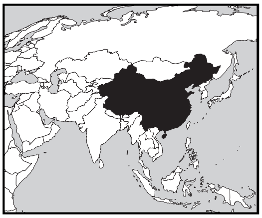

Urban and peri-urban agricultural production in Beijing municipality and its impact on water quality

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SUMMARY: *This paper reviews water use and water resource issues in Beijing Municipality, the main trends in the agricultural production systems in and around the city with respect to land use, input use, production and economic role, and the impacts of agricultural activities on water quality. Rapid urbanization and strong intensification of agricultural production have meant that the quantity and quality of available water resources have become matters of concern. The agricultural sector still has a major role in supplying the municipality's population with food products, but it is also a major water user and has contributed to large gaps between water supply and demand and to high levels of water pollution. Among the main changes in agriculture in the last decade are the loss of arable land to urbanization, the rapid reduction in the area under grain, and the rapid increase in livestock numbers and in areas under vegetables and orchards. Intensive crop and vegetable production and intensive livestock rearing are major water polluters. The paper also points to some measures being taken to address these problems.*

I. BACKGROUND

THIS PAPER IS based on the work of a large team of researchers, and is the result of the first phase of the project Resource Management Options in the Greater Beijing area (RMO–Beijing). This project, launched in September 2002 with a joint planning meeting of project partners, has three major objectives:

- to increase awareness among policy makers and other stakeholders in peri-urban Beijing, and to provide sound information about the impact of different agricultural production systems on environmental quality;
- to define and analyze alternative sustainable land use options for solving resource use problems in a regional context;
- to discuss the results with stakeholders as a step in the formulation of resource management policy and the implementation options.

The RMO–Beijing project is funded by the research programme International Cooperation (DLO–IC) of the Wageningen University and Research Centre (Wageningen UR), and the work is carried out by a project consortium that is composed of the Beijing Academy of Agricultural and Forestry Sciences (BAAS), China Agricultural University (CAU), the Institute of Geographical Sciences and Natural Resources Research (IGSNRR) in Beijing (China); and Alterra, Agricultural Economics Research Institute, the Institute for Animal Science and Health, and Plant Research International of Wageningen University and Research Centre in Wageningen (the Netherlands).

Wageningen, the Netherlands); C H Lu (Institute of Geographical Sciences and Natural Resources Research, Beijing, PR China) and R Roetter (Alterra).

II. INTRODUCTION

DURING THE 1990s, China's urban population grew by about 16 million per year to a total of 456 million in the year 2000.(1) This urbanization process and rising incomes have been the driving forces behind changes in the agricultural sector, with a consequent impact on the environment. Around the many very large and fast-growing cities in China, and in particular mega-cities such as Beijing, intensification of agricultural production is taking place at an accelerated pace. For instance, demand is rapidly increasing for high quality food products (e.g. vegetables and dairy products), creating incentives for farmers to abandon traditional farming systems. The associated increase in animal production can cause pollution of the environment and, furthermore, the increasing production of horticultural crops around urban areas, which generally require large fertilizer and biocide applications and large amounts of irrigation water, can have negative effects on the environment.

The conditions in which the agricultural sector is operating in urban and peri-urban zones are quite specific. A review of the international and national Chinese scientific literature revealed that only a few studies have examined the characteristics of the peri-urban agricultural sector of Beijing. This is in line with earlier reports, which pointed out that the urban and peri-urban agricultural sector has been largely ignored by city planners, local and national policy makers and researchers.(2) Only in the last few years has more attention been paid to these very specific conditions for peri-urban agricultural production.

For Beijing Municipality, the quantity of available water resources and the quality of the available water have already become matters of major concern. Rapid urbanization and the intensification of the agricultural sector have led to serious water scarcity and, in many places, to poor quality water resources. For that reason, a literature review for Beijing Municipality has been compiled, with a focus on both the general structure of the agricultural sector of Beijing and the impacts of urbanization and agriculture on water resources and quality. It covers the following main topics:

- water use and water resources;
- major trends in the agricultural production systems with respect to land use, input use, production and economic role; and
- the impacts of agricultural activities on water quality.

The aim of the RMO–Beijing project,(3) the initial phase of which resulted in this review, is to raise awareness of the impact of different agricultural production systems on environmental quality and, in particular, on water quality in Beijing Municipality and to identify sustainable solutions for such problems. Finding such solutions requires, among other things, integrated planning which takes into account the multiple objectives of future land use, the resource constraints and the various agro-technology options. The first step in such an integrated planning exercise is the identification of opportunities for policy and technical changes. This can be done with Interactive Multiple Goal Linear Programming (IMGLP) models. An IMGLP model forms the core of the modelling framework LUPAS (Land Use Planning and Analysis System), which will be applied to a district in Beijing Municipality in the second phase of the RMO–Beijing project. LUPAS(4) analyses allow quantification of the impacts of current and possible future

1. Statistics Agency of P R China (2002), *China Development Report 2002*, China Statistics Press, page 162.

2. Pothukuchi, K and J L Kaufman (2000), "The food system: a stranger to planning", *Journal of the American Planning Association* Vol 66, No 2, pages 113–124; also Drakakis-Smith, D and C Dixon (1997), "Sustainable urbanization in Vietnam, *Geoforum* Vol 28, No 1, pages 21–38; Yue-man, Yueng (1993), "Urban agriculture research in East and Southeast Asia: record, capacities and opportunities", Cities Feeding People, report 6, IDRC; and Hubbard, M and G Onumah (2001), "Improving urban food supply and distribution in developing countries: the role of city authorities", *Habitat International* Vol 25, pages 431–446.

