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FAO
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40

Guidelines to control water pollution from agriculture in China

Decoupling water pollution from agricultural production

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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Foreword

This publication is the result of the collaboration over a number of years between the Chinese Ministry of Agriculture and FAO in the field of agricultural non-point source (NPS) pollution and its role in water quality. The aim of this collaboration was to exchange knowledge and experience in dealing with NPS pollution. It also sought to improve identification of the causes and assessment of the impacts of agriculture on water quality, and promote the development and application of technologies to control NPS in China.

The role of agriculture in water pollution has been recognized in the United States, the European Union and other developed countries for many decades. China's rapid economic growth and green revolution have placed unprecedented pressure on the availability and quality of its water resources and is rapidly moving towards the situation in many developed countries where agriculture has become the main source of water pollution. In the past decade, increasing scientific evidence from Chinese water chemists, agronomists, geographers, limnologists, and others has shown that non-sustainable agriculture is a serious problem for water quality. The response to this problem has been to shift agricultural policies towards sustainable growth. This has led to the development of many new techniques and integrated resource management practices to address agricultural NPS pollution.

International experiences have proved that technology alone will not suffice to prevent agricultural NPS pollution, the efficacy of such technologies and measures will be highly dependent on actions to improve education, training and farm advisory support services so as to raise public awareness of the causes and consequences of agricultural NPS pollution. As there were no guidelines on the meaning, consequence and control of agricultural NPS pollution in China, the Ministry of Agriculture, therefore, delegated CAAS-IEDA to fill this gap in collaboration with FAO. While the science behind NPS pollution is universal, the agricultural system in China is very different to that of western countries, especially in the following aspects: fields are small and bounded by bunds to retain water (for paddy rice in the south, and to retain rainwater and irrigation water in the drier northern half of the country), which means that the relationship between rainfall/irrigation and runoff is quite different to that of western agriculture. Much agriculture is carried out by hand in China so that western best management practices are only useful to a limited extent; and the scientific basis for the assessment of agriculture NPS pollution is much more limited than in western countries. For these reasons these Guidelines expand upon an earlier FAO monograph[1] that addressed the role of agriculture in water pollution at a more general level.

1 Control of Water Pollution from Agriculture. FAO Irrigation and Drainage Paper No. 55, Food and Agriculture Organization of the United Nations, Rome

These Guidelines address all major forms of agricultural production and are intended to be practical rather than academic. We hope that the Guidelines will be useful in building awareness of this issue in China as well as for training farmers, agricultural extension workers, pollution control officials, and young professionals. Because many other countries in South and Southeast Asia have similar agricultural systems, we anticipate that these Guidelines will have practical value in other countries. The fact that China is now aggressively addressing the NPS issue through research, new and revised regulations; and education, other countries may learn from the Chinese experience.

Hiroyuki Konuma

Assistant Director-General
and Regional Representative

FAO Regional Office for
Asia and the Pacific

Wang Ying

Director-General,
Department of International Cooperation

Ministry of Agriculture of the
People's Republic of China

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ADB	Asian Development Bank
ARC	American Red Cross
AWDI	Alternative wet and dry irrigation
BCE	Before Common Era
BOD	Biochemical oxygen demand
CA	Conservation agriculture
CIA	Central Intelligence Agency
COD	Chemical oxygen demand
CWA	Clean Water Act (United States)
DO	Dissolved oxygen
DTW	Deep tube wells
EPA	Environmental Protection Agency
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
FAO	Food and Agriculture Organization of the United Nations
FAP	Flood action plan
FCD	Flood control and drainage
FCDI	Flood control, drainage and irrigation
FLIA	Farm land improvement associations
FMTW	Force-mode tubewell
FWUC	Farmer water user communities
GBH	Gravel bed hydroponics
GDD	Growing degree days
GDP	Gross domestic product
GIS	Geographical information systems

