Can China Feed Itself?

An Analysis of China's Food Prospects with Special Reference to Water Resources

Gerhard K. Heilig
Günther Fischer
Harrij van Velthuizen

RR-01-06
April 2001

Reprinted from *The International Journal of Sustainable Development and World Ecology*, **7** (2000) 153–172.

International Institute for Applied Systems Analysis • Schlossplatz 1 • A-2361 Laxenburg • Austria
Tel: (+43 2236) 807 • Fax: (+43 2236) 71313 • E-mail: publications@iiasa.ac.at • Web: www.iiasa.ac.at

Reprinted with permission from *The International Journal of Sustainable Development and World Ecology*, **7** (2000) 153–172.

Int. J. Sustain. Dev. World Ecol. 7 (2000) 153–172

Can China feed itself?

An analysis of China's food prospects with special reference to water resources

Gerhard K. Heilig, Gunther Fischer and Harrij van Velthuizen

International Institute for Applied Systems Analysis, Laxenburg, Austria

Key words: China, development, agriculture, water

SUMMARY

Water is certainly an important factor in China's food security. Some authors have argued that up to 70% of the country's grain production depends on irrigation. Since the water resources for agriculture in northern China are getting increasingly exhausted and diverted to urban and industrial consumption, they have published grim predictions of food shortages. The following analysis uses a detailed agro-climatic model to estimate China's maximum grain production potential under rain-fed and irrigated conditions. It shows that far less than 70% of China's grain production critically depends on irrigation. Large areas in the south and some areas in the north-east can produce substantial amounts of grain using only natural precipitation. According to our model, some 492 million tons of grain can be produced at current technology without additional irrigation. However, depending on diet, this may still not be enough for China's grain demand in 2025, which was estimated at up to 650 million tons. Only with additional irrigation would China be able to produce these amounts of grain. According to our model, the country has a grain production potential of some 672 million tons, if irrigation is available in those areas, that do not have enough precipitation for rain-fed cultivation. Water conservation in irrigation and the development of water resources for agriculture is therefore critical for China's food security.

INTRODUCTION

There can be no doubt that water is an important issue in China's development process. All major sectors will have increasing demands: industry, the service sector, residential areas, and certainly agriculture. However, before we analyze the specific problems of water use in China's agriculture, one observation should be emphasized: in its long history, this civilization had been confronted with water shortages for centuries. Hence, the Chinese developed one of the most sophisticated systems of irrigation long ago. Already during the early Han Dynasty, in the fourth and third century BC, they started systematic land reclamation and irrigation schemes, converting large areas of natural land into rice paddies (Fang and Xie, 1994). The process, which was systematically planned and coordinated by subsequent dynastic bureaucracies, reached a first climax in the eleventh and twelfth centuries (Braudel, 1990). While past success in water management is certainly no guarantee for the future, it still suggests a deep cultural experience with this resource. This accu-

An abbreviated version of this paper was presented at the Second World Water Forum & Ministerial Conference 17-22 March, The Hague, The Netherlands. The session on 'China Water Vision – Meeting the water challenge of rapid transition in China' was coordinated by Frank Rijsberman and Rusong Wang

Correspondence: G.K. Heilig, International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria. e-mail: heilig@iiasa.ac.at

mulated knowledge in large groups of China's (agricultural) population – transformed into institutions and traditions – is a good starting point to master the challenges of the future. There is no need for nervous pessimism or blunt doomsday scenarios.

What are the core problems?

While various authors have emphasized different aspects of China's water problems, most experts would probably agree that each analysis must take into account at least the following dimensions:

(1) The highly **uneven spatial distribution** of China's freshwater resources.

(2) The strong **seasonality** in precipitation and – consequently – river flows.

(3) The increasing **discharge of untreated wastewater** from industry and urban areas.

(4) The **insufficient capacity** of urban water supply systems as compared to the rapidly increasing demand.

(5) The **low efficiency of traditional irrigation systems** based on open canals and field flooding, if compared with high-tech irrigation schemes.

(6) The lack of adequate **pricing mechanisms** that would signal scarcity to the water consumers.

(7) The **institutional and political frictions** between various administrative levels, concerning planning, financing, construction and maintenance of water-related infrastructure.

(8) The **conflicts between different types of water use,** such as hydropower generation, freshwater supply, extraction and discharge of industrial process water, irrigation in agriculture, fishery and river transport.

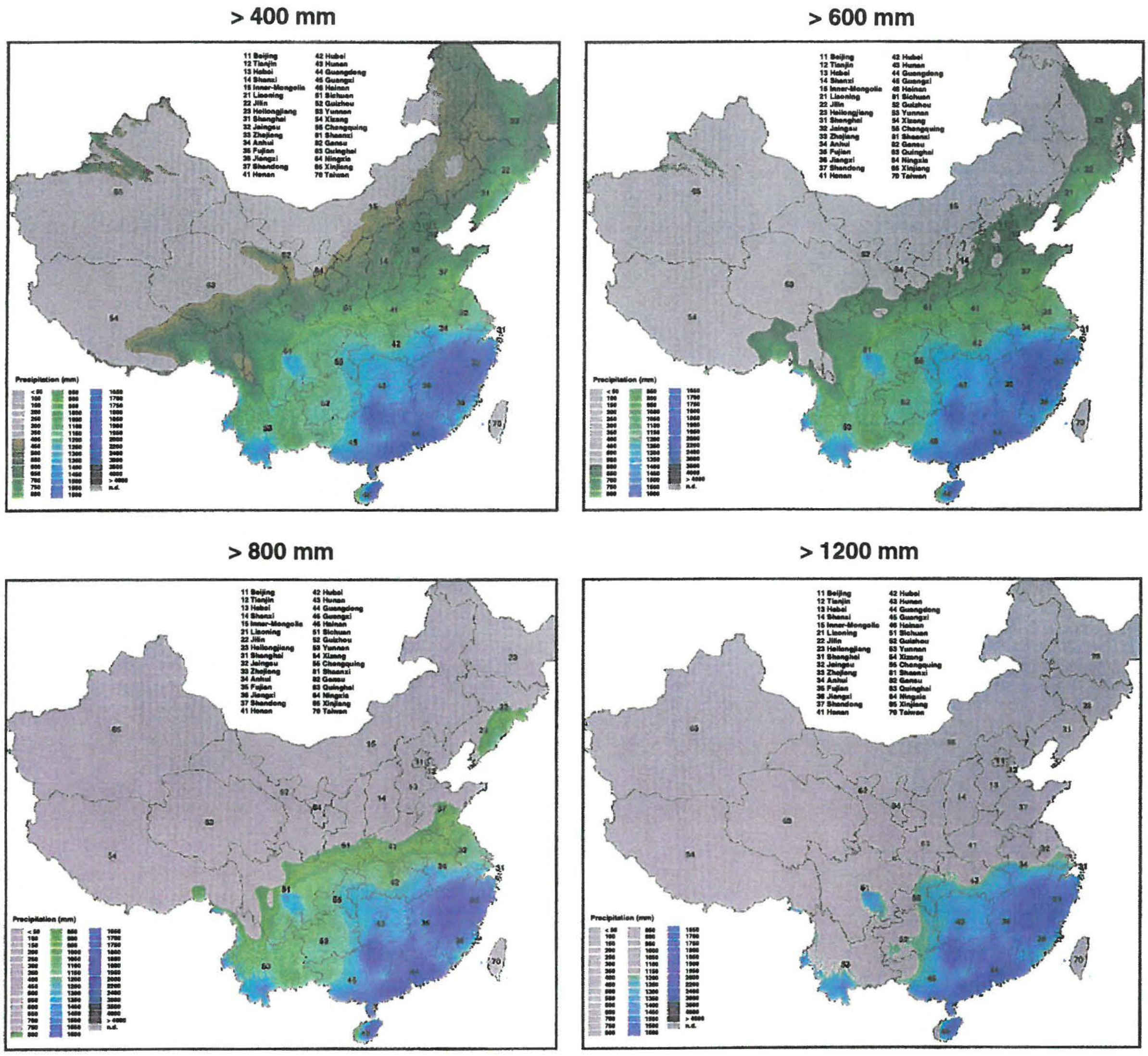
These water problems have already led to a number of secondary effects that clearly are a reason of great concern:

- Large amounts of groundwater extraction (particularly for irrigation and municipal use in the northern part of the North China plain) have caused the groundwater table to fall and might lead to an aridification of the topsoil.
- There is serious ecosystem deterioration in those watersheds and coastal areas, where industrial pollution has been increasing rapidly in recent years. This affects not only the biodiversity in these areas, but threatens the fishing and/or tourist industry and the farmers who need irrigation water downstream.
- The construction of dams and reservoirs for irrigation, municipal use, and industry and for hydropower generation is affected by very serious siltation problems – particularly along the Middle Reach of the Yellow River. Reservoir siltation not only reduces the storage capacity (and thus the amount of possible water withdrawal), but also affects turbines and other power-generating equipment. And it clogs up irrigation infrastructure (Brismar, 1998).
- Dams and dykes in China, which are essential for the water infrastructure, are frequently in poor condition. Up to one third of all dams are potentially dangerous and need better maintenance. On March 23, 1999 *China Daily* reported that almost 33 000 smaller and medium-sized dams would need repairs, which would require an investment of about US$3.6 billion. A deteriorating water infrastructure has seriously increased the risk of flooding in China (which is already quite high from natural causes). Natural conditions, such as the siltation of the Yellow River, amplify these problems: there is an ongoing battle to increase the height of the dams, as the Yellow River is constantly raising its bed by sediment deposition (in some places it is some 8 m above the surrounding area).