3. Resource Management Options in the Greater Beijing area.

4. Hoanh, C T, R P Rötter, P K Aggarwal, I A Bakar, A Tawang, F P Lansignan, S Francisco, N X Lai and A Laborte (2000), "LUPAS: an operational system for land use scenario analysis" in Rötter, R P, H Keulen, A G van Laborte, C T Hoanh and H H van Laar (editors), *Systems Research for Optimizing Future Land Use in South and Southeast Asia*, SYSNET Research Paper Series No 2, IRRI, Los Banos, Philippines, 266 pages.

agricultural activities on the degree of pollution and environmental quality, and the achievement of other goals such as employment and income from agriculture in Beijing Municipality. For these LUPAS analyses, the information in the current review will be used as a starting point for the knowledge base on agriculture–environment interactions in Beijing.(5)

5. Diepen, C A, M S van Wijk, X Cheng, R P Rötter, A W Jongbloed, Y Hu, C H Lu, H van Keulen, and J Wolf (2003), "Urban and peri-urban agricultural production in Beijing municipality and its impact on water quality", Alterra Report 757, Alterra, Wageningen.

III. WATER USE AND WATER RESOURCES

A WORLD BANK study estimates that the demand for water in the year 2000 in northern China (i.e. the total in Yellow, Hai (which contains Beijing Municipality) and Huai river basins, which was 169 billion cubic metres per year) exceeded supply (132 billion cubic metres per year).(6) These water shortages are projected to increase over time, although water use efficiency (e.g. for irrigation and urban purposes) is assumed to have improved. This indicates that measures need to be taken to reduce demands and augment supplies. The current solution to dealing with these water shortages is the increasing use of groundwater. However, groundwater is a buffer source of water for dry years, when surface water supply is more limited, and this buffer supply has almost disappeared because of excessive use. As a result, groundwater tables have dropped considerably.

6. World Bank (2002), "Agenda for water sector strategy for North China – summary report", report No 22040-CHA, World Bank, Washington DC.

Surface and groundwater quality in China has seriously deteriorated as a result of pollution from point sources associated with rapid urbanization, industrial development and rising population, and diffuse pollution (nutrients, biocides) from agriculture. The current quality status of surface water in northern China is such that most rivers and lakes fail to meet the state environmental standards, and more than 80 per cent of surface water is classified as seriously polluted.(7) It has also been estimated that about 25 per cent of all lakes in China are adversely affected by eutrophication.(8)

7. See reference 6.

8. World Bank (2001), *China: Air, Land and Water. Environmental Priorities for a New Millennium*, World Bank, Washington DC.

a. Water supply and use

Located near the northern tip of the semi-arid North China plain, Beijing has only 600 millimetres of annual precipitation. This average amount does not mean much in terms of water supply to the city, as annual precipitation can fluctuate by 50 per cent in either direction (Figure 1). In a year of average rainfall, available water resources in Beijing range from 4.2 to 4.5 billion cubic metres, and in a dry year this is reduced to 3.3 billion cubic metres, which is already less than the current consumption in Beijing.(9)

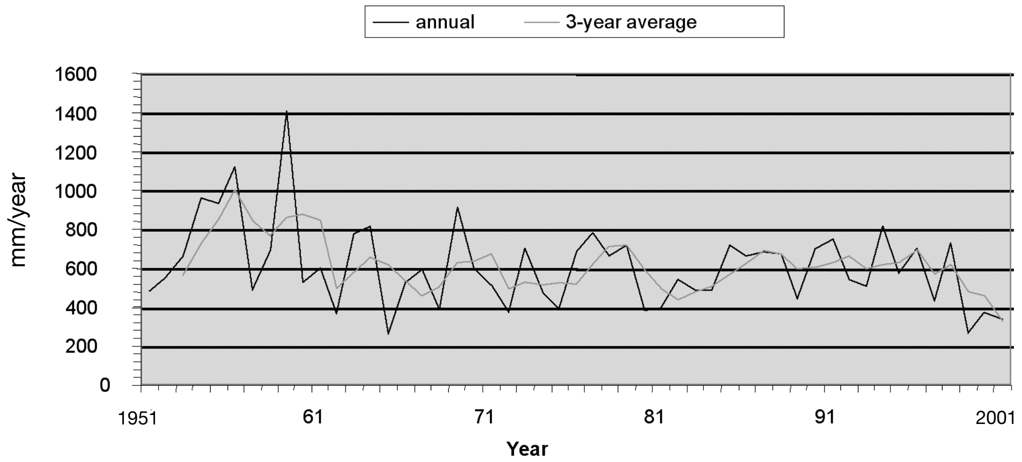
9. Chang, S-D (1998), "Beijing: perspectives on preservation, environment and development", *Cities* Vol 15, pages 13–25.

The climate is characterized by a dry winter and a short rainy period in the warm summer. More than 60 per cent of the annual precipitation is concentrated in the two months of July and August, and more than 80 per cent falls within the four-month period of June to September. The time-series of annual rainfall over the last 50 years (Figure 1) shows that, in spite of strong year to year variations, the 10-year averages were remarkably stable for the period 1961–2000. Ten of these years had rainfall below 400 millimetres, and may be labelled dry years.

Main data on water supply and use in Beijing Municipality in an average year are as follows.

- Total annual water use (10.86 billion cubic metres) consists of natural evapo-transpiration (6.76 billion cubic metres); net human consumption (2.3 billion cubic metres) – i.e. all water in agricultural, industrial and domestic uses minus water re-use; and outflow leaving Beijing (1.8 billion cubic metres).

