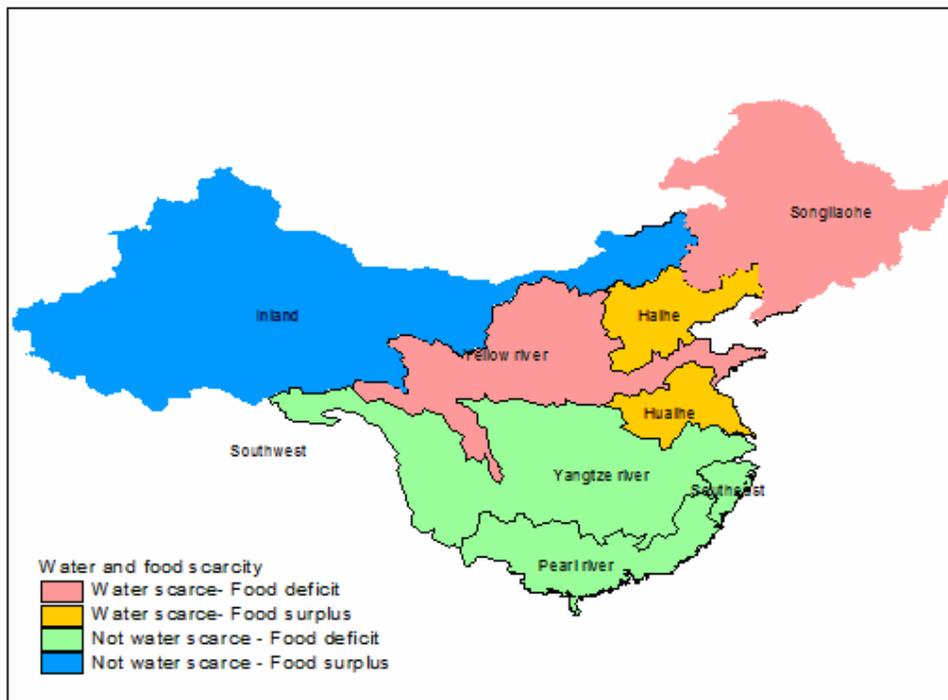**Figure 4.** Water Scarcity grouping

Table 8. Crop production surpluses or deficits

Basin	Paddy	Wheat	Maize	Other cereals	Pulses	Oil crops	Vegetables	Roots and tubers	Sugar	Fruits	Cotton
	mmt	mmt	mmt	mmt	mmt	mmt	mmt	mmt	mmt	mmt	mmt
Huaihe	-6.9	16.1	-1.6	-1.0	0.0	0.4	5.2	-0.2	-1.5	-2.8	0.4
Haihe	-17.7	7.3	4.0	-0.4	-0.1	-3.5	8.8	-2.5	-1.0	0.6	0.0
Yellow	-14.9	9.9	4.9	0.2	0.0	-0.9	-8.0	1.0	-0.9	-1.2	-0.1
Songliaohe	-0.1	-6.5	26.4	0.7	1.7	-4.3	-13.3	-1.8	-1.0	-5.9	-0.4
Northern Basins	-39.6	26.9	33.6	-0.5	1.6	-8.3	-7.3	-3.4	-4.4	-9.3	-0.2
SouthEast	3.5	-5.4	-6.4	-0.5	-0.1	-2.7	-4.9	0.3	-0.4	1.8	-0.2
Pearl river	5.9	-11.9	-10.0	-1.4	-0.3	-5.0	-4.9	-0.5	4.8	3.2	-0.6
Yangtze	34.2	-16.3	-21.9	-0.7	-0.6	-5.6	-27.5	3.6	-2.2	-3.9	-0.6
Southern Basins	43.6	-33.6	-38.3	-2.6	-1.1	-13.3	-37.3	3.4	2.3	1.0	-1.4
Southwest	0.8	-0.7	0.1	0.5	0.0	-0.8	-2.5	-0.5	1.3	3.0	-0.1
Inland	-3.4	3.8	2.1	0.2	0.0	0.2	-1.5	-0.1	-0.2	4.8	1.4
Inland basins	-2.6	3.1	2.2	0.7	-0.1	-0.6	-4.0	-0.6	1.1	7.8	1.4
All basins	1.3	-3.7	-2.4	-2.4	0.5	-22.2	-48.5	-0.6	-1.1	-0.5	-0.3