There are, of course, many other specific consequences of water problems in the country, but now we would like to focus on the situation in agriculture.

ANALYSIS OF WATER PROBLEMS IN AGRICULTURE

Climate factors, particularly precipitation, are critical for China's agriculture. Rainfall is very

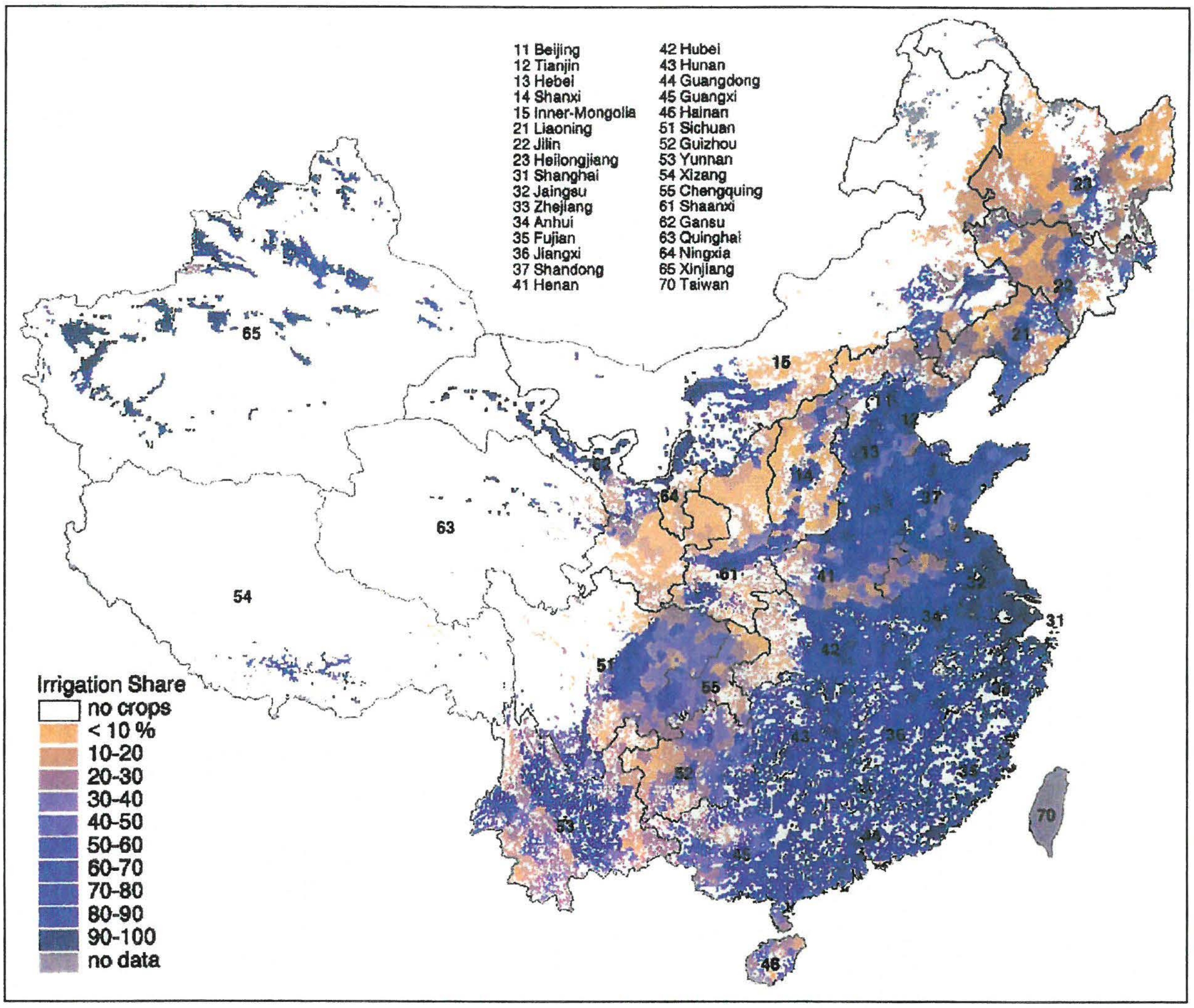


Map 1 Average annual precipitation in China, 1958–1988 (selected precipitation ranges)

Primary data sources: Leemans and Cramer (1991); IIASA database for mean monthly values of temperature, precipitation and cloudiness on a global terrestrial grid, IIASA Report, RR-91-18, Laxenburg, 63 pp.; Inst. of Soil Science, Academia Sinica (1986). The Soil Atlas of China, Cartographic Publishing House, Beijing, p. 6

Map Projection Details: Projection: LAMBERT_AZIMUTHAL, Datum: NONE, Units: METERS, Spheroid: DEFINED, Major Axis: 6370997.00000, Minor Axis: 0.00000; Parameters: radius of the sphere of reference: 6370997.00000, longitude of centre of projection: 105 0 0.00, latitude of center of projection: 44 0 0.000, false easting (meters): 0.00000, false northing (meters): 0.00000

unevenly distributed within the country: there is more than enough in the southeast and almost none in the West. The Xi Jiang (Pearl River) basin and delta have the highest precipitation levels in mainland China with more than 2000 mm per year. Very high precipitation can be also found in Guangdong province (see Map 1). From high precipitation in the coastal provinces of the southeast, rainfall gradually declines toward the northwest. An area of moderate precipitation stretches from Yunnan in the south through the North China plain to the northeastern province of Heilongjiang. Most of Xinjiang and Gansu provinces and most parts of Inner Mongolia, Tibet, and Qinghai in the centre are extremely dry. Average precipitation in these provinces is below 200 mm per year; some areas have almost no rainfall. A critical level of precipitation is around 400 mm per year; below that level, rain-fed agriculture is usually very difficult or impossible. The orange and yellow areas in Map 2 show that



Map 2 Share of irrigated land in China's cultivated areas

Map developed by IIASA LUC Project. Primary Data Sources: (1) State Land Administration of the People's Republic of China/ United Nations Development Program/State Science and Technology Commission of the People's Republic of China/Food and Agricultural Organization of the United Nations: Land Resources – *Use and Productivity Assessment in China.* Project CPR/87/029, Beijing (1994). (2) Institute for Remote Sensing Applications: Land-cover map of China. Beijing (1994)

precipitation in much of China's land areas is below that critical level.

Settlement patterns in China reflect these greatly varying precipitation levels. In Table 1 we have analyzed how many people live in areas with insufficient precipitation. In the three decades between 1958 and 1988, some 3.97 billion ha in China (or 42% of the total area) had average precipitation below 400 mm; **but only 38 million people** (or **3.3% of the 1992 population**) were living in these areas with very low precipitation.

Thus, the great majority of the Chinese population has settled in regions, where precipitation is, in principle, sufficient for rain-fed agriculture. Actually, about 51% of China's population of 1992 (589 million people) lives in areas where average precipitation is quite high – about 1000 mm per year or above (corresponding to some 22% of the total land). The population density in these areas is 280 people per square kilometer (see Map 1 and Table 1). This fundamental relationship between precipitation patterns and population distribution suggests that **seasonal surplus of water** (in the form of flooding) **is likely to affect many more people in China than a lack of water**. This is reflected in statistical data which, for most years in recent history, indicate that more arable land areas and more people are affected by flooding than by drought (see Figure 1).

Table 1 Population and land area in China by precipitation zones

Precipitation (average for 1958–1988) (mm)	*Area (sq km)*	*Area (% of total)*	*Population (millions)*	*Population (% of total)*	*Population density*
2000–4000	36 350	0.4	12	1.0	324
1000–2000	2 064 700	21.9	577	49.8	280
800–1000	544 000	5.8	148	12.8	272
600–800	986 075	10.4	214	18.5	217
400–600	1 845 250	19.5	170	14.7	92
200–400	1 229 225	13.0	24	2.1	20
< 200	2 742 900	29.0	14	1.2	5

Source: IIASA LUC-GIS

The Table should be read as follows: about 50% of the Chinese population of 1992 (or 589 million) lived in some 22% of the total land area, in which average annual precipitation between 1958 and 1988 was between 1000 and 2000 mm per year (in some small areas it was even up to 4000 mm). The population density in these areas was between 280 and 324 people per sq km

From the Table, we can also see that roughly 82% of the population lives in areas, where average precipitation over the three decades between 1958 and 1988 was 600 mm per year or more. This precipitation level is usually sufficient for rain-fed agriculture (provided that the timing of the rain is adequate for cultivation or that water storage systems are in place for buffering seasonal variation)

If we consider precipitation levels of more than 400 mm as still adequate for some kind of rain-fed agriculture (with a low level of productivity), we find that almost 97% of the Chinese population live in these areas. While there are some places in the world where agriculture is successfully practiced at such low precipitation levels, it is clear that the range between 400 and 600 mm is difficult for cultivation

To be on the safe side, we can say that roughly 5–10% of the Chinese population lives in areas where precipitation levels are so low that rain-fed agriculture is marginal or impossible. This first crude estimate is confirmed by our more detailed LGP estimates in the AEZ model (which take into count several other climate factors, such as minimum and maximum temperature, sunshine duration, frost-free days, wind speed, etc.)