Figure 1: Annual rainfall in Beijing, 1951–2001



- Total annual water supply (10.75 billion cubic metres) is close to the total water use, and consists of precipitation (9.55 billion cubic metres including the part of precipitation that recharges groundwater) and water inflow (1.2 billion cubic metres) from the neighbouring province. This indicates that, on average, there is no surplus water and that in dry years (e.g. 300 millimetres precipitation results in 5.04 billion cubic metres) excessive groundwater extraction is needed.
- Total water supply from surface water inflow (1.2 billion cubic metres) and from groundwater extraction (2.8 billion cubic metres) is 4 billion cubic metres.
- Water is used (in total 3.85 billion cubic metres in the year 2001) by agriculture (1.64 billion cubic metres); industry (1.01 billion cubic metres); domestic use (1.16 billion cubic metres); and environment (0.03 billion cubic metres).(10) Total re-usable water is estimated at 0.7 billion cubic metres, which results in a human consumption of 2.8 billion cubic metres (higher than the value mentioned above because it includes water re-use).
- Regarding industrial water use, the power industry was the largest user of water, responsible for more than 45 per cent of total water consumed in industry. Other intensive water users include chemical, petroleum and textile industries and ferrous metal processors.(11)

10. China Water Conservancy and Hydropower Press (2002), *China Yearbook of Water Resources*, page 309.

11. See reference 8.

b. Quality and quantity of groundwater

Total groundwater reserves in Beijing Municipality are estimated at 68 billion cubic metres, down to the fourth water-bearing stratum. However, the maximum recoverable groundwater supply is estimated at 2.45 billion cubic metres/year,(12) based on the annual recharge rate. At present, the share of groundwater in the total water supply is 70 per cent. The water supply to agriculture wholly consisted of surface water until the late 1960s. During the 1990s, however, about 80 per cent of agricultural irrigation water was extracted from groundwater.

12. See reference 9.

The extracted amount of groundwater was very low in the 1950s and 1960s (e.g. 0.52 billion cubic metres in 1961). In 1971, it amounted to 1.38 billion cubic metres and increased rapidly in the following years and, in the 1990s (with more than 40,000 wells in Beijing), it reached a level of about

13. See reference 9.

2.7 billion cubic metres annually.[13] This shows that groundwater extraction continues to increase, and in 2000 the groundwater deficit had accumulated to 5.7 billion cubic metres. This development of groundwater extraction is definitely not sustainable. The turning point of the groundwater balance occurred at the end of the 1970s, when annual extraction exceeded total recharge. The consequence of this over-pumping was a serious drop in the depth of the groundwater table in the extraction area (a radius of 25 kilometres from Beijing city centre), from 5 metres below the surface in the 1950s to, on average, 10–20 metres below soil surface at present and 50 metres below the surface in the most heavily extracted areas.

Due to this excessive extraction and the insufficient protection of groundwater, quality has deteriorated since the 1980s. According to one investigation, the amounts of volatile phenol, cyanide, mercury, cadmium and arsenic detected in groundwater increased by 8.6 per cent, to 36 per cent, between 1985 and 1994. The frequency at which environmental standards were exceeded ranged from 22.5 per cent to 47.4 per cent of the time for degree of water hardness, NO_3-N, NO_2-N and NH_4-N. According to Wu (personal communication), the area with excessive nitrate (NO_3-N) concentrations increased from 72 square kilometres in 1981 to 169 square kilometres in 2000, and a monitoring of the groundwater origin protection zone in 1995 found that the major pollutant was nitrates. And only half of the total Beijing Municipality area has shallow groundwater that meets the quality requirements for producing drinking water.

c. Quality and quantity of surface water

The average amount of available surface water is 3.89 billion cubic metres. However, in recent relatively dry years (Figure 1), this amount has markedly decreased. The inflow into the Miyun water reservoir (previously Huairou water reservoir) in the 1950s was 3.13 billion cubic metres, but this has decreased to 1.2 billion cubic metres since the 1970s. Simultaneously, total inflow from neighbouring areas into Beijing Municipality decreased from 2.5 billion cubic metres to 1.0 billion cubic metres.

The quality of surface water started to deteriorate from 1970 when precipitation and inflow from the upper reaches both decreased. From 1970 onwards, diffuse pollution (e.g. from agricultural land areas) increased, as did water use by industry and the urban population. However, the treated fraction of sewage wastewater was only 20 per cent and, hence, rivers and lakes became severely polluted. Monitoring of the quality of the Guanting and Miyun reservoirs showed that, by the end of the 1980s, water quality in Guanting reservoir had deteriorated to "polluted" status, meaning that the water could no longer be used for drinking. And eutrophication is occurring in the Miyun reservoir (Zhu, personal communication).

d. Future trends in water supply and use

An official programme for "sustainable application of water resources during the first decades of the twenty-first century" was set up in 2001 by the Municipal Bureau of Water Conservation. This programme focuses on saving water, on pollution control, on more efficient water resource exploitation and on integrated water utilization.

Three main goals have been set for achievement by 2010.

- Water supply and consumption should be brought into equilibrium. This means that the gap of 1.2 billion cubic metres should be closed through a series of measures, including saving water, especially in agriculture, more wastewater treatment and use of regenerative water, more runoff interception for use, and better protection of waters against pollution. The required investment has been estimated at 17.6 billion Yuan RMB.[14] The measures relating to agriculture will be to convert 80,000 hectares of arable land to grasses and fruit, and to use 0.4 billion cubic metres of regenerative water (i.e. re-use of wastewater from industries, municipalities and agriculture, preferably after treatment) for irrigation.

14. US$ 1 equals 8 Chinese Yuan.

- The quality of surface water should be improved considerably. This means that the water quality in the two biggest reservoirs (Guanting and Miyun), as well as the quality of the inflow (entering from the upper reaches) into Beijing Municipality, should be improved to "non-polluted".
- The gap in the groundwater balance should be closed.

Three further goals have been set for 2030.

- The groundwater that has already been partly polluted should be completely recovered to meet acceptable standards.
- The problem of water resource shortages should be resolved. During the years 2010 to 2030, an additional annual amount of 1.5 billion cubic metres water from the Yangtze River will be diverted into Beijing by means of large-scale engineering.
- Annual water consumption should maintain at a constant level, i.e. 3.57 billion cubic metres. The share of water used by agriculture will be reduced to 0.7 billion cubic metres, which requires a strong reduction compared to present use.