Source: Authors estimation using data of PODIUM China (2004) model

Cluster 2: Water scarce-Food surplus: Basins in this group show high degrees of water scarcity as reflected in degree of development, depletion fraction and abstraction ratios, but nonetheless are agricultural surplus regions. Two northern basins, the Huaihe and Haihe, which together contain 26 percent of China's total population but only 5 percent of the water resources, fall in this group. Both basins have few opportunities for increased recycling and both also exhibit un-sustainable groundwater use. Nonetheless, the two basins together account for 57 percent of the wheat and 22 percent of the vegetable shortfall in production deficit basins. As with the previous cluster, the non-agricultural sector will increasingly compete for water supplies, placing increased pressure on the basins' ability to continuing supplying food to the rest of the country. In addition, there are clear signs that continued use of water even at present levels may not be sustainable.

Cluster 3: Not water scarce-Food deficit: All of the southern basins as well as the Southwest basin fall in this cluster. Together these basins contain 54 percent of the total population and 77 percent of the total water resources. While each of the basins has adequate water resources for food production, other factors hold food production below demand. In particular, while the basins do have sufficient paddy surpluses to meet deficits in northern basins, for most other crops including wheat, maize, pulses, oil crops, and vegetables they are dependent on supplies from Northern basins or imports. The production deficits in these basins account for a large share of China's total production deficits and hence agricultural imports. It is these basins which may be may be affected most if food surpluses in the north decline.

Cluster 4: Not water scarce-Food surplus: Only the inland basin falls into this cluster. As the basin has a small agricultural sector (producing 3 percent of total grains) and population (2 percent of China's total), its plays a relatively minor role in China's overall food production and water picture.

The basic conclusions of this analysis give new insights into the relationship between water scarcity food production surplus and deficit across China. In particular, it is important to look at the pattern, or lack thereof, revealed in the cluster analysis. The clusters show that water scarcity does not seem to be a major indicator of food surplus or deficit at the basin scale. Some water deficit areas have crop production surpluses while some water surplus areas have crop production deficits. This finding brings up a number of important questions related to our understanding of China's agricultural future. It suggests that water is not now the primary factor in driving China's internal, and hence external, agricultural trade. For external trade, this finding is consistent with the recent work of De Fraiture (2004) who found little connection between water scarcities, bilateral trade patterns or agricultural trade policy. As such, it also suggests that our understanding of both the constraints to agricultural production and the value of "scarcity" measures may be insufficient.

At the same time, the findings also seem to indicate that there is impending water related constraints for China's food production system which, if not remedied, will increasingly require China to look to the international market for food supplies. The key issue for the future is whether the water scarce northern basins will be able to continue being major food suppliers to the rest of the nation. In particular in the Yellow, Hai and Huai basins, water supplies are already essentially fully allocated, and there is a general perception (codified in China's 2002 Water Law) that future domestic and industrial demand should take precedence of agriculture. At the same time, at least some of the agricultural production in these basins is already based on unsustainable abstraction of groundwater, placing additional concerns on the viability of future production.

7.   Major Issues for China's Water and Agricultural Future

In trying to understand whether or not the northern basins can continue their status as surplus agricultural producers, whether the southern basins can themselves increase agricultural production, or whether China will be forced in the future to rely more on the world food market with all that implies for global agricultural conditions, there are a number of key variables which must be considered. In this final section, some these variables are presented, not with the purpose of projecting particular outcomes, but rather to provide a basis from which discussions of China's alternative water can place. First we discuss four basic variables which directly or indirectly impact on domestic, industrial and irrigation water demand and can be con be considered as consumption factors.

(a)   Consumption Factors

Population Growth A primary driver of change in China's direct and indirect water demand will be change in population. China's population growth rate has fallen rapidly over the past 30 years, from 2.4 percent in the early 1970's to 0.9 percent in late 1990's, due to a combination of policy and changing family preferences. China's population growth is expected to further decline and perhaps stabilize by 2040 according to the U.N.'s medium growth scenario (UN 1998, CNBS 1999). However, China will have an additional 200 million people by that time. Based on current agricultural water requirements (143 m^3/capita/year), these additional people would consume 28 billion cubic meters of water per year, a 16 percent increase from current levels.