LESTER BROWN'S ALARMING DIAGNOSIS OF WATER SHORTAGES IN CHINA'S AGRICULTURE

The above conclusion might surprise those who have read Lester Brown's alarming diagnosis of China's water shortage. He argued that:

> 'China depends on irrigated land to produce 70% of the grain for its huge population of 1.2 billion people. But it is drawing more and more of that water to supply the needs of its fast growing cities and industries (p. 10). While four-fifths of the water is in the south, two-thirds of the cropland is in the north. As a result, the water per hectare of cropland in the north is only one-eighth that in the south (p. 12) . . . in a country, where 70 percent of an even larger grain harvest [than in the US] comes from irrigated land, and where groundwater mining is widespread, the impending consequences of aquifer depletion are far greater'. (Brown and Halweil, 1998, p. 18)

These arguments suggest that China's water problems – which no one familiar with the situation would deny – actually affect the *bulk* of China's grain production. We cannot confirm this with our data.

First, our sources indicate that much less of the cultivated land is in the water-constrained river basins of the north. In 1997, the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) commissioned a large study on China's freshwater resources. It was conducted in collaboration with the Nanjing Institute of Hydrology and Water Resources of the Ministry of Water Resources of China. The main results, reproduced in Table 2, indicate that all river basins in the south, southeast and southwest have more than enough water. The per capita surface water runoff ranges from 2400 to 32 000 cubic meters. The annual water resources per hectare of cultivated land range from 39 300 to 327 000 cubic meters, which is certainly enough by all measures. The problem should also be less serious in the northeast, where almost 1480 cubic meters

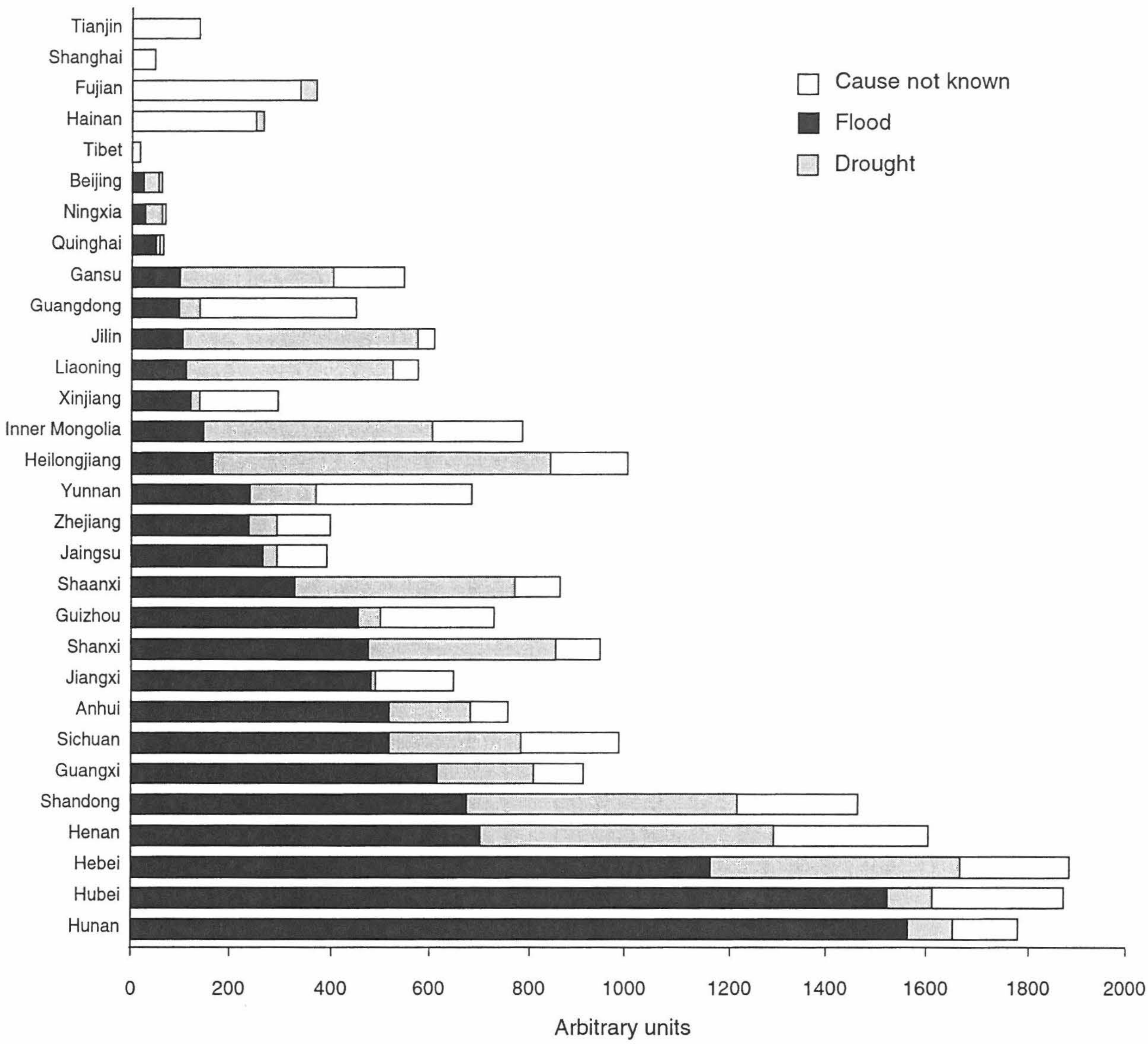


Figure 1 Areas affected by natural disasters by province, 1996 (1000 ha).

Source: China Statistical Yearbook, 1997, State Statistical Bureau, People's Republic of China, Beijing, China, p. 397. Note: For Tianjin and Shanghai, only total area affected by disasters was available. For Fujian and Hainan, only total disaster area and area affected by droughts were available. For Tibet, only total disaster area and area affected by floods were available

are available per person per year and 9560 cubic meters per hectare of cultivated land.

The situation is certainly different in the *rain-fed* cultivation areas in the middle and northern parts of the North China plain, especially near the urban agglomeration of Beijing and Tianjin, where farmers pump water from the groundwater table. There are also problems with those irrigation systems that are fed by the water-scarce rivers of the north, such as the Yellow River. However, these problems of water *scarcity* in the north and northwest must be sharply distinguished from the situation in the humid south and southeast. In the northern part of the North China plain, strong competition has emerged between the water consumption of industry and urban areas, on the one hand, and the irrigated cultivation, on the other hand. Here are serious water *resource* deficits, but they clearly affect only part of China's agricultural production.

According to the ESCAP report, the situation is certainly serious in the Hai He-Luan He Basin, which covers about 11% of China's cultivated area and is home to some 10% of the population. Very limited surface water runoff is also reported

Table 2 Surtace water runoff and availability in China, 1993 (% of national total)

River System	*Region*	*Water resources (%)*	*Population (%)*	*Cultivated land (%)*	*Per capita water resources (cubic meter per year per person)*	*Water resources per ha cultivated land (cubic meter per year per ha)*
I	Northeastern	6.9	10.0	19.8	1479	9560
II	Hai He-Luan He Basin	1.5	10.0	10.9	225	3760
III	Huai He Basin	3.4	16.0	14.9	389	6310
IV	Huang He Basin	2.6	8.0	12.7	656	5730
	II + III + IV	7.5	34.0	38.5		
V	Chang Jiang Basin	34.2	34.0	24.0	2369	39 300
VI	Southern	16.8	12.0	6.8	3465	67 950
VII	Southeastern	9.2	6.0	3.2	2999	73 800
VIII	Southwestern	20.8	2.0	1.7	31 679	327 000
	V + VI + VII + VIII	81.0	54.0	35.7		
IX	Interior basins	4.6	2.0	5.8	4832	21 850
	National total	100	100	100	2323	28 000

Source: United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) (1997): Study on Assessment of Water Resources of Member Countries and Demand by User Sectors: China – *Water Resources and Their Use*, New York, p. 9
Note: The water resources per ha cultivated land are calculated with the 'old' estimate of 96 million ha

for the Huai He and the Huang He basin. Together, these three northern and eastern basins account for 38.5% of the cultivated land and are home to some 34% of the population. However, while there are serious problems in these areas, one cannot say that the *complete* crop production in these regions is threatened by water scarcity. The yields might be much lower than they could be, but some grain is certainly produced.