IV. LAND USE AND MAJOR AGRICULTURAL PRODUCTION SYSTEMS

a. Population and land use

BEIJING MUNICIPALITY HAS a total area of about 16,808 square kilometres, and is divided into a city centre, near suburbs, outer suburbs and counties. With a total permanent resident population of 11 million in the year 2000 and almost 2 million temporary resident workers, Beijing has become the eleventh largest city in the world and the second largest city in China. For the whole of Beijing Municipality, the majority of the permanent population can be considered as consisting of non-agricultural residents (69 per cent). However, in the outer suburbs, 64 per cent of the permanent population is defined as agricultural, and in the counties the figure is 73 per cent. With regard to land distribution, the counties cover the largest part of the total land area of Beijing Municipality, followed by the outer suburbs. The majority of the population of Beijing Municipality lives in the city centre and the near suburbs.

The population of Beijing Municipality has roughly tripled in the last 50 years. The main impact of the associated urbanization on the agricultural sector is the loss of arable land areas due to conversion to urban areas. In the period 1947–1997, the city centre expanded annually by about 8.1 square kilometres.[15] In addition to city centre growth, there was also rapid urbanization of Beijing's suburbs (the near and outer suburbs) and counties. Whereas there were only 38 small towns in 1953, in 1993 the suburbs had developed into 78 small towns, 14 satellite towns and 26 areas under construction. As a consequence, the area of arable land has declined by 204,000 hectares since 1949 (a loss of 36 per cent). These rapid changes have

15. Lu, Q (1999), "Historical perspectives of land use and land cover changes in Beijing", mimeo.

resulted in a strong decrease in per capita area of arable land in Beijing Municipality, with a figure at present of only 0.03 hectares of arable land per capita.(16)

16. See reference 15.

A more detailed analysis of land use changes between 1991 and 2001 shows that non-agricultural land in Beijing Municipality covered about 1.2 million hectares in 1991 and had increased to 1.3 million hectares by 2001 (from 71 to 76 per cent of the total land area). These figures clearly show how much pressure the agricultural sector is under from increasing claims for non-agricultural land uses. Within a period of ten years, 72,000 hectares of land had changed from agricultural to non-agricultural use. Not surprisingly, the greatest changes occurred in the near suburbs, where half of the agricultural land area was converted to non-agricultural uses.

b. Arable production systems

Land use. The decline in agricultural land area took place entirely in the arable land category (Table 1), and this land was converted to orchards and non-agricultural land use. In 1991, orchards covered 10 per cent of the total agricultural land area, but by 2001, this had increased to 21 per cent. The absolute increase in orchard area was considerable at 35,000 hectares. This increase is a direct response to the higher demand for fruits from the urban consumers. At the same time, these changes are also stimulated by the Chinese government, which subsidizes the conversion of arable land to perennial crop lands such as orchards. The government is stimulating this conversion guided by the expectation that farmers will not be able to compete with their grain crops on the world market, and that orchards will better serve the objectives of sustainable land use, especially with regard to water and soil conservation, sufficient farmer income, and the demands of urban consumers.

The total area of land that is used for arable cropping can be divided into the following categories:

- food crops (wheat, rice, maize, millet, sorghum, tubers, beans);
- cash crops (cotton, peanut, sesame, sunflower, tobacco);
- vegetables; and

Table 1: Distribution of total agricultural land over different land use types in 1991 and 2001 in the different parts of Beijing Municipality, and the change in land use over this time period (hectares)

	1991			2001			Difference 1991–2001		
	Arable land	Orchards	Aqua-culture	Arable land	Orchards	Aqua-culture	Arable land	Orchards	Aqua-culture
Near suburbs	43,555	5,174	1,667	20,206	2,526	1,189	-23,349	-2,648	-478
Outer suburbs	196,827	17,359	5,398	153,924	33,025	5,024	-42,903	15,666	-375
Counties	167,672	27,201	15,121	126,426	49,439	15,950	-41,245	22,238	828
Beijing Municipality	408,054	49,735	22,187	300,557	84,991	22,162	-107,497	35,256	-24

SOURCE: Compiled by authors from data of the Beijing Municipal Statistical Bureau (2002), *Beijing Statistical Yearbook 2001*, China Statistical Publishing House, Beijing, China.

Table 2: Distribution of arable land area over different crop categories in 1991 and 2001 in different parts of Beijing Municipality (hectares)

	1991				2001			
	Food crops	Cash crops	Vegetables	Others, flowers and nurseries	Food crops	Cash crops	Vegetables	Other, flowers and nurseries
Near suburbs	19,265	105	2,180	22,005	6,295	45	6,076	7,790
Outer suburbs	151,388	5,333	4,569	35,536	67,483	7,326	36,495	42,621
Counties	117,600	10,674	4,804	34,593	63,486	11,148	35,463	16,330
Beijing Municipality	288,254	16,112	11,554	92,135	137,264	18,519	78,033	66,741

SOURCE: Compiled by authors from data of the Beijing Municipal Statistical Bureau (2002), *Beijing Statistical Yearbook 2001*, China Statistical Publishing House, Beijing, China.

- flowers, nurseries and other (e.g. forage crops and grassland).

Table 2 shows considerable differences in land use change for these categories for the period 1991–2001. The land area used for grain crops dropped sharply. Surprisingly, the land area used for flowers and nurseries also declined. With rising incomes and urbanization, one would expect that the land area used in the ornamental sector would increase instead of decrease. The main explanation is probably the strong decrease in arable land area (Table 1) due to the very rapid urbanization.

The area under vegetables increased substantially, in line with expectations. The vegetable land area grew by 19 per cent per year for the period 1991–2001, a total increase of 66,000 hectares (Table 2). This has changed the arable land use distribution considerably. In 1991, the share of vegetables of the total arable land use was only 3 per cent, with grain crops dominating (71 per cent). However, in 2001, the area with vegetables had increased to 26 per cent, and the area with grain crops had decreased to 46 per cent (Table 2).

If we look at the location of the different types of arable land use, it is clear that most arable land uses are moving away from the near suburbs to the more distant zones (Table 2). Flowers and nurseries are moving from both the near suburbs and counties towards the outer suburbs.