Figure 5. Total and Urban Population projections
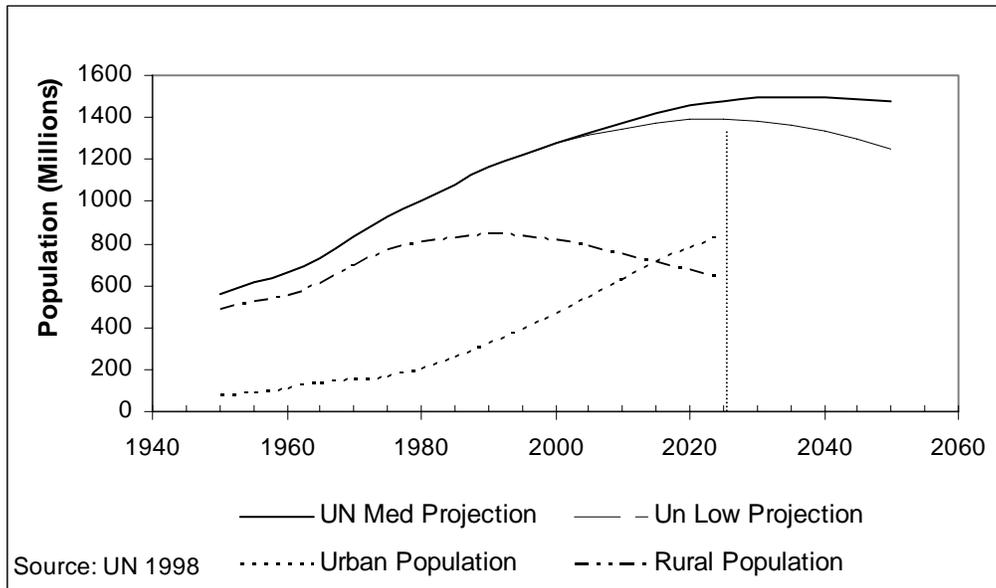
Urbanization While population will be the primary factor driving overall water demand, urbanization of that population will also be important. China has had some of the world's fastest growing cities over the past few decades, and China's urban population is expected to continue expanding, perhaps doubling from present levels by 2025 (Figure 5). Urban domestic water use is twice as high as rural and so the shift in population, coupled with increasing per capita use in both the urban and rural sectors (Quan and Zhang 2000), could increase domestic water demand by more than 50 percent over the next 25 years. However, it must be remembered that depletion rates for domestic water use can be relatively low and so the net effect on total water availability will depend on how domestic waste water is recycled.

Income growth Income growth influences agricultural water demand in two important ways. First, expanding income provides a means for increasing food expenditures. Second, income growth is associated with changing dietary composition, in particular a shift away from direct grain consumption and towards meats. As shown in Table 9, China's per capita food consumption increased dramatically after economic reforms, and per capita economic growth, began in the late 1970s. At the same time, dietary composition shifted away from grains and towards meats and other products. The increased food production to meet rising consumption levels obviously increases agricultural water use. Also important, the shift towards meat actually increases the rate at which additional water must be used to meet a given level of demand, due to the caloric cost of converting grains to meet (grain to meet conversion rations are between 2 and 7 to 1 depending on animal type and production process). In China's case, between 1985 and 2000, feed grain demand increased by almost 300 percent from 81 million metric tons to 220 million metric tons. A key question for China's agricultural water future will be not only how much income will continue to grow, but how the correlation of income growth with both increased food demand in general and increased meat demand in particular will change as China reaches even higher consumption levels.

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Table 9. Daily calorie supply per person

Year	Total calorie supply	Distribution - % of total			
		Grains	Animal products	Oil crops, vegetables & Fruits	Other crop products
	Ca/day/person	%	%	%	%
1965	1,956	85	6	7	2
1975	2,071	84	6	7	3
1985	2,621	78	9	9	4
1995	2,861	65	16	13	6
2000	2,974	60	20	16	4

Source: FAO 2003

Economic structure Part of the increase in China's per capita income stems from the rapid shift in China's economic base from agriculture to industry. Industry (including the service sector) now makes up 81 percent of the total economy. Along with industrial growth has come an increase in industrial water demand. Since the early 1990s, industrial water demand has grown at an annual rate of some 6 percent. If the same pattern holds, industrial water use will increase four fold by 2025. As is the case with domestic use, however, industrial water use tends to have low depletion rates. As such, much of the water used in industrial output can be recycled for other uses if appropriate technologies are applied.