Second, the discrepancy to Brown's conclusions is even greater when we consider crop *production.* In the south, Chinese farmers can frequently harvest 2 to 3 times per year at high yields. In addition to rice during the monsoon season, they can also grow winter wheat in some areas.

To obtain a better understanding of what percentage of crop *production* (not just the area) is actually affected by water constraints, the IIASA Land Use Change Project has conducted a detailed assessment of China's agro-climatic and biophysical conditions for rain-fed versus irrigated agriculture. The key questions were: (a) What is China's grain cultivation potential under purely *rain-fed* conditions? (b) What is the grain cultivation potential of the country when irrigation would (and could) be used in addition to natural rainfall? (c) In which regions of the country would irrigation produce the highest *increase* in the grain production potential?

MODELLING CHINA'S RAIN-FED AND IRRIGATED CROP PRODUCTION POTENTIAL: THE AGRO-ECOLOGICAL ZONES (AEZ) METHODOLOGY

To understand the basic idea of the AEZ approach let us imagine a hypothetical farmer who has the task to evaluate the suitability of a particular land area for crop production. He would use a whole range of criteria, such as the quality of the soil, the local climate conditions, and the possibilities of using different types of agricultural input (fertilizers, pesticides, machinery). The farmer would also consider various kinds of crops because a particular area might be very suitable for one crop (for instance rice), while only moderately suitable for another.

The AEZ algorithm proceeds in the same way. However, the model systematically tests the growth requirements of 154 major crop types and subtypes (including 83 types of grain) against a very detailed set of agro-climatic and soil conditions. For China, the model operates on a 5 by 5 kilometer grid; so that the total grid matrix has 810 by 970 cells, of which some 374 814 grid cells cover the mainland of China. Water bodies are automatically excluded. In each of these land-related grid cells the AEZ model performs the following (principal) steps:

1. The algorithm first evaluates the climate conditions. Obviously, crop cultivation is only possible if temperature and precipitation are within a certain range. From an agronomic point of view, the key concept is the potential evapotranspiration. Plants need a constant supply of water for their metabolism, in which they lose moisture due to evapotranspiration. In rain-fed agriculture, the moisture supply to plants depends on the precipitation and the waterholding capacity of the soil. Some soils (such as Andosols or Chernozems) can store water much better than others. A given amount of rainfall might be sufficient for a particular crop production on a soil with high waterholding capacity, while it might be insufficient when the soil lets the water seep away or evaporate. To take into account these principal differences between soils, the AEZ algorithm evaluates the climate conditions for 6 soil classes of waterholding capacity – from 150 mm to 15 mm, depending on soil characteristics and depth. For each soil class, the algorithm calculates a soil moisture balance under local climate conditions. So far, we have only mentioned temperature and precipitation as climate parameters, but the AEZ algorithm actually uses a more detailed set of climate indicators which include (a) monthly precipitation, (b) minimum/maximum temperature, (c) relative humidity, (d) sunshine fraction, and (e) wind speed. For each grid cell the algorithm uses these climate parameters to calculate a crop-specific potential reference evapotranspiration. The algorithm determines how much water the various crops would need under the climate conditions of a particular grid cell. These crop water requirements vary with crop type, soil class, and climate conditions.

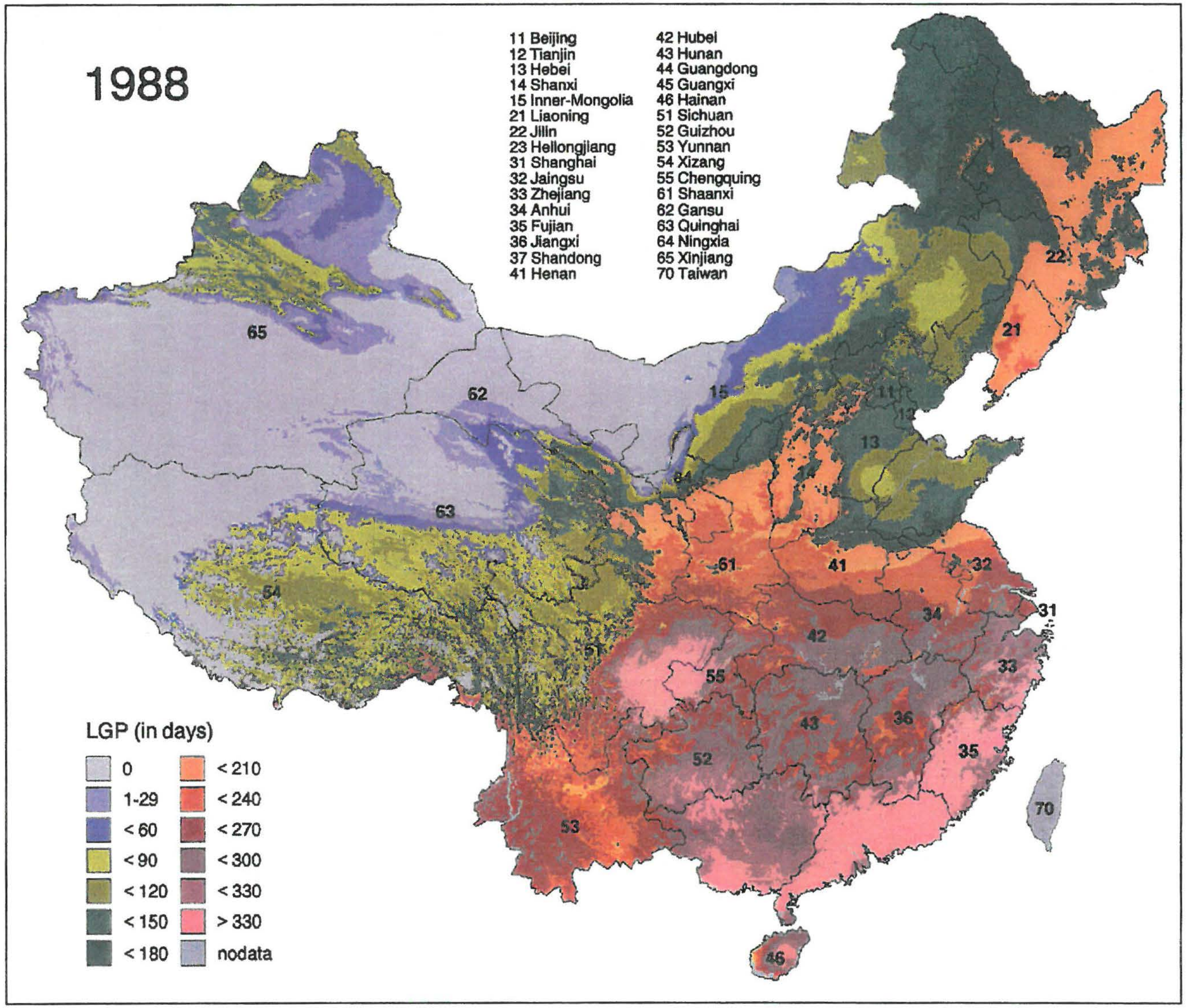
2. The algorithm uses the results from step one to estimate location-specific **potential biomass** and **yields** for each crop. For this calculation, the program applies a crop model and the length of growing period (LGP) concept (see Map 3). The algorithm simulates a series of growth cycles on a daily basis for each crop – with starting days covering a complete 365-day period from January to December. In other words, the model tries to match crop-specific growth cycles into the LGP of a particular grid cell, which is determined by its climate conditions. For each growth cycle the algorithm calculates a crop-specific photosynthesis response in a two-step procedure:

(a) First, the *thermal* conditions of each grid cell (temperature profile) are compared with the thermal requirements of the crops during their growth cycles. For the calculation of biomass, the crops are grouped into four classes (so called adaptability groups) because in some crops photosynthesis is more sensitive to changes in thermal and radiation conditions than in others. Crops are also adapted to different temperature ranges.

(b) Second, the actual *moisture* supply in the particular grid cell is compared with the water requirements of the crop. The AEZ model essentially calculates – on a day-by-day basis – a crop-specific soil moisture balance. If the water supply is less than the water demand of a particular crop, empirical yield loss factors are applied which reduce the potential biomass yield. The water balance also shows the crop-specific irrigation demand for each grid cell.

The purpose of this two-step procedure is to determine the starting date for a growth cycle that produces *maximum* potential yield. Under some climate conditions, it is obviously better for a particular crop to start cultivation early in the year, while under other conditions it might be better to wait for a rainy period. This procedure is repeated for both rain-fed and irrigated conditions and for three levels of agricultural inputs. To quantify potential yields, the programme uses three characteristics: (a) the so-called maximum leaf area index (LAI) which is the ratio of leaf area as compared to the crop cultivation area. (b) The model also uses the so-called harvest index which is the proportion of the primary produce (e.g. grain) to total biomass. (c) And the crop adaptability group defines the relationship between maximum rate of photosynthesis and the daytime temperature. The first two measures vary with the type of crop and level of input.