Input use. Water quality is strongly affected by the extent of fertilizer and biocide use. In the period 1991–2001, total fertilizer use increased by only 1 per cent per year (Table 3). However, as the arable land area decreased by 108,000 hectares (26 per cent) (Table 1) in the same period, total fertilizer use per hectare increased considerably, from 351 kilograms per hectare to 522 kilograms per hectare on average for Beijing Municipality as a whole. Fertilizer use within Beijing Municipality varied widely, for example, in 2001, between 158 and 1,060 kilograms per hectare total fertilizer on average per district in Beijing Municipality (in total 14 districts). In both 1991 and 2001, nitrogen made up the majority of all fertilizer application (Table 3). In 1991, the contribution of nitrogen to total fertilizer consumption was 75 per cent, and in 2001, 66 per cent.

Total annual biocide use increased over the decade by about 2 per cent. Biocide consumption per hectare increased more rapidly, from 9 kilograms

Table 3: Use of fertilizers and biocides in 1991 and 2001 on arable land areas in Beijing Municipality

	Fertilizer use in effective components				Fertilizer use per hectare of arable land				Total biocide use	
	Total (tons)	Nitro-gen (tons)	Phospho-rus (tons)	Potass-ium (tons)	Total (kg/ha)	Nitrogen (kg/ha)	Phospho-rus (kg/ha)	Potass-ium (kg/ha)	(tons)	(kg/ha)
1991										
Near suburbs	11,060	8,682	1,640	739	254	199	38	17	843	19
Outer suburbs	79,076	55,503	15,853	7,720	401	282	80	39	1,462	7
Counties	53,488	43,197	7,817	2,475	318	257	47	15	1,324	8
Beijing Municipality	143,624	107,382	25,309	10,934	351	263	62	27	3,629	9
2001										
Near suburbs	5,329	3,802	1,051	477	264	188	52	24	287	14
Outer suburbs	79,471	49,638	19,940	9,894	516*	322	130	64	1,755	11
Counties	71,981	49,851	14,576	7,455	569*	394	115	59	2,431	19
Beijing Municipality	156,781	103,291	35,566	17,826	522	344	118	59	4,473	15

*This high number may partly be explained by fertilizer and biocide use on orchard area which is not considered in the arable land area.

SOURCE: Compiled by authors from data of the Beijing Municipal Statistical Bureau (2002), *Beijing Statistical Yearbook 2001*, China Statistical Publishing House, Beijing, China.

in 1991 to 15 kilograms in 2001. This was due to the increasing relative share of biocide-intensive crops (such as vegetables) in the land use pattern.

The area of irrigated land has decreased considerably (by 94,000 hectares) in the ten years since 1991. This was mainly caused by the decrease in agricultural land area (Table 1). Moreover, the fraction of the total arable land area that was irrigated decreased from 70 per cent in 1991 to 60 per cent in 2001,[17] probably as a result of the increase in orchard land area (Table 1). This decline in irrigated area resulted in a reduction in total water use for irrigation from 1.8 billion cubic metres in 1991 to 1.2 billion cubic metres in 2001.

17. See reference 8.

c. Animal production systems

General. From 1978, when China adopted an "open and reform" policy, animal husbandry systems developed very quickly. At the time, backyard rearing played an important role in livestock production. At the start of the 1980s, an official government-supported campaign was launched to guarantee the supply of animal/poultry produce to urban residents. To realize this target, advanced technology using intensified, mechanized and confinement rearing was introduced. A large number (more than 3,000) of large and medium-sized livestock farms were established. For example, in 1990, there were already 1,254 large-scale swine farms (farms with more than 100 sows and with an annual production of about 1,500 pigs). These state-owned livestock farms have made a large contribution to livestock production. However, due to the central planning system and out-dated management, the majority of these livestock farms work at a loss, even though they get considerable subsidies from the municipal government.

A new household responsibility system was introduced in around 1992. Since then, a large proportion of state-owned livestock farms have been changed to collectively owned or specialized rearing household-owned farms. In 1997, the Beijing municipal government decided to promote the so-called "small rearing plot". Such plots consist of several specialized rearing households and receive subsidies from the government for their technical innovation. As a result, the current number of farms with backyard rearing has dropped to less than 10 per cent of the total. Also, the number of large-scale livestock farms has been reduced from more than 2,300 farms (swine and poultry) in 1990 to 1,445 in 1997 and 897 in 2001. Simultaneously, the number of "small rearing plots" grew quickly, amounting to 1,928 in 2001, with the number of specialized rearing households reaching 159,000.

Because livestock production is regarded as the best way to increase farmers' incomes, in 2001, the Beijing government decided that the proportion of livestock production in the total agricultural production value should increase from the present 50 per cent to 60 per cent by the year 2010. Simultaneously, the government emphasized the importance of so-called "green animal husbandry" which, in future, should result in less environmental pollution.

In 1996, the municipal government decided to move the livestock farms that were located within the fourth ring road (near the suburbs) into the outer suburban areas. The next step will be the removal of all livestock farms located within the fourth and fifth ring roads. This means that livestock production will disappear from the near suburban districts.

Production and consumption. A review of the livestock sector in Beijing[18] clearly indicates a growing demand for meat in the city, as well as the resulting increase in production. Following a more than ten-fold increase in per capita income in the period 1980–1995, increasing numbers of people can afford to buy meat. This, combined with the large population growth in Beijing, has resulted in a booming livestock sector around the city.

According to Ke, the demand for meat has increased at an annual rate of 9 per cent. This has brought enormous pressure on local production to reach self-sufficiency, which for meat in Beijing is estimated at around 60 per cent.[19] This resulted in rapid increases in meat production, i.e. a doubling of the pork production, an increase in poultry production by a factor of 3.7, and a 12-fold increase in beef production. Ke states that this growth in production was achieved through improved production technology, such as the introduction of high-yielding animal breeds and the use of modern feed processing.

For livestock production in Beijing Municipality as a whole, total feed input consisted of 2.3 million tons of concentrates, 2.8 million tons of corn silage (fresh weight), 0.44 million tons of alfalfa (dry) and 0.40 million tons of hay (dry) in 2001. This was associated with the production of 312,000 tons of pork, 258,900 tons of poultry, 30,200 tons of mutton, 43,400 tons of beef, 155,600 tons of eggs and 429,000 tons of milk in 2001.