(b)   Production Factors

Agriculture sector is by far the highest water user at present. Irrigation contributes to about 70 percent of the grain production. Contribution to growth of crop yield and cropping intensity in the past were significant. Agriculture water demand in the future depends on the extent of yield growth both in irrigation and rainfed, and increase in cropping intensity. We discuss these briefly here.

Cropping Intensity: While arable crop lands have decreased from 99 to 94 million hectares between 1980 to 2000, net irrigated area or area equipped for irrigation has increased from 45 to 53 million hectares. The overall cropping intensity in the arable crop area over the same period has increased from 151 percent to 175 percent. The increase in irrigation was the main contributor to cropping intensity increase. Following the methodology in Amarasinghe et al (2005), It is estimated that increase in irrigation has contributed to about 80 percent of the overall cropping intensity increase in China over the last two decades.

Crop yield: The exact association of the growth of irrigation with the growth of crop productivity in China is not clear For example, while irrigated area increased by 27 percent over the last two decades, the grains yields increased by over 70 percent. Though several inputs other than irrigation have contributed to the growth in crop yield, many argue that the contribution from other inputs such as high yielding varieties would not have been realized with out irrigation. Thus irrigation is an important factor growth in crop yield.

The contributions of irrigation to the growth of irrigation intensity and yield were very important factors for projecting future food demand. This is increasingly important due to the fact that the total growth in irrigated area is projected to decline from about 27 percent in the period from 1980 to 2000 to only about 9 percent in the period from 2000 to 2025.

Groundwater irrigation: Groundwater irrigation has a positive influence in increasing crop yield through reliable water supply and has positive influence in reducing water demand through higher application efficiencies. Growth in groundwater irrigation (figure 6), mainly in Northern China is a key factor in both these aspects. However, groundwater tables in northern China are falling 1 to 3 meters per year (Shah et al. 1999) and sustainability of the present pattern of water use is a key issue. Therefore, the extent of groundwater use in the future is a key factor in determining future water demand.

Figure 6. Tubewell development in China
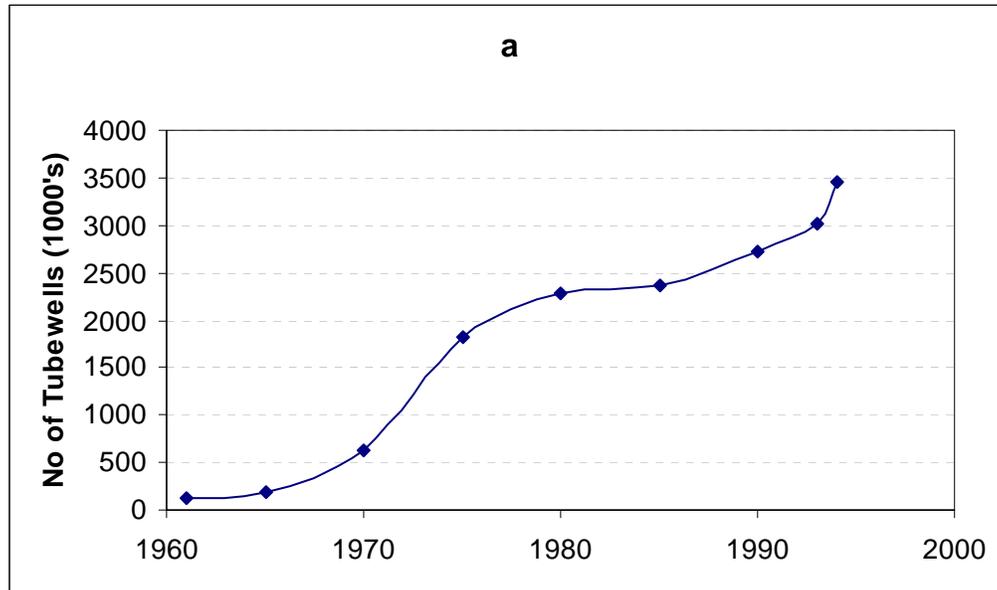
Rainfed agriculture: Though the total arable area is only 94 million ha, according to other statistics this is an underestimate (FAO 2001). The arable area estimate of FAO is 124 million ha. In either case there is a substantial rainfed crop area at present (44% or 57% of the arable area according to China Statistics or FAOSTAT respectively). The crop yields estimates of rainfed area are only 63 percent of the yields of irrigated areas. Improvement of rainfed yields by at least one ton/ha would have significant positive contribution to future food supply. This would reduce the target food production from the irrigated areas and hence irrigation demand. Therefore potential yield improvements in rainfed agriculture would be a key factor in estimating future irrigation requirements. Not necessarily in irrigation requirements, but in how much China would have to import.