HYV	High-yielding variety
IBRD	International Bank for Reconstruction and Development
IA	Irrigators' association
ICARDA	International Center for Agricultural Research in the Dry Areas
ICID	International Commission on Irrigation and Drainage
IDA	International Development Association
IEC	Information education and communication
IFAD	International Fund for Agricultural Development
IAEA	International Atomic Energy Agency
IRBM	Integrated river basin management
IRC	International Water and Sanitation Centre
IRSWR	Internal renewable surface water resources
IRWR	Internal renewable water resources
ISEAS	Institute of Southeast Asian Studies
ISRWR	Internal renewable surface water resources
IWASRI	International Waterlogging and Salinity Research Institute
IWM	Improved irrigation water management
IWMI	International Water Management Institute
JBIC	Japan Bank for International Cooperation
JCWR	Nepal-India Joint Committee on Water Resources
JICA	Japan International Cooperation Agency
LGU	Local government unit
LLP	Low lift pump
MDG	Millennium Development Goals
MOP	Manually operated pumps
MPO	Master Plan Organization
MRC	Mekong River Commission

MSF	Multi-stage flash
MV	Modern variety (seeds)
NGO	Non-governmental organization
O&M	Operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OFWM	On-farm water management
OPEC	Organization for the Petroleum Exporting Countries
PARC	Pakistan Agricultural Research Council
PDR	People's Democratic Republic (Lao)
PIMD	Participatory Irrigation Management and Development
RAP	Regional Office for Asia and the Pacific (FAO)
R&D	Research and development
RO	Reverse osmosis
RSC	Residual sodium carbonate
SAR	Sodium adsorption ratio
SCARP	Salinity Control and Reclamation Project
SIDA	Swedish International Development Agency
SME	Small and medium enterprises
SMO	SCARP monitoring organization
SMP	Strategic management plan
SOF	Securing Our Future (The Asia Foundation)
SOPAC	Scripps Orbit and Permanent Array Centre
SRI	System of rice intensification
SSWRD	Small-scale water resources development
STW	Shallow tube wells
SWIM	Small water impounding management
TA	Technical assistance

TDS	Total dissolved solids
TRWR	Total renewable water resources
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
USDA	United States Department of Agriculture
USSR	Union of Soviet Socialist Republics
VDSSTW	Very deep-set shallow tubewell
WEPA	Water Environment Partnership in Asia
WFP	World Food Programme
WHO	World Health Organization
WM	Water management
WSI	Water-saving irrigation
WUA	Water user association
WUG	Water user group
WWF	World Wildlife Fund

1. Role of agriculture in water pollution

Edwin D.ONGLEY[1] and YU Tao[2]

1.1 INTRODUCTION

Since the beginning of the Eleventh Five-Year Plan (2006–2010) the People's Republic of China has greatly increased its efforts to control water pollution, but the situation is still very serious in much of the country. Agriculture, including plant production, animal breeding and aquaculture, together with rural villages, are major contributors to this problem. This chapter introduces key concepts to assist understanding of the role of agriculture in water pollution in China and provides figures and specific examples to illustrate the challenge, it also provides a rough review of the international experience with agriculture pollution control.

1.2 WATER POLLUTANTS

Water pollution in China tends to be more narrowly defined than in other countries, and the main targets for control continue to be chemical oxygen demand (COD) and ammonia (NH_3 – a form of nitrogen), which are major contributors to water pollution. Nevertheless, Chinese law and Chinese scientists recognize there are many types of water pollution. The United States Environmental Protection Agency (US-EPA) classified water pollutants under the following categories (US-EPA, 2009) listed in Table 1.1.

1.3 WHAT IS NON-POINT SOURCE POLLUTION?

Point source pollution – We tend to think of environmentally or health-damaging pollution as wastewater that comes from factories, municipal and industrial wastewater treatment plants, urban storm sewers, and any other sources where polluted water is discharged through a pipe or channel. This type of pollution is known as 'point source' (PS) pollution. Because it is discharged through pipes or channels, it can be easily monitored for quantity and water quality (physical and chemical properties). Also, because it flows through pipes or channels, PS pollution can be controlled by collection and treatment of the polluted water before it is discharged into rivers, lakes or reservoirs.