Livestock numbers and density. Data compiled for this review indicate that the rate of growth in number of livestock has declined in recent years for pigs (only 0.2 per cent per year at present), but that rates for cattle, poultry and sheep are still high at 7 per cent, 7 per cent and 30 per cent per

18. Ke, B (1998), "Area-wide integration of crop and livestock: case study Beijing", regional workshop on area-wide integration of crop–livestock activities, 18–20 June, 1998, FAO Regional Office, Bangkok, Thailand.

19. See reference 18.

Table 4: Livestock in the various parts of Beijing Municipality in 1994 and 2001, and the change over this time period (thousands)															
	1994					2001					Difference				
	Cattle	Swine	Goats	Sheep	Poultry	Cattle	Swine	Goats	Sheep	Poultry	Cattle	Swine	Goats	Sheep	Poultry
Near suburbs	17	1,124	15	14	14,580	11	468	11	53	2,392	-6	-656	-5	39	-12,187
Outer suburbs	119	3,474	711	194	55,203	234	4,117	702	1,221	109,980	115	643	-9	1,027	54,777
Counties	138	2,240	509	162	47,296	189	2,363	411	1,066	83,220	50	123	-98	903	35,925
Beijing Municipality	274	6,838	1,235	370	117,078	434	6,948	1,123	2,340	195,592	159	110	-112	1,970	78,514

SOURCE: Compiled by authors from data of the Beijing Municipal Statistical Bureau (2002), *Beijing Statistical Yearbook 2001*, China Statistical Publishing House, Beijing, China.

year, respectively. This growth has resulted in nearly 7 million pigs, 195 million poultry birds, more than 2 million sheep and 434,000 cattle in the year 2001 (Table 4).

Differences in growth rates among the various districts of Beijing Municipality are considerable.[20] For all livestock types, except for sheep (as a strong increase in the number of sheep is found in all parts of Beijing Municipality), the growth rates were negative for the near suburbs, mostly very high for the outer suburbs, and high for cattle and poultry (but not for pigs) in the counties (Table 4).

In 1994, highest livestock densities (i.e. number of animals per hectare of total agricultural land) were observed in the near suburbs, in particular for pigs and poultry. Between 1994 and 2001, livestock densities in the near suburbs decreased, and in the outer suburbs strongly increased. Also in the counties, livestock densities increased, although to a lesser extent. Consequently, in the year 2001, livestock densities were highest in the outer suburbs. These strong increases in livestock density are the result of both the strong increases in the number of livestock (mainly cattle, sheep and poultry) (Table 4) and the decrease in total agricultural land area (Table 1).

d. Economic role of the agricultural sector

The two most important objectives of the agricultural sector are to generate income and to supply food.

Income generation. The contribution of the primary sector[21] to the gross domestic product (GDP)[22] of Beijing Municipality has considerably decreased since 1991, and appears to be relatively small in 2001. Only 3 per cent of the total GDP is generated by the agricultural sector which, however, still generated employment for about 11 per cent of the total working force in Beijing Municipality. The relatively low productivity of the primary sector is reflected in the value of GDP per employed person, which was about US$ 1,637[23] in 2001, i.e. one-third of that in the other sectors.

Within the primary sector the largest shares are contributed by the farming sub-sector, which includes both arable cropping and fruit tree cultivation, and the animal husbandry sub-sector. The latter shows the highest labour productivity, generating US$ 4,748 per person-year, and currently employs only 13 per cent of the total number of persons active in

20. See reference 5.

21. The primary sector is defined by the Beijing Statistical Office to contain all the following agricultural activities: farming, forestry and fishery.

22. GDP is the value (at market prices) of all outputs minus the value of all non-fixed inputs that are used.

23. Based on the following exchange rate: US$ 1 = 8 Chinese Yuan.

Table 5: Economic structure of the agricultural sub-sectors in Beijing Municipality in 2001

	Gross Domestic Product (at current prices)			Employment		GDP per employed person	
	(million Yuan)	(million US$)*	%	(persons)	%	(Yuan/ person)	(US$/person)
Farming**	4,866	608	52	526,230	74	9,247	1,156
Forestry	433	54	5	76,576	11	5,654	707
Animal husbandry	3,604	451	39	94,886	13	37,984	4,748
Fishery	405	51	4	13,072	2	30,988	3,873
All agricultural sub-sectors	9,308	1,163	100	710,763	100	13,096	1,637

*Based on the exchange rate: US$ 1 = 8 Chinese Yuan.
**Farming consists of arable cropping (grains, oil crops, fibre crops and horticulture) and fruit tree cultivation.

SOURCE: Compiled by authors from data of the Beijing Municipal Statistical Bureau (2002), *Beijing Statistical Yearbook 2001*, China Statistical Publishing House, Beijing, China.

Table 6: Contribution of products from different crop categories to total farming gross output value in Beijing Municipality in 1991 and 2001

	1991		2001		Change	
	(million US$)	%	(million US$)	%	(million US$)	%
Cereal	181	38	72	11	-109	-60
Beans	3	1	8	1	5	167
Cash crops	10	2	27	4	17	170
Vegetable and melon	196	41	386	57	190	97
Fruit and mulberry	58	12	122	18	64	110
Others	31	6	65	10	34	110
All output	478	100	680	100	202	42

*Based on the exchange rate: US$ 1 = 8 Chinese Yuan.

SOURCE: Compiled by authors from data of the Beijing Municipal Statistical Bureau (2002), *Beijing Statistical Yearbook 2001*, China Statistical Publishing House, Beijing, China.

the agricultural sector (Table 5). The farming sub-sector, showing a four times lower labour productivity, still employs the largest share of the agricultural workforce.