Changes in cropping patterns: Increasing water stress conditions in the northern basins, inadequate forage crops for livestock feed and increasing international trade with the China's participation in the World Trade Organization influence China to make significant changes in overall cropping patterns. The future agriculture plan envisages a change of 40%, 30% and 30% respectively of grain to economic to forage crop areas at present to 30%, 30% and 40% of grain to economic crops to forage crops by 2025 (Quan Z and Zhang G. 2000). These changes will have a significant impact on the future food production and irrigation water requirements.

Irrigation Efficiency: The estimate of overall project irrigation efficiency, i.e., the ratio of crop water requirement to irrigation withdrawals, is 47 percent. Increasing water use efficiency to keep water future irrigation withdrawals at present level is a major thrust of the China's water conserveryancy policy. Past trend show increasing efficiency of water use. For example, between 1950 and 1980, net irrigated area of China has more than doubled and the irrigation withdrawal has increased more than three times. Since 1980 irrigated withdrawals remains more or less same but the net and gross irrigated area increased (15 and 35 percents respectively). At present more area was irrigated from the same available irrigation water supply than in the past indicating improving irrigation efficiency. But most of the river basins, especially in the north are operating at high basin efficiency level. Thus how much more increase in water use efficiency at field scale can be achieved is not clear. This is crucial issue in determining future water requirement.

(c)   Changing Environmental Values and Practices

Outsiders often maintain an idealized vision the interrelationship between China's people and her environment in which harmony is maintained. At present, nothing could be further from the truth. Environmental degradation in China, whether related to land, air or water resources, can be as severe as anywhere. However, perhaps in part because of the severity of the problem and in part because of growing incomes, there is an increasing recognition of the costs of environmental destruction and efforts have been launched to reverse the decline. Within this changing framework, two areas are especially important with regards to China's water future: recognition of the need to maintain environmental river flows and efforts to control water pollution. While little research has been placed on these factors as related to agricultural outcomes, it is possible that the trajectory of China's environmental policy may in the end be one of the biggest factors in shaping the future of her agricultural water availability.

Environmental Flow: Environmental water requirements are receiving increasing attention in China (Naiman et al, 2002) as elsewhere. However, exact environmental water needs have yet to be defined, environmental needs are not included in water statistics, and Chinese definitions differ from the rest of the world (Zhu et al. 2004). Table 10 provides two sets of estimates from Chinese (Quan Z. and Zhang G., 2000) and outside sources (Smakhtin et al, 2003) of what environmental water needs might be. The Chinese estimates are based on such factors as erosion control, afforestation, sediment flushing, and groundwater recharge while the other is based on minimum environmental flow requirements. Using either set of estimates, it would appear that environmental flow requirements could be met with the un-utilizable portion of total water resources at basin and national scales. However, the average annual figures in the table mask the significant variation in both requirements and available supplies which can occur both within and between years. In fact it appears that in some cases, especially in north China, environment "requirements", if ever met, could have a more significant impact on future agricultural water availability than any of the other factors discussed here.

Pollutions creation, Pollution control While addressing one of China's environmental issues- meeting environmental flow requirements -might reduce future water supplies for direct human use, addressing another might increase supplies. China's rivers are notoriously polluted. Chinese statistics show while pollution does not directly consume water, it does reduce effective supplies and limit options for water use. In the Yellow River, considered China's second most polluted, some 16% of the water by reach is too polluted for anything but industrial use while 25% is too polluted for any use at all. In the Yangtze, the Jiangsu Provincial Water Bureau has cited pollution as the number one issue in basin management (Authors' interview). One major

question for the future will be the degree to which pollution control efforts will be able to in effect create new water supplies by providing cleaner, more usable water.