3. So far, the algorithm has dealt with hypothetical yields; now the model tries to determine the level



Map 3 Length of Growing Periods (LGP) according to AEZ model, 1988

of *attainable* production per grid cell. For that purpose, the model applies three types of *constraints:*

(a) *Agro-climatic constraints:* In addition to the temperature and moisture factors which the model already takes into account in step 2, climate-related aspects affecting crop management are taken into account: (a) workability constraints; and (b) constraints due to pests, diseases and weeds. For instance, if a particular grid cell has a high level of excess moisture (as determined by step one), harvest operations with machinery can become difficult, so that a high input level cultivation may become impossible. On very dry and hard soils, on the other hand, ploughing is more difficult which also limits the workability. The procedure also takes into account that humid conditions typically reduce yields through higher frequency of pests, crop diseases and weeds.

(b) *Agro-edaphic constraints:* These deal with soil chemical and physical constraints to crop production (in addition to the soil moisture factors, which the model includes in the calculations of step 2). The AEZ model uses an agro-edaphic suitability classification (developed by the FAO and other organizations) to take into account information on soil types, soil texture and soil phase. This soil rating scheme defines the suitability of each soil unit for each individual crop at defined levels of inputs and management circumstances. For instance, some soils may be very stony, others may have chemical problems, which will reduce the attainable crop production.

(c) *Terrain constraints:* These are limitations of crop production due to landform characteristics. For instance, soils on steep slopes are much harder to cultivate than soils in flood plains. They are also more susceptible to erosion and, consequently, fertility loss. For each grid cell the AEZ model takes into account a number of these constraints (which are specified by a terrain slope suitability classification) to further reduce the attainable grain production if necessary.

4. In the above calculation the algorithm has only considered *one* particular crop per year. Obviously, this would be unrealistic in many grid cells because multiple crops can often be grown in one season. To take into account the possibility for *multi-cropping* the AEZ model assigns each grid cell to one of 10 cropping zones for both irrigated and non-irrigated conditions – from single cropping zones (for cryophilic crops) to triple cropping zones (for thermophilic crops). Several climatic parameters are used to determine the cropping zone for a particular grid cell, such as the LGP, the days with minimum temperature above 5° C, the accumulated temperature during the growing period, and other factors.

Now everything is prepared for the actual selection of an optimal crop for each grid cell (or a sequence of up to three optimal crops, in the case of multi-cropping). The model has calculated the potential yields of all 83 grains under the specific climatic, soil and landform conditions of a particular grid cell; and the algorithm has assigned each grid cell to a cropping zone. Now the algorithm only has to select those grains among the 83, which maximize production in that particular grid cell. In the case of multi-cropping, the algorithm has to combine up to three grains to find the maximum potential yield.

5. The selection of the 'best' grain for a particular grid cell can be described as the task of matching the requirements of the grain crop with the characteristics of a particular grid cell in such a way that *maximum* grain production can be achieved. For this, all crops are grouped into classes. Some crops have long growing periods (more than 120 days) others have short ones (less than 120 days). Some grains are typically sown before the winter (such as winter wheat), others are adapted to hot temperatures. The AEZ algorithm uses a scheme of 8 generic crop groups to characterise the typical growth requirements of the crops and to construct multiple cropping patterns. Each crop type belongs to one of these eight groups (for details of the selection process concerning single and multi-cropping conditions see: Fischer *et al.*, 1999).

6. With the above calculations the AEZ algorithm can now compare the potential yields of the selected crop in a particular grid cell with the overall maximum potential yield of that crop in

all other grid cells of China. For instance, the algorithm might find that in a particular grid cell the selected wheat has a potential yield of 9 tons per ha. This potential yield is now compared with the overall maximum yield for wheat in China (which might be 10 tons per ha). Now the algorithm 'knows' that in this grid cell one can potentially produce 9/10 = 90% of the maximum yield, which would be equivalent to a grid cell that is 'very suitable' for wheat production. In other words, the potential yields of the primary crop are used to classify each grid cell into one of five *suitability classes.* For each individual grid cell the algorithm can thus calculate potential maximal yield estimates by level of input.

7. However, not all the suitable land can be cultivated. Some arable land must be set aside for settlements and for water and transportation infrastructure. China has a large network of open irrigation canals which take up a considerable amount of land suitable for cultivation. Some of the potentially suitable land is also needed for mining and industrial production sites. Finally, some land with cultivation potential should not be used for agriculture because it is still covered by valuable ecosystems, such as natural forests or wetlands. In a final step the AEZ methodology, therefore, takes into account non-agricultural land use within arable areas. First, a digital land-cover map is used to determine the size of the inhabited land area. The inhabited land area is the total land area, minus water bodies and (almost) unused land, such as mountains, deserts, forests and grassland. This actually usable land is used as the denominator for calculating the percentages of land areas that are used for settlements, infrastructure, and mining (which are taken from province-level statistics). Second, this province-specific percentage of infrastructure and settlements is multiplied by 1.33 to account for future urban and infrastructure expansion. Third, the potential arable land area from the AEZ model is reduced according to this province-specific correction factor. This procedure reduces the areas that are suitable for crop cultivation by a province-specific **correction factor for infrastructure**.

It must be emphasized that the AEZ estimates do not give the actual production, but show what production would be possible, if **all suitable areas** in China (with the exception of infrastructure and non-grain crops) could be cultivated at currently available levels of technology. The estimates are, of course, higher than the current production, because not all potentially suitable areas are currently used, and the productivity has not reached its maximal sustainable level everywhere (especially in remote inland areas where grain yields are still significantly lower). (For technical details of the study see: Fischer *et al.*, 1999).

RESULTS

China's rain-fed versus irrigated grain cultivation potential

According to our AEZ model, China has a total **rain-fed** cultivation potential of 147 million hectares, which can produce some 492 million tons of grain (see Tables 3 and 4). This takes into account all areas in China with appropriate soil, terrain and climate conditions – in both the south and the north. The estimate also takes into account that some 5 to 15% of the suitable land will have to be reserved for infrastructure and that 25% of the suitable land will be used for non-grain crops, such as vegetables, fruits and fibre crops. When we used the same methodology to calculate the rain-fed plus irrigated cultivation potential of China, we ended up with a total of 159 million hectares – which would be equivalent to an annual production of some 672 million tons of grain (see Tables 5, 6 and 7). In other words: By using irrigation, China can expand its areas with cultivation potential from 147 to 159 million hectares or 7.7%. The grain production potential can be boosted from 592 to 672 million tons – or by 36%. The increase in production is, of course, higher than in area because, with irrigation, the productivity on many rain-fed fields in the north and northeast could be increased.

From these analyses, we can conclude that water **deficits** might affect those 36% of China's grain *production,* which are produced on areas that either totally depend on irrigation or have significantly higher productivity when irrigated. However, that also means that some **64% of the crop production is not systematically threatened by water shortages** – either because it comes from fields in humid

Table 3 Potential arable land: mixed input levels, without irrigation (1000 ha)

		High Input		*Intermediate Input*			*Low Input*					
Province/ Region	*Infrastructure correction factor (%)*	*Very suitable*	*Suitable*	*Very suitable*	*Suitable*	*Mod. suitable*	*Very suitable*	*Suitable*	*Mod. suitable*	*Marg. suitable*	*Total arable land*	*Not suitable*
North	17.7	9673	11 785	313	4134	8222	0	189	1741	3480	39 537	20 298
Northeast	13.5	4808	9964	320	8227	8530	0	181	1503	3128	36 661	35 447
East	21.5	5854	5609	294	941	1858	0	6	191	1532	16 284	12 162
Central	14.8	5925	5859	6	1354	4859	0	8	610	6637	25 257	27 090
South	10.6	1705	4311	5	1187	4899	0	67	1169	5627	18 971	33 453
Southwest	8.8	809	4248	54	1546	9414	0	99	2038	7917	26 126	82 788
Northwest	13.2	166	1265	277	1430	6155	152	203	2539	7378	19 566	322 809
Plateau	8.0	60	44	1	66	160	0	11	101	387	830	190 324
China Total	14.5	29 001	43 086	1271	18 886	44 097	152	764	9890	36 087	183 234	724 407
TOTAL Arable land (without land areas that are only marginally suitable at low input levels)											**147 147**	

Source: IIASA China AEZ Project. Based on methodology described in Fischer *et al.* (1999): Global AgroEcological Zones Assessment: Methodology and Results. IIASA Interim Report, IR-98-110, Laxenburg, Austria

Table 4 Potential arable land: mixed input levels, with irrigation if necessary (1000 ha)

		High Input		*Intermediate Input*			*Low Input*					
Province/ Region	*Infrastructure correction factor (%)*	*Very suitable*	*Suitable*	*Very suitable*	*Suitable*	*Mod. suitable*	*Very suitable*	*Suitable*	*Mod. suitable*	*Marg. suitable*	*Total arable land*	*Not suitable*
North	17.8	11 061	11 372	313	4021	7863	0	186	1729	3317	39 862	19896
Northeast	13.5	7501	10 388	381	8008	9181	0	168	945	1883	38 454	33 398
East	21.5	6303	5224	251	962	1928	0	6	190	1511	16 375	12 040
Central	14.8	5966	6004	7	1309	4924	0	9	603	6544	25 366	26 965
-South	10.6	1673	5023	5	1002	5115	0	57	1108	5143	19 125	33 284
Southwest	8.8	881	4353	43	1500	9485	0	99	2017	7806	26 184	82 724
Northwest	13.2	3316	4194	226	1415	6809	144	202	2509	7169	25 985	315 400
Plateau	8.7	64	123	1	65	197	0	11	101	387	949	190 189
China Total	14.4	36 764	46 683	1226	18 282	45 505	144	738	9201	33760	192 303	713 931
TOTAL Arable land (without land areas that are only marginally suitable at low input levels)											**158 543**	

Source: IIASA China AEZ Project. Based on methodology described in Fischer *et al.* (1999): Global AgroEcological Zones Assessment: Methodology and Results. IIASA Interim Report, IR-98-110, Laxenburg, Austria

regions (where there is certainly enough water), or because precipitation is still sufficient for (some) rain-fed production.