For the farming sub-sector, the relative contributions to the total gross output value are given for the main crop categories (Table 6). Between 1991 and 2001, total output of all farming activities increased by 42 per cent, to which all crops contributed except for cereals. Vegetable production contributes most to the total value of outputs in the farming sub-sector, followed by fruits and cereals.

Food supply. The agricultural sector in Beijing Municipality plays a

Table 7: Production per capita of various food products by the agricultural sector in the different parts of Beijing Municipality in 2000

	Vegetables	Fresh eggs	Cows' milk	Dry and fresh fruits	Fish	Slaughtered pigs	Hens
	(kg/capita/ year)	(kg/capita/ year)	(kg/capita/ year)	(kg/capita/ year)	(kg/capita/ year)	(head/capita/ year)	(head/capita/ year)
Near suburbs	80.8	1.7	3.1	3.3	1.6	0.07	0.12
Outer suburbs	815.4	20.6	27.9	78.1	13.8	0.89	1.92
Counties	1,114.8	46.8	41.7	189.5	14.4	0.67	4.04
Beijing Municipality	382.7	12.5	23.7	47.7	5.9	0.33	1.10

SOURCE: Compiled by authors from data of the Beijing Municipal Statistical Bureau (2002), *Beijing Statistical Yearbook 2001*, China Statistical Publishing House, Beijing, China.

Table 8: Comparison of production of agricultural outputs and consumption in Beijing Municipality in 2001

	Total consumption (kg)	Total production (kg)	Self-sufficiency in agricultural products (%)
Grain	1,148,638,380	1,049,169,000	91
Vegetables	1,151,079,020	5,228,671,000	454
Pork, beef, mutton	190,960,940	382,244,000	200
Milk	343,043,320	429,004,000	125
Fresh eggs	151,679,860	155,587,000	103
Aquatic products	128,349,360	74,302,100	58

SOURCE: Compiled by authors from data of the Beijing Municipal Statistical Bureau (2002), *Beijing Statistical Yearbook 2001*, China Statistical Publishing House, Beijing, China.

major role in the supply of food products to the population of Beijing. Table 7 gives an overview of the production of the most important agricultural products in the different parts of Beijing Municipality, expressed as total production per capita of the total population. These data indicate that with respect to vegetable production, the municipality can be regarded as self-sufficient. The large variation in per capita production among parts of Beijing Municipality indicates which areas (outer suburbs and counties) (Table 7) produce surplus vegetables and can supply other areas. Overall, outer suburbs and counties produce the largest shares of all agricultural products in Beijing Municipality. The only exception is cows' milk, of which 42 per cent is still produced by the municipal farms. This large production of cows' milk at state farms is inherited from pre-reform times, when all dairy cattle in Beijing were raised at state and collective farms. Individual farmers were not allowed to raise large animals.(24)

Comparing the major agricultural production data for Beijing Municipality in 2001 with consumption for 2001 (Table 8) shows that, in general terms, the agricultural sector in Beijing Municipality appears to be self-suffi-

24. See reference 18.

cient. For vegetables and meat, there even seems to be an oversupply, and it is only for aquatic products that the agricultural sector of Beijing Municipality can not meet demand. This is not surprising, as Beijing Municipality is not located near the sea and, hence, all marine products have to be transported there. Of course, these figures are rough and lack detail, such as, for example, the types of vegetables and the kinds of meat. Hence, there might be a shortage of certain types of vegetables (in a certain season) or meat.

V. IMPACT OF AGRICULTURAL ACTIVITIES ON WATER QUALITY

THE AGRICULTURAL SECTOR has a strong impact on both the quantity and the quality of water resources. Water pollution is mainly caused by runoff and by leaching of pesticides and organic and chemical fertilizers from, in particular, the intensive (i.e. high input levels of fertilizers and biocides) arable and vegetable cropping areas. In addition, the livestock sector and the associated manure production are major causes of air, land and water pollution, as described in a review of the livestock sector in China.(25)

25. Ke, B (2002), "Perspectives and strategies for the livestock sector in China over the next three decades", *Livestock Policy Discussion Paper* No 7, FAO, Rome, Italy.

a. Vegetable crop production

In northern China, increasing fertilizer application rates result in N-pollution of groundwater. Zhang et al. showed that nitrate pollution of ground and surface water has become a serious problem.(26) At more than half of their measuring points, nitrate concentrations exceeded the permitted limit (50 milligrams per litre) for drinking water. Critical situations were found particularly in the vegetable production areas, with nitrate concentrations in groundwater and drinking water up to 300 milligrams per litre. Results from this study showed that at all locations with excessive nitrate concentrations, high N-fertilizer doses (exceeding 500 kilograms of nitrogen per hectare) were applied, whereas less than 40 per cent of applied nitrogen was taken up by the crop.(27) This indicates that nitrogen fertilizer management needs substantial improvement, in order to achieve efficiency gains and to reduce total N-applications in the near future.

26. Zhang, W L, Z X Tian, N Zhang and X Q Li (1996), "Nitrate pollution of groundwater in northern China", *Agriculture, Ecosystems Environment* Vol 59, pages 223–231.

27. See reference 26.

The relationship between the level of application of chemical fertilizers on vegetable crops and the degree of groundwater pollution has been studied in three areas in northern China, namely, Beijing Municipality, Tianjin Municipality and Tangshan Municipality (Zhang, personal communication). From the collected samples of drinking water and groundwater, 73 per cent showed nitrate concentrations above the permitted level of 50 milligrams per litre for drinking water. The highest nitrogen application was recorded in Qinshuiyin village, in Daxing County, Beijing, in a rotation of cucumber and spinach (558 kilograms per hectare per year), and the nitrate concentration in shallow groundwater exceeded 500 milligrams per litre. In another study on the impact of excessive use of nitrogen fertilizer in vegetable fields on nitrate concentration in groundwater (in Haidian District, Beijing),(28) average annual nitrogen fertilizer rate was 780 kilograms per hectare per year. Average doses of nitrogen, phosphate and potassium fertilizer for all Beijing Municipality were 674, 460 and 211 kilograms per hectare per year, respectively. Nitrate concentrations in shallow groundwater in a quarter of the vegetable plots in Beijing Municipality exceeded the permitted level (50 milligrams per litre) for drinking water.