Table 10. Environmental water requirements estimates

River Basin	Environmental water requirement		Un-utilizable water resources Km^3
	Estimate 1[a] Km^3	Estimate 2[a] Km^3	
Huaihe	10.0	23.7	33.0
Haihe	9.3	8.2	19.0
Yellow	22.9	20.2	29.0
Songliaohe	-	33.0	100.0
Inland	41.5	26.0	80.0
Northern Basins	85.0[b]	111.1	261
SouthEast	-	76.0	208
Pearl river	-	139.0	345
SouthWest	-	173.3	557
Yangtze	-	286.0	603
Southern Basins	-	785.4	1713
All Basins	-	896.5	1974

A – Estimate 1 is based on Quan Z. and Zhang G., 2000 and the estimate 2 is based on Smahktin et al 2003.
b – Includes 1.3 km^3 as requirements for aquifer replenishments.
Sources: Quan Z. and Zhang 2000, Smakhtin V., 2003, PODIUM China 2003

8.   Conclusion

This paper used a basin approach to highlight spatial variation in water supply, demand and scarcity in China. Results clearly indicated major differences between northern and southern regions with northern basins water stressed and those in the south still water abundant. The results also showed that basin level food production surpluses and deficits at present were not well correlated with water stress levels. In the water stressed north, the Songliaohe and Yellow River basins have overall food deficits but the Huai and Hai basins are both food exporters. At the same time, the southern basins, with their high levels of water availability, are all in overall food deficit. This finding clearly highlights the need to apply caution in using water scarcity or water stress indicators to predict agricultural outcomes.

At the same time, however, the results also highlight warning signs for the future of China's food self-sufficiency. It is the northern basins which have the main agricultural surpluses within China and it is also those basins which appear to be near or, in some cases, beyond the limits of sustainable agricultural water use. Furthermore, it is almost certain that industrial and domestic water demand in those same basins will continue to grow at rapid rates and that such growth will require a reallocation of water away from agriculture, almost necessarily reducing food surpluses which could have been used to meet deficits elsewhere. Changes taking place in China's food consumption economy are also set to exacerbate the problems. Income growth will continue to shift food demand towards flour and meat based products and away from rice. Unfortunately, it is the water stressed northern basins which must serve as the base for the production of the additional wheat and feed grains necessary to meet this demand while demand for rice output in the water abundant south will decline, at least in relative terms.

Of course, the actual path which China's water and agricultural future takes will depend on the outcome of key variables including population and income growth, changes in the domestic and industrial sectors, and changes in attitudes and policies towards the environment. While many of these factors have been discussed elsewhere, what has been less emphasized is that it is not only the national rates of change in these variables which will drive future water outcomes but also how the factors vary across space and in particular by basin. In fact, taking such variation into account will be critical in understanding how China's agricultural future may develop. At the same time, it must be remembered that caution must be used in drawing conclusions about China's future agriculture and the potential role of China in world food markets based on projections of any variables. There has been no shortage of prognosticators claiming that the end of China's ability to feed itself is just around the corner. Analysis of the warning signs is prudent. Extrapolation has proven dangerous.

(a) *Estimating Irrigation Water Demand*

First we estimate irrigation water requirement. The irrigation water requirement of a basin depends on several factors including cropping patterns, crop-growth periods, crop coefficients (kc), potential evapotranspiration (Et^P), effective rainfall and percolation in paddy areas. Crop- water requirement (CWR) of the paddy crop is estimated as

$$CWR^{Paddy} = Paddy\ Area \times \left(\sum_{j \in Growthperiod} (kc_j^{paddy} \times Et_j^P - Effective\ rain\ fall_j) + deep\ percolation \right)$$

and the crop-water requirement of other crops is estimated as

$$CWR^{other\ crops} = \sum_{i \in other\ crops} Area_i \left(\sum_{j \in Growth\ periods} \left(kc_j^i Et_j^P - Effective\ rain\ fall_j \right) \right)$$

Total irrigation water demand of a basin is estimated as

$$ID^{all\ crops} = (CWR^{Paddy} + CWR^{Other\ crops}) * (1 - GWI\%) / IE^{Surfacewater}$$
$$+ (CWR^{Othercrops}) * GWI\% / IE^{Groundwater}$$

(b) *Estimating the Total Grain and Non-grain Crop Production and Demand*

The grain crops in the analysis include paddy, wheat, maize, and other cereals (millet, sorghum, barley. etc.), pulses and dry equivalent roots and tubers. Non-grain crops include six crop categories: roots and tubers, oil crops, fruits, sugar crop, vegetables and cotton.

Our method of aggregating production and demand of different crop categories is to value them in terms of export unit prices. We use the world's average unit export prices of different crop categories to aggregate the demand and production of different crop categories. We acknowledge here the fact that the World's average unit export prices are different from the export prices of China and also the fact that the export prices may differ between river basins. However, in this estimation, we ignore these differences as unit export price here is only used as a mean of observing the relative difference of value of the different crops for aggregating the demand and production.