In many countries, such as in China and the United States, most forms of PS pollution are controlled by legislation that requires treatment of PS pollution to specific water quality standards, however the level of treatment and level of enforcement of legislation vary greatly from country-to-country.

1 Formerly, National Water Research Institute, Environment Canada (retired; currently international consultant).

2 Chinese Research Academy of Environmental Sciences.

TABLE 1.1

Categories of major water pollutants[1]

Highlighted categories can be caused by agriculture and/or rural living.

Pollutant category	Definitions/Examples
Dioxins	Highly toxic, carcinogenic, petroleum-derived chemicals that are persistent in the environment and may be found in fish tissue, water column, or sediments.
Metals	Substances identified only as 'metals'; also, selenium, lead, copper, arsenic, manganese, others (Note: may, in some cases, include mercury).
Mercury	A toxic metal with neurological and developmental impacts on wildlife and humans; found in fish tissue, water column, or sediments. In agriculture, mercury can be associated with mercury-treated seed.
Nutrients	Primarily nitrogen and phosphorus; in excess amounts, these nutrients over-stimulate the growth of weeds and algae and can lead to serious algae blooms and oxygen depletion in rivers and lakes that can cause fish-kills. Agricultural use of fertilizer is a major source of nutrients in rivers, lakes and reservoirs.
Organic enrichment/ oxygen depletion	Low levels of dissolved oxygen; high levels of COD or biochemical oxygen demanding substances (e.g. organic materials such as plant matter, food processing waste, sewage) that use up dissolved oxygen in water when they degrade. Runoff from fields contributes to the build up of organic matter in rivers, lakes and reservoirs.
Pathogens	Bacteria and pathogen indicators *E.coli*, total coliforms, faecal coliforms, *Enterococci*; used as indicators of possible contamination by sewage, livestock runoff and septic tanks.
Polychlorinated biphenyls (PCBs)	A toxic mixture of chlorinated chemicals that are no longer used in the US but some are still used in China; these are persistent in the environment; used in industry and electrical equipment; primarily found in fish tissue or sediments.
Pesticides	Substances identified as 'pesticides'; also, chlordane, atrazine, carbofuran, and others; many older pesticides such as DDT are banned in China, but are used illegally and are persistent in the environment.
Sediment	Excess sediments, siltation; affects aquatic life by altering and suffocating habitat and clogging fish gills. Agriculture is a major cause of sediment runoff into rivers, lakes and reservoirs.
Toxic organics	Chemicals identified only as 'toxic organics'; also, priority[2] organic compounds, non-priority[2] organic compounds, polycyclic aromatic hydrocarbons (PAH), and others; often persistent in the environment.
Salts	High salt concentrations prevent the uptake of water by plants. The plant symptoms are similar in appearance to those of drought. Agricultural drainage has higher salt concentration than irrigation water and increases salinity in water bodies.

1 Adapted from US-EPA, 2009

2 The United States classifies organic compounds as 'priority' (most polluting) and 'non-priority' (less polluting or for which there are inadequate data).

Non-point source pollution – Other types of landuse activities such as road construction, mine drainage, rainwater runoff from city streets (that is not collected in storm drains), from agriculture and from many rural villages, produce water pollution that does not come from any specific pipe or channel but instead tends to be dispersed across the landscape. Therefore it cannot be easily measured because of the 'diffuse' nature of this type of pollution, which is collectively called 'non-point source' (NPS) pollution.

1.4 WHAT IS AGRICULTURAL AND RURAL NON-POINT SOURCE POLLUTION?

In this publication, agricultural and rural non-point source pollution refers to four different types of activities[3].