28. Chen, X-P and F S Zhang (1996), "The problems and countermeasures of vegetable fertilization in Beijing", *Journal of China Agricultural University* Vol 1, No 5, pages 63–66.

b. Livestock production

According to statistics from the Ministry of Agriculture (1997), total animal manure production in Beijing Municipality was 11.93 million tons, containing 243,000 tons of chemical oxygen demand, 183,000 tons of biological oxygen demand, 17,000 tons of phosphorus and 59,000 tons of total nitrogen. Average manure excretion per hectare of agricultural land for 2001 was 29 tons. Only 3 per cent of this livestock excretion has been treated to prevent pollution. Pollution from seven livestock farms was investigated in the year 2000 by the Section of Rural Energy and Environment of the Beijing Municipal Bureau of Agriculture.[29]

29. For the degree of pollution in the water discharged from these farms, see Diepen et al. (2003), reference 5.

Among the different types of livestock and poultry production systems, the strongest pollution comes from swine production, as swine farms adopted the so-called "wet cleaning method for excretion". The shortcomings of this method are, first, that the mixture of swine urine and faeces drops through the slatted floor and, second, that the manure is washed away by running water into ponds. This liquid manure from swine production has no value for arable farming and cannot easily be treated or transported to other areas because of its high water content.[30] This results in its disposal into ditches and ponds, and in serious pollution of ground and surface waters. According to the statistics of the Livestock Section of the Beijing Municipal Bureau of Agriculture, annual discharge of chemical oxygen demand from pig farms reached 103,000 tons, which accounts for 54 per cent of the total chemical oxygen demand produced by the whole livestock sector.

30. See reference 25.

All other livestock and poultry farms adopted the dry cleaning method to collect manure. This solid manure has a high market value for arable and vegetable farmers, in particular the chicken manure, which can be transported relatively easily[31] and can be used on arable and vegetable production areas with limited soil and water pollution, if applied in recommended doses.

31. See reference 25.

Livestock in Beijing Municipality consumes 25.6 million cubic metres of water annually and produces 15.7 million cubic metres of wastewater. For each ton of pork produced, 200 cubic metres of water are needed. According to monitoring by the Municipal Bureau of Environment Protection, the annual increase in groundwater pollution from diffuse sources of pollutants (from agricultural activities) amounts to 28.8 per cent in recent years.

Due to the rapidly expanding and industrialized livestock production sector, which also uses large amounts of raw materials for animal feeding from other regions, the mean nitrogen and phosphorus loads on agricultural land in Beijing Municipality have greatly increased. This leads to enhanced levels of nitrate and phosphate in ground and surface water. In addition, the use of high supplementary levels of copper and zinc in the feeds may lead to unacceptable accumulation in the soil and leaching of these heavy metals.

Some effort has been put into the treatment of excreta from the livestock sector. Examples are heat drying of chicken manure, separating solid fraction from liquid fraction in liquid manure, and fermenting animal manure to generate methane.[32] No ideal method has been identified. Even if a relatively good method were available, such as the separation of the solid fraction from the liquid fraction, the solid fraction being used for making organic fertilizer and the liquid fraction being anaerobically fermented in a biogas generator, this method of discharge treatment could not be applied. The reasons are, first, the investment and maintenance costs are too high and, second, the relevant laws appear not to be compulsory. Hence, in the

32. See reference 25.

foreseeable future, the pollution problems arising from the livestock production sector will not be solved easily.

VI. SUMMARY AND CONCLUSION

FOR BEIJING MUNICIPALITY, the quantity and quality of available water resources have become matters of concern, as a result of rapid urbanization and the strong intensification of agriculture.

A review of water use and water resources indicates that current water consumption is much higher than water supply and, consequently, groundwater levels have dropped substantially. This indicates the need for changes such as water saving, especially in agriculture, more wastewater treatment and use of regenerative water, and more runoff interception for use. In the long term, the water supply may be increased by water diversion from the Yangtze River.

The main changes that have taken place in the agricultural production systems in Beijing Municipality in the last decade are as follows:

- a loss of arable land area due to conversion to urban area;
- a marked decrease in arable land area and a marked increase in orchard land area;
- a rapid reduction in grain crop land area and marked increase in vegetable crop land area;
- a strong increase in fertilizer use per hectare;
- a sharp reduction in total water use for irrigation;
- a shift in livestock production from the near suburbs to the outer suburbs and counties; and
- a rapid increase in livestock numbers, in particular cattle, sheep and poultry.

The quality of surface water has deteriorated since the 1970s, when the diffuse pollution (from agricultural land areas) increased substantially, as did total water use by industry and the urban population. The treated fraction of sewage waste was low and, hence, rivers and lakes became severely polluted. Also, the quality of groundwater has deteriorated since the 1980s. The frequency with which environmental standards for groundwater are exceeded is high, in particular for nitrates. Water pollution from agricultural activities is mainly caused by both runoff and leaching of pesticides, and organic and chemical fertilizers from, in particular, the intensive arable and vegetable cropping areas (i.e. those characterized by high input levels of fertilizers and biocides and high cropping intensity). In addition, the intensive livestock sector and the associated high manure production are major causes of water pollution.

In the subsequent phase of the RMO–Beijing project, the intensification of agricultural production and its impact on water quality and the competitive demands (i.e. from agriculture and urban areas) on the limited water resources are to be analyzed with LUPAS. Results of these analyses will indicate the effects of, and identify options for, change in land use, water saving, improved production technologies and more environment-friendly agricultural production systems. Promising options for future development, based on these analyses, and supportive policies will be developed and discussed in close collaboration with stakeholders. These analyses and discussions should finally indicate the range of possible policies, the future options for urban, industrial and agricultural development, possible conflicting effects of these policies, and the land use, soil and water pollution, water quality, water supply and demand in Beijing Municipality that would result from the different policies.