First, we define

p_{ijk}- World's export prices of the jth crop or crop product in i^{th} crop category in the kth year
e_{ijk}- World's export quantity of the jth crop in i^{th} crop category in the kth year
P_{ik}- World's production of the ith crop category in the kth year
D_{ik}- World's demand of the ith crop category in the kth year (demand includes food demand, feed demand, and seeds, waste and other uses)

In deed, we observe that there is a difference of export prices of China with that of the average world prices and also crop

The 3-year weighted average export price of the of the ith crop category is defined as:

$$p_i = \frac{1}{3} \sum_{k=1999}^{2001} \frac{\displaystyle\sum_{j=all\,crops\,in\,crop\,or\,cropproducts\,in\,i^{th}crop\,category} e_{ijk} \times p_{ijk}}{\displaystyle\sum_{j=all\,crops\,in\,crop\,or\,cropproducts\,in\,i^{th}crop\,category} e_{jkc}}$$

The total value of grain production P^{Grains} or grain demand (D^{Grains}) in 2000 are defined as:

$$P_{2000}^{Grains} = \sum_{i=1}^{6} p_i \times \frac{1}{3} \sum_{k=1999}^{2001} P_{ik} \quad and \quad D_{2000}^{Grains} = \sum_{i=1}^{6} p_i \times \frac{1}{3} \sum_{k=1999}^{2001} D_{ik}$$

$$j = 1(= rice),\, 2(= wheat),\, 3(= maize),\, 4(= other\ cereals),\, 5(= Pulses),\, 6(= Roots\ \&\ tubers)$$

The total value of non-grain crop production and non-grain crop demand in 2000 are defined as:

$$P_{2000}^{Non-Grains} = \sum_{i=1}^{5} p_i \times \frac{1}{3} \sum_{k=1999}^{2000} P_{ik} \quad and \quad D_{1995}^{Non-Grains} = \sum_{i=1}^{5} p_i \times \frac{1}{3} \sum_{k=1999}^{2000} D_{ik}$$

$$j = 1(= Oilcrops),\, 2(= Vegetables),\, 3(= Sugar\ crops),\, 4(= Fruits),\, 5(= Cotton)$$

(c)   Estimating the contribution of Irrigation to Cropping Intensity growth

The decomposition of cropping intensity into different factors is shown below. First, we define

CI – Overall cropping intensity
NSA – net sown area
NIA – net irrigated area
CI^I - Cropping intensity in irrigated area
CI^R – Cropping intensity in rain-fed area
Then the gross sown area at time t_0 can be written as
$CI_{t_0} \times NSA_{t_0} = NIA_{t_0} \times CI_{t_0}{}^I + (NSA_{t_0} - NIA_{t_0}) \times CI_{t_0}{}^R$.

The gross sown area at time t= $t_0 + \Delta t$ can be written as

$$(CI_{t_o} + \Delta CI) \times (NSA_{t_0} + \Delta NSA) = (NIA_{t_0} + \Delta NIA_{t_0}) \times (CI_{t_0}{}^I + \Delta CI^I) +$$

$$((NSA_{t_0} + \Delta NSA) - (NIA_{t_0} + \Delta NIA)) \times (CI_{t_0}{}^R + \Delta CI^R)$$

By subtracting the first equation by the second we get

$$\Delta CI \times (NSA_{t_0} + \Delta NSA) + CI_{t_0} \times \Delta NSA = CI_{t_0} \times \Delta NIA + NIA_{t_0} \times \Delta CI^I + \Delta CI^I \Delta NIA +$$
$$(NSA_{t_0} - NIA_{t_0}) \times \Delta CI^R + CI_{t_0}^R \times \Delta NSA + (\Delta NSA - \Delta NIA) \times \Delta CI^R$$

This can be further simplified to

$$\Delta CI \times (NSA_{t_0} + \Delta NSA) = (CI_{t_0})\Delta NIA + (NIA_{t_0}) \times \Delta CI^I + \Delta CI^I \Delta NIA +$$
$$(NSA_{t_0} - NIA_{t_0}) \times \Delta CI^R - (CI_{t_0} - CI_{t_0}^R) \times \Delta NSA + (\Delta NSA - \Delta NIA) \times \Delta CI^R$$

The six components in the right-hand side can be interpreted respectively as the

1. Positive contribution due to changes in net irrigated area expansion only.
2. Positive contribution due to growth in irrigation intensity only.
3. Positive contribution due to increase in both irrigation intensity increase and net irrigated area expansion.
4. Positive contribution due to intensity increase only in the existing rain-fed area.
5. Negative contribution from expanding net sown area with existing rain-fed cropping intensity.
6. Positive/negative contribution from converting rain-fed area into irrigation had there been only rain-fed intensity increase (a negative contribution could occur if the rain-fed cropping intensity at time $t + \Delta t$ is still less than the average cropping intensity at time t).