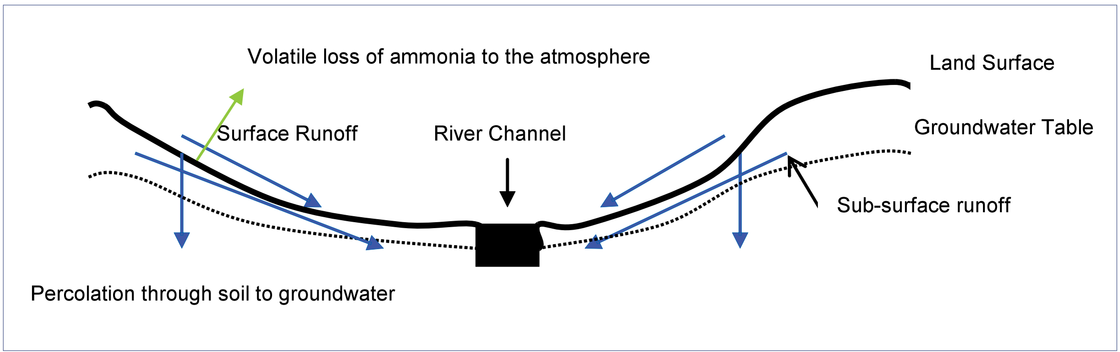
3 The impact of pollution on township and village enterprises that are often located in rural areas have not been considered in this publication.

Plant production – involves activities such as ploughing, planting, fertilizing, irrigation and pest management. The principal pressures on water bodies are derived from fertilizer runoff after rainfall or in irrigation water that flows back to watercourses ('irrigation return flows'), nutrients (especially nitrogen) that percolate through the soil and contaminate the groundwater, and sediment that is eroded from fields and washed into watercourses during and after rainfall.

In areas where rainfall carries organic waste (straw, mulch, manure) from the fields into watercourses, the increase of COD becomes a problem. Other types of plant production pressures on water quality include flushing of salt from farmland that has been salinized by irrigation practices, and improper disposal of pesticide containers that can contaminate surface and groundwater.

The main vectors by which nutrients (and pesticides) contaminate surface and groundwater are shown in Figure 1.1.

FIGURE 1.1
Loss of N and P from fertilizer through surface runoff, subsurface runoff and percolation through the soil to groundwater. P is mainly lost as a result of surface runoff. N is lost both through surface runoff and from percolation to groundwater. In dry northern China, the groundwater table is much lower and does not intersect the river channel because of excessive drawdown of the groundwater for irrigation and municipal use.



Rural living – refers to thousands of small agricultural villages across China that are mainly occupied by farmers. Water pollution from rural living is largely from disposal of human waste (solid and liquid) and liquid and solid manure from domestic animals that live in or around individual farmhouses (but not from feedlots – see below). The effect of rural life on water quality varies greatly across China; on the North China Plain, villages are usually not located on watercourses and have relatively little impact on surface water quality. In contrast, villages in southern China are usually located on the banks of watercourses and may greatly affect water quality when waste flows directly into the watercourse.

Aquaculture – refers to farming of aquatic organisms, such as fish, crabs or shrimp, in inland and coastal areas, involving intervention in the rearing process to enhance production of the stock being cultivated. The water quality impacts include fed aquaculture and, particularly, excess feed that is not consumed by farmed species such as faecal matter produced by caged species and antibiotics that contaminate the surrounding water area.

Livestock raising – focuses on family-operated raising of livestock, and on village and community feedlots that are not usually controlled by Chinese laws for feedlot operation and pollution control. Feedlots are often located on the banks of watercourses so that liquid animal waste (urine) can be cleaned directly into the watercourse. Solid waste (manure) is usually collected for fertilizer. In many cases, however, this is not stored in contained areas and runs off into watercourses when there is significant rainfall. The impact of raising livestock on water quality is especially serious in many areas of China. The main pollutants are: nutrients (especially N in the form of ammonia), heavy metals (contained in urine and manure), pathogens (that are excreted in urine and

TABLE 1.2
Forms of NPS pollution from agriculture and rural living[1]

Activity	Type of NPS pressures	Variables of concern
Animal feedlot irrigation Pastures Dairy farming Orchards Aquaculture Chicken/duck raising	Runoff from all categories of agriculture leading to surface water and groundwater pollution. In northern climates, runoff from frozen ground is a major problem, especially where manure is spread during the winter. Growth of aquaculture is becoming a major polluting activity in many countries. Irrigation return flows carry salts, nutrients and pesticides to rivers, lakes and reservoirs. Tile drainage rapidly carries leachates containing, especially nitrogen to surface waters.	Phosphorus Nitrogen Metals Pathogens Sediment Pesticides Salt BOD_5, COD Trace elements (e.g. selenium).
Forestry	Increased runoff from disturbed land, especially in hilly or mountainous areas. Most damaging is forest clearing for urbanization and for agricultural projects such as land conversion for palm oil or other plantation forms of agriculture.	Sediment Pesticides BOD_5, COD
Liquid waste disposal	Disposal of liquid wastes from animal feedlots (single-family, village and community feedlots); wastewater from home septic systems.	Pathogens Metals Organic compounds BOD_5, COD
Rural sewage systems	Overloading or malfunction of septic systems leading to surface runoff and/or direct infiltration to groundwater. Leaching pits in rural villages contribute to groundwater contamination.	Phosphorus Nitrogen Pathogens (faecal matter) Heavy metals
Solid waste disposal	Contamination of surface and groundwater by leachates from disposal of solid waste. This may include hazardous wastes from agriculture that includes agricultural chemicals, oils and fuel.	Nutrients Metals Pathogens Organic contaminants
Atmospheric pollution (air pollution)	Agriculture is both a cause of, and is affected by, atmospheric pollution. Volatilization of ammonia from manure is a major source of nitrogen in air pollution. Pesticides can be carried into the air and transported long-distances. Pesticides are now found in Arctic mammals, far from the source of these pesticides. Burning of forests and agricultural wastes contribute to climate warming adding CO_2 to the atmosphere. Agriculture is impacted by air pollution, especially by nitrogen, from burning of fossil fuels (coal, gas, oil, etc.) and from automobile exhaust emissions.	Nutrients Metals Organic contaminants
Conversion of peatlands	Conversion of peat lands for agricultural use is often accompanied by emission of greenhouse gases following the drying out of organic-rich soils.	CO_2 Nitrous Oxide

1 Adapted from FAO (1996)

manure), and feed additives (antibiotics, etc.). In China, elevated levels of COD and ammonia are often linked to upstream animal feedlots. Note that raising animals on an industrial scale (large commercial feedlots), although when still a concern, is now less of a water quality problem than in the past because animal waste is perceived to be an economic product that can be converted to fertilizer or biogas and sold.

The various forms of agricultural and rural NPS pollution are noted in more detail in Table 1.2. The impacts vary from country-to-country, especially as some developing countries use, for example, very little pesticide or fertilizer because of the cost. However, in China, use of fertilizer and pesticides is very high (refer to Chapters 3 and 4), often 30–50 percent more than is required for crop growth, therefore the probability of serious pollution of surface and groundwater from agriculture is very high.

1.5 WATER POLLUTION FROM AGRICULTURAL AND RURAL NON-POINT SOURCES

In Western countries PS pollution is well controlled, yet water pollution remains a problem in many rivers and lakes. The United States, which regularly monitors and reports upon the status of water quality in rivers, lakes/reservoirs and coastal estuaries has found that agriculture is the principal cause of surface water pollution. In China, as discussed below, the extent of agricultural pollution in surface and groundwater is not known with precision, however it is well known that agriculture and related rural living (agricultural villages) can be significant sources of water pollution. The following paragraphs briefly describe the major effects of agriculture and rural living on water quality. In this publication, the categories of agriculture and rural NPS pollution include cultivation (ploughing, fertilizing; irrigation); animal-raising (large animals – pigs, cows; fowl – chickens, ducks, etc.), rural living (small agricultural villages) and aquaculture.

Pollution in lakes and reservoirs

In China, as elsewhere, a common environmental problem is the occurrence of algae blooms in rivers, lakes and reservoirs. Algae is a symptom of eutrophication, which is the technical term that describes the enrichment