Of course, our analysis does not imply that this potential production could be achieved every year. As anywhere else in the world, in certain years a drought may strike. There could even be multi-year droughts. However, the long-term precipitation (and temperature) trends for those areas that can produce 64% of China's grain do not indicate a systematic water deficit. It would not be correct to extrapolate from a few dry years the imminent water crisis of China's total agriculture.

One might argue that without irrigation and water management even in the humid south, the paddy rice fields could not produce their current two or three harvests, but only one or two. That is correct, but not the point of argument. **We argue that in a large area in China's south and southeast – from the coast to about halfway up between the Yangtze and Beijing – water is a management issue, not a problem of water scarcity.** With proper water management, this area has usually enough water (from precipitation and surface water resources) to produce at least two harvests. One has to distinguish the technical water management problems in the southern half of

Table 5 Potential grain production: mixed input levels without irrigation (1000 tons)

Province Region	*High input* Very suitable 1	Suitable 2	*Intermediate input* Very suitable 3	Suitable 4	Mod. suitable 5	*Low input* Very suitable 6	Suitable 7	Mod. suitable 8	Marg. suitable 9	Total potential production (1 – 9)	Total attainable production (1 – 8)
North	47 122	46 248	1824	9257	14 969	0	211	1266	1594	122 491	120 897
Northeast	22 047	32 353	1039	18 351	12 021	0	149	784	1162	87 906	86 744
East	61 162	39 784	1731	3878	5933	1	12	272	1697	114 470	112 773
Central	55 637	49 162	32	5945	18 366	0	15	981	7601	137 738	130 137
South	20 758	46 634	24	7150	23 144	0	95	1147	6886	105 839	98 953
Southwest	7400	35 045	188	5831	31 355	0	124	2050	8070	90 063	81 993
Northwest	590	4303	672	4328	11 329	232	226	1865	3154	26 698	23 544
Plateau	495	303	5	218	383	0	14	94	198	1709	1511
China Total	215 219	253 841	5515	54 960	117 503	232	847	8458	30 361	686 936	656 575
Total production (with correction for other crops)	161 414	190 381	4136	41 220	88 127	174	635	6344	22 771	515 202	492 431

Source: IIASA China AEZ Project. Based on methodology described in Fischer *et al.* (1999): Global AgroEcological Zones Assessment: Methodology and Results. IIASA Interim Report, IR-98-110, Laxenburg, Austria

Table 6 Potential grain production according to IIASAFAO AEZ model: Scenario 3: mixed input levels, with irrigation if necessary (1000 tons)

Province Region	*High input* Very suitable 1	Suitable 2	*Intermediate input* Very suitable 3	Suitable 4	Mod. suitable 5	*Low input* Very suitable 6	Suitable 7	Mod. suitable 8	Marg. suitable 9	Total potential production (1 – 9)	Total attainable production (1 – 8)
North	111 588	85 710	1942	9412	15 056	0	210	1268	1526	226 713	225 187
Northeast	46 100	43 189	1640	18 277	14 028	0	137	557	770	124 697	123 927
East	81 137	51 435	1563	4277	6409	0	13	271	1651	146 756	145 105
Central	55 675	51 125	35	6000	18 531	0	18	968	7465	139 816	132 352
South	27 073	54 843	27	5998	24 569	0	82	1005	6073	119 670	113 598
Southwest	7945	36 500	160	5721	31 686	0	120	2026	7919	92 076	84 158
Northwest	24 890	23 221	1472	4856	13 345	220	225	1849	3074	73 151	70 077
Plateau	558	621	5	216	438	0	14	93	198	2142	1944
China Total	354 970	346 658	6843	54 759	124 065	220	818	8037	28 674	925 044	896 370
Total production (with correction for other crops)	266 227	259 994	5132	41 070	93 049	165	614	6027	21 505	693 783	672 278

Source: IIASA China AEZ Project. Based on methodology described in Fischer *et al.* (1999): Global AgroEcological Zones Assessment: Methodology and Results. IIASA Interim Report, IR-98-110, Laxenburg, Austria

the country from the resource scarcity problems in the north.

This can be clearly demonstrated when we analyze the regional differences between China's rain-fed and irrigated grain production potential. Table 7 shows that the biggest advantage of irrigation is in the north (including the provinces of Beijing, Tianjin, Hebei, Shanxi, Shandong, and Henan) and the northwest (including Inner Mongolia, Shaanxi, Gansu, Ningxia, and Xinjiang). If sufficient water was available in these regions, irrigation could boost the grain production by 104 million tons in the north and by 47 million tons in the northwest – as compared to purely rain-fed cultivation. In percentage terms, irrigation makes the biggest difference in the northwest: under rain-fed conditions the maximal attainable grain production (according to the AEZ model) is in the range of less than 25 million tons – with irrigation, this area could produce more than 70 million tons of grain (or some 198% more). Table 7 also indicates some irrigation

Table 7 Differences in the maximal attainable grain production between rainfed cultivation and cultivation with additional irrigation (where necessary)

	Maximal attainable grain production (in mio tons)			
	Without irrigation	*With irrigation*	*Difference*	*Difference in %*
North	120 897	225 187	104 290	86.3
Northeast	86 744	123 927	37 183	42.9
East	112 773	145 105	32 333	28.7
Central	130 137	132 352	2214	1.7
South	98 953	113 598	14 645	14.8
Southwest	81 993	84 158	2165	2.6
Northwest	23 544	70 077	46 533	197.6
Plateau	1511	1944	433	28.6
China total	656 575	896 370	239 795	36.5
(minus 25% for cultivation of non-grain crops)	492 431	672 278	179 847	36.5

potential in the northeast (Liaoning, Jilin, Heilongjiang): without irrigation, these regions can produce a maximum of some 87 million tons of grain – with additional irrigation, however, the maximal grain production could increase to 124 million tons.

What are the major water problems in China's agriculture?

It is clear that the water situation in the north, northwest and northeast of China needs careful monitoring and decisive measures to increase resources. This is necessary to prevent a serious decline in agricultural productivity and to stop the degradation process that is already under way in the natural environment. We believe that there are three conditions which we have to take into account, in particular, when we analyze the water situation in the north:

- One of the major, rapidly growing population centres in China – the Beijing–Tianjin urban agglomeration – is located very close to a **climatic border line** where the long-term precipitation patterns fall below the 400 mm threshold – which is a critical level for rain-fed agriculture. Essentially, all of Beijing's hinterland to the west and northwest is more or less arid. The soaring water demand of this urban agglomeration competes with north-China's agriculture in an area of natural water scarcity (that is a big difference from other big cities in China, such as Wuhan or Shanghai).
- There is a belt of **extreme instability** in precipitation patterns, expanding from Ningxia province to the northern part of Shaanxi, most of Shanxi, Hebei province and the eastern parts of Inner Mongolia. As can be seen from Map 3 this is clearly reflected in the LGP, which we have calculated for the period between 1958 and 1988. They strongly fluctuate from year to year in these regions – indicating that climatic production conditions are very unstable (other than, for instance in Sichuan province, which is an 'island of agro-climatic stability').
- **Siltation** is the major problem in the **Yellow River basin**, which has a multitude of consequences. In its upper and middle reaches the sediment load of the river is filling up the water reservoirs thus reducing their storage capacity, ruining the turbines and clogging irrigation pipes and canals. It was estimated that between 1949 and 1975 the reservoirs in the provinces of Shaanxi, Shanxi, Gansu, and Inner Mongolia lost 1.15% of their total capacity

each year due to siltation (Wang, 1998). The declining capacity reduces their buffer function against the extreme seasonality of water flow in the Yellow River – which, in turn, increases the risk of flooding downstream (and reduces their hydropower potential). The alternative is not much better: with larger reservoir capacity upstream, the water flow downstream would slow down – giving the sediment load that is picked up subsequently an even better chance to settle on the bottom (which, in turn, increases the risk of flooding again). There is no easy solution for the Yellow River.

With these conditions, water is certainly a major problem in north China's agriculture. However, there are many technical, economic and administrative possibilities to deal with these problems. Some of them will be discussed below.

The most obvious measure to cope with China's water problem is, of course, to develop existing water resources and improve the institutional structure of the water sector. Since its foundation, and particularly since the 1980s, China has initiated a large number of water projects. These include the massive Three Gorges Project on the Yangtze River, the Xiaolangdi Multi-Purpose Dam Project on the Yellow River, the Huai He River Cleaning project, the Taihu Lake Harnessing and the preparation for the South-to-North Water Transfer Project. In 1988, a new water law of the People's Republic of China concentrated the responsibility for the water sector in the Ministry of Water Resources. It primarily oversees (a) the implementation of a rational water assets operation and management systems; (b) introduction of effective pricing mechanisms; (c) the legal and regulatory structures; (d) water quality and water services; and (e) the construction of reservoirs, dams and embankments. Since the early 1950s, China has built about 85 000 reservoirs with a total storage capacity of 479.7 billion cubic meters and 2953 large and medium-sized dams with storage of 417 billion cubic meters. China has regulated almost all the medium and small rivers, with 247 000 km of embankment and 31 000 water gates. Despite these impressive measures, much remains to be done. Some of the dams, embankments and canals have serious quality deficits – they are poorly engineered, built with inadequate materials, or badly maintained. The institutional structures often do not effectively handle water conflicts between sectors and the legal and regulatory measures are poorly enforced.

Irrigation efficiency is critical for saving water, since in China almost 66% of all water is still used in irrigation – about 343 billion cubic meters, as compared to 24 billion cubic meters in urban areas and 89 billion cubic meters in industry (see Tables 8a and 8b). If estimates of experts are correct – that China is wasting some 30–40% of its irrigation water – then China's irrigated agriculture could save between 100 and 137 billion cubic meters of water. With this saving current

Table 8 (a) Water use by economic sector in China, 1993 (billions of cubic meters)

Basin System	*Region*	*Industry*	*Urban water supply*	*Agriculture* *Irrigation*	*Agriculture* *Forestry pastures fishery*	*Agriculture* *Rural water supply*	*Agriculture* *All agriculture*	*Total*
I	Northeastern	9.90	2.66	33.13	2.75	1.39	37.27	49.83
II	Hai He-Luan He Basin	6.82	3.62	27.47	1.59	1.76	30.82	41.26
Ill	Huai He Basin	6.08	2.29	39.86	4.71	3.97	48.54	56.90
IV	Huang He Basin	4.86	2.07	29.88	1.95	1.42	33.25	40.18
V	Chang Jiang Basin	40.92	7.23	101.00	7.35	7.71	116.06	164.16
VI	Southern	13.88	4.22	48.00	2.25	4.31	54.56	72.66
VII	Southeastern	4.61	1.36	20.21	0.97	1.75	22.93	28.89
VIII	Southwestern	0.33	0.09	4.83	0.81	0.38	6.02	6.44
IX	Interior basins	1.45	0.56	38.97	16.80	0.45	56.22	58.23
	National total	88.85	24.10	343.23	39.18	23.14	405.72	518.70

Table 8 (b) Water use by economic sector in China, 1993 (% of total)

				Agriculture				
Basin System	*Region*	*Industry*	*Urban water supply*	*Irrigation*	*Forestry pastures fishery*	*Rural water supply*	*All agriculture*	*Total*
I	Northeastern	19.9	5.3	66.5	5.5	2.8	74.8	100.0
II	Hai He-Luan He Basin	16.5	8.8	66.6	3.9	4.3	74.7	100.0
III	Huai He Basin	10.7	4.0	70.1	8.3	7.0	85.3	100.0
IV	Huang He Basin	12.1	5.2	74.4	4.9	3.5	82.8	100.0
V	Chang Jiang Basin	24.9	4.4	61.5	4.5	4.7	70.7	100.0
VI	Southern	19.1	5.8	66.1	3.1	5.9	75.1	100.0
VII	Southeastern	16.0	4.7	70.0	3.4	6.1	79.4	100.0
VIII	Southwestern	5.1	1.4	75.0	12.6	5.9	93.5	100.0
IX	Interior basins	2.5	1.0	66.9	28.9	0.8	96.5	100.0
	National total	17.1	4.6	66.2	7.6	4.5	78.2	100.0

Source: Nanjing Institute of Hydrology and Water Resources (1996): Report on the mid- and long-term plans for water demand and supply in China. Nanjing (cited from: UN Economic and Social Commission for Asia and the Pacific (ESCAP): Study on Assessment of Water Resources of Member Countries and Demand by User Sectors: *China – Water Resources and Their Use* (1997)

urban water consumption could quadruple – at least. Of course, in practice, these water savings are unlikely, but even 10% of this amount would be equivalent to about half the current urban water consumption. These numbers show that investment in irrigation efficiency is a serious option for developing China's water resources.

There are several simple technologies available. A first measure would be to invest more into the maintenance of irrigation canals because many are in poor condition or broken. Pipelines, instead of open canals, would largely prevent evaporation. However, there are also more advanced technologies: For instance, low-level sprinklers or drip irrigation might be applicable in vegetable and fruit cultivation. Here we cannot discuss all the possibilities because they very much depend on the specific local conditions. However, there can be no doubt that the saving potential is considerable and that technology is available to realize it.

Grain import is essentially equivalent to the import of water. Hence, it seems that wheat imports could be a cost-efficient alternative to developing water resources in the north where most of the wheat is produced. Moreover, the import of grain would free up some of the cropland for the production of high-value and labour-*intensive* products, such as vegetables or fruit. This could certainly increase farmer's income and help to provide labour to the millions of rural un(der)employed. However, it is not so clear that grain imports would actually reduce the pressure on China's water resources, since the alternative production (vegetables, fruit, fishponds) might need even *more* water. Nevertheless, economic rationality certainly suggests that China should consider importing some 30 to 50 million tons of grain per year – in particular, feed grain and wheat. For example, Canada, France, the USA and Australia would be more than happy to export some of their water to China (in the form of grain). By the way, there is no reason why these countries would not be able to supply China with this amount of grain. The world grain exports from Argentina, Australia, Canada, the European Union and the USA have been stagnating at about 200 million tons annually since the early 1980s – not because these countries could not produce more, but because of a lack in demand, low prices and declining export subsidies. The European Union has been fighting over-production for many years – farmers are still being paid real money for taking fields out of production.

WHAT CAN BE DONE?

There is a great *diversity* of water conditions in China: in some places, water is abundant, in others, people face severe shortages. In a large belt from the south-central to the northeast precipitation is extremely seasonal – in some years, all the rain falls in a few days, washing away the topsoil instead of soaking the soil. In the Loess Plateau water erodes the arable land and downstream, in the Yellow River basin, people fight the problems of siltation. In some other places, industry and urban discharges pollute the water for irrigation. In up-stream areas, farmers (and other users) often waste the water, while in the downstream provinces these rivers are completely dry. These specific water problems can only be analyzed (and solved) on a case-by-case basis, taking into account local and regional conditions.

The intention of this paper was to consider strategic issues at the national level that can be summarized in the following question: 'What are the key measures the Chinese Government should initiate to improve the water security of various users in the coming decades – including agriculture?' Based on our models and analyses, we believe that the following three measures are most important:

First, effective **pricing mechanisms** for freshwater consumption must be implemented and/or improved. Adequate water allocation between competing users is impossible without a clear price signal. All efforts to improve efficiency in irrigation, in the industry or in private households are doomed if water is considered essentially a free resource. Obviously, the problem is that poor farmers in arid regions, who need water for irrigation, cannot afford to pay the same price as rich coastal cities. Some kind of government regulation is, therefore, inevitable to protect poor segments of the population and economy from the booming water demand of rich urban areas. Various schemes to raise the price of water are possible, such as a water tax with different rates for farmers, industry and urban consumers.

Second, almost everywhere in the country water **technology** and **infrastructure** must be modernized if China wants to avoid running into big problems in coming decades. In particular, China needs a strategic initiative to introduce and expand modern water supply and sewage systems in all its rapidly growing urban areas and towns. With further economic development, China – as any other country in the world – will experience a 'sanitary revolution'. Residential water consumption will surge when more and more people are using washing machines, kitchen sinks, flush toilets and bathrooms in their apartments. Better technology is also necessary to clean up wastewater discharge from industry and mining. The biggest improvement, however, could be achieved with more efficient irrigation methods, since China still uses most of its water in agriculture. Many experts have estimated water losses of up to 60% due to evaporation and leaky canals. China has a sea of water in its conservation potential. China must also increase its efforts to build new reservoirs that are needed as a buffer against the extreme seasonality of river flow and/or precipitation. Existing reservoirs have to be cleaned of sediment. Finally, integrated hydrological control schemes consisting of dams, reservoirs, reserved flood plains, and advanced monitoring and early warning systems could reduce the risk of flooding – one of the biggest threats to China's agriculture.

Third, the **trans-basin water diversion** from the south (Yangtze) to the north and the north-central provinces seems to be inevitable. According to our detailed geobiophysical and climate assessment (in the AEZ model), we believe that China has some 20 million hectares of arable land reserves – in addition to its 140 million hectares of currently cultivated land (133 million hectares of cropland plus about 7 million hectares of horticulture). These land reserves are – in principle – suitable for crop cultivation according to their soils, terrain and temperature conditions. Unfortunately, about 60% of these reserves are located in areas where precipitation is insufficient (and would lead to very low yields or prevent cultivation altogether). However, with adequate and carefully managed irrigation these areas, which are mostly located in the north-central and northeast, could be used for sustainable crop production. There are also many currently cultivated areas in the northern half of the North China plain, which would benefit from a better water supply. Since pumping of groundwater is not a long-term alternative (the demand is higher than the renewable resource), water diversion from the water-rich south is certainly a realistic alternative. We know that there are very serious concerns with some of the massive water diversion projects China is currently implementing (Liu,

Table 9 (a) World Bank projection of China's grain demand in 2020 (milled form)

	Rice	*Wheat*	*Coarse grain*	*Total*
Per cap. consumption (kg/person)	107.7	99.4	53.2	258.3
Direct cereal consumption	66.5	51.5	23.1	141.1
Manufactured food consumption	39.2	47.9	30.1	117.1
Requirements (million tons)	208.6	174.8	224.5	607.9
Direct and processed consumption	150.9	142.5	75.0	368.3
Feed grains	46.3	21.6	138.2	206.1
Seed and losses	11.5	10.7	11.3	33.5

Source: World Bank Data and Staff Estimates. In: World Bank (1997): China 2020. At China's Table. Food Security Options. Washington, DC, p. 2
This World Bank estimate projects a total grain demand of 608 million tons, which is equivalent to about 697 million tons of un-milled grain

Table 9 (b) China's food demand, 1995-2020: Various projections compared

	Brown and Halweil			*Rosegrant et al.*			*Huang et al.*			*USDA*			*World Bank*		
	Production	*Demand*	*Imports*	*Production*	*Demand*	*Imports*	*Production*	*Demand*	*Imports*	*Production*	*Demand*	*Imports*	*Production*	*Demand*	*Imports*
1995	355	375	20	355	375	20	355	375	20	355	375	20	355	375	20
2000	342	405	63	385	403	18	410	450	40	362	387	25	411	420	9
2005	329	437	108	418	434	16	438	480	42	382	414	32	445	459	14
2010	317	472	155	453	468	15	469	513	44	403	443	40	483	502	19
2020	294	549	255	541	565	24	552	594	42	449	506	57	568	600	32

Source: OECD, 1997, p. 242

1998; Barber and Ryder, 1993; CIDA, 1988; Fearnside, 1988; Heilig, 1998). The basic idea, however, is sound. Why should China not develop its north with water from the south – in just the same way as the USA have developed California with water from the Colorado River? Phoenix, Arizona – a booming city in the middle of a desert, was the most rapidly growing urban area in the USA in the last decade. China needs water in the north and central provinces not only for their agriculture – but also for the rapidly growing urban–industrial agglomerations such as Beijing–Tianjin.

CAN CHINA FEED ITSELF?

Coming back to our initial question, we believe that China can feed itself. Most experts predict that within the next three decades the country will need – depending on diet – between 500 and 600 million tons of grain per year (in milled form) for its projected population of about 1.5 billion (see Tables 9a and 9b). This already includes the necessary amount of feed grain. Based on our AEZ model, we have calculated that China has the biophysical potential under rainfed conditions to produce roughly 490 million tons of grain if 75% of all areas suitable for grain cultivation are used. This could be achieved with current technology based on agro-climatic conditions (soils, temperature and precipitation profiles, terrain). However, if irrigation would be available for all those areas where the water balance is not sufficient, China could increase its maximum potential production to about 690 million tons of grain. These estimates are conservative, because they assume that 25% of suitable land will not be used for grain production, but for cultivation of other crops. They also generously deduct land for housing and infrastructure.

The estimates indicate that on rain-fed cultivation alone China would certainly have problems feeding its population (only if people were on a strictly vegetarian diet would it perhaps be possible). However, with adequate irrigation, China's farmers can produce enough grain for a 1.5 billion population if we assume a (milled) grain demand of about 550 million tons (the average of available demand estimates).

This shows that the **development of a sustainable water supply for China's north and northwest is an essential factor of the country's food security.** The numbers also indicate that moderate (feed) grain imports – in the range of 30 to 50 million tons – could reduce the pressure on China's arable land and water resources if the land not necessary for grain cultivation were taken out of production. Grain imports could, in particular, reduce the pressure on marginal land that would have to be cultivated otherwise – such as slopes or areas that should not be cultivated due to high environmental risk.

BIBLIOGRAPHY

Barber, M. and Ryder, G. (1993). *Damming The Three Gorges; What Dam Builders Don't Want You to Know.* (Probe International: Earthscan Publications Limited)

Braudel, F. (1990). Sozialgeschichte des 15.–18. Jahrhunderts. DerAlitag. Munchen (Kindler Verlag). Original: Civilisation matérielle et capitalisme, XV–XVIII siécie. Le structures do quotidien: Le possible et l'impossible. Paris, 1979

Brismar, A. (1999). *Environmental challenges and impacts of land use conversion in the Yellow River basin.* Interim Report, IR–99–016, IIASA, Laxenburg

Brown, L.R. and Halweil, B. (1998). China's Water Shortage Could Shake World Security. *World Watch,* **11**(4), July/August, 1998

Canadian International Development Agency (1988). *Three Gorges Water Control Project Feasibility Study, People's Republic of China.* **1**(Feasibility Report); **8**(Environment), and **5**(Sediment)

Fang, J.W. and Xie, Z. (1994). Deforestation in pre-industrial China: The Loess Plateau as an example. *Chemosphere,* **29,** 983–99

Fearnside , P.M. (1988). China's Three Gorges Dam: Fatal Project or Step Toward Modernization? *World Development,* **16**(5), 615–30

Fischer, G. and Heilig, G.K. (1997). Population Momentum and the Demand on Land and Water Resources. *Philosophical Transactions of the Royal Society of London B,* **352,** 869–89

Fischer, G., van Velthuizen, H.T. and Nachtergaele, F.O. (1999). *Global Agro-Ecological Zones Assessment: Methodology and Results.* Laxenburg (Interim Report, IR–98–110), Laxenburg, Rome (IIASA, FAO)

Goodland, R. (1995). *Environmental Sustainability Needs Renewable Energy: The Extent to Which Big Hydro is Part of the Transition.* Environment Department, The World Bank, December 1995

Heilig, G.K. (1999). Can China feed itself? An analysis of China's food prospects on CD-ROM. IIASA, Laxenburg

Heilig, G.K. (1997). Anthropogenic Factors in Land-Use Change in China. *Population and Development Review,* **23**(1),139–68

Heilig, G.K. (1994). Neglected Dimensions of Global Land-Use Change: Reflections and Data. *Population and Development Review,* **20**(4), 831–59

Liu, C. (1998). Environmental Issues and the South-North Water Transfer Scheme. *The China Quarterly,* 899–910

Menenti, M. (1997). Regional water resources management and land surface processes in northwestern China. In *Proceedings Workshop Wageningen-China,* Wageningen, May 13, Agricultural Research Department, Research Institute for Agrobiology and Soil Fertility

National Security Council (1995). *Three Gorges Project in the People's Republic of China.* Report by the National Security Council, May 12, 1995

OECD (1997). Agricultural Policies in China. In *China in the Global Economy.* (Paris: OECD)

Prieler, S. (1999). *Temperature and Precipitation Variability in China – A gridded monthly time series from 1958 to 1988.* Interim Report, IR–99–076, IIASA, Laxenburg

Sarkaria, G.S. (1995): A Balanced Perspective on Three Gorges Water Project, China and American Involvement. *Consulting Engineer,* November 20, 1995

United Nations. Economic and Social Commission for Asia and the Pacific (ESCAP) (New York) (1997). *China: Water resources and their use. Study on assessment of water resources of member countries and demand by user sectors*

Wang, H. (1998). Deforestation and Desiccation in China. A preliminary study. In *The Economic Costs of China's Environmental Degradation.* Smil, V., Yushi, M. (coordinators) Project on Environmental Scarcities, State Capacity, and Civil Violence. Committee on International Security Studies, American Academy of Arts and Sciences

Wang, R. (1995). *Three Gorges Project and the Environmental Impacts.* China Yangtze Three Gorges Project Development Corporation, October 1995

World Bank (1997). *Clear water, blue skies: China's environment in the new century.* (Washington, DC)