Literature Cited

Brown, L. R. 1995. Who will feed China?: Wake-up call for a small planet. (The Worldwatch environmental alert series), New York, NY, USA: W. W. Norton & Co.

Brown, L. R. 2001. How water scarcity will shape the new century. In Stockholm International Water Institute (SIWI), Water security for the 21st century - Innovative approaches: Proceedings of the 10th Stockholm Water Symposium, held in Stockholm, Sweden, 14-17 August, 2000. Stockholm, Sweden: SIWI.

FAO (Food and Agriculture Organization) 2001. The state of food and agriculture 2001. Rome, Italy: FAO

FAO (Food and Agriculture Organization) 2003a. Review of world water resources by country. (FAO water reports 23). Rome, Italy: FAO. xiii, 110p.

FAO (Food and Agriculture Organization) 2003b. FAOSTAT Statistical Database. www.fao.org. Rome, Italy: FAO.

Huang, J.; Rozelle, S.; Rosegrant, M. W. 1997. China's food economy to the twenty-first century: Supply, demand, and trade. (Food, agriculture, and the environment discussion paper 19), Washington,DC, USA: International Food Policy Research Institute.

ICID (international Commission of Irrigation and Drainage) 2002. Country Policy Support Studies, Inception Report.

IWMI (International Water management Institute). 2000. *World water supply and demand 1995 to 2025.* Draft report prepared for World water vision. Colombo, Sri Lanka: International Water Management Institute

IWMI (international Water Management Institute) 2004. China PODIUM model, www.iwmi.org, Colombo, Sri Lanka: International Water Management Institute.

Changmin, L., and Zhikai, C. 2001. CNBS (China's National Bureau of Statistics) 1999, China Statistical Year Book 1999. People's Republic of China: China Statistics Press

Quan Zang 2000, Rosegrant, M. W.; Cai, X.; Cline, S. A. 2002. *World water and food to 2025: Dealing with scarcity.* Washington, D. C., USA: International Food Policy Research Institute.

Seckler, D.; Amarasinghe, Upali A.; Molden, David; de Silva, Radhika; Barker, Randoloph. 1998. *World water supply and demand, 1995-2025*. IWMI Research Report 19. Colombo, Sri Lanka: International Water management Institute.

Shah, T.; Molden, D.; Sakthivadivel, R.; Seckler, D. 2000. The global groundwater situation: Overview of opportunities and challenges. Colombo, Sri Lanka: IIMI

Smakhtin, V.; Revenga, C.; Doll, P. 2003. Environmental water requirements and global water availability. Colombo, Sri Lanka: International Water Management Institute, Sri Lanka (In Draft).

Yongsong, Liao 2003. PhD Thesis (in Chinese).

Wang, R.; Ren, H.; Ouyang, Z. (Eds.) 2000. China water vision: The eco-sphere of water, life, environment and development. Beijing, China: China Meteorological Press.

United Nations (UN) 1999, Long-range world population projections: based on the 1998, New York, USA: UN Department of Economic and Social Information for Policy Analysis

Xuetao, S., Zhengying, Q., Bingnan, L. and Wenzheng Z. 2002. Comprehensive Report of Strategy on Water Resources for China's Sustainable Development for the Consultative project to the State Council by the Chinese Academy of Engineering (English translation), China: www.waterpub.com.cn

Zezhen, Z.; Bingxin, C,; Zhikai, C.; Xinyi, X. 1992. Challenges to and opportunities for   development   of China's water resources in the 21st century. Water International, 17(1):21-27

Zhu, Zhongping; Giordano, M.; Cai, X.; Molden, D. 2003.

Zhu, Zhongping; Giordano, M.; Cai, X.; Molden, D. 2004. The Yellow River Basin: Water accounting, water accounts and current issues. Water International (Forthcoming)

Zhengying, Q. 1994. Water Resources Development in China. Beijing, China: China Water and Power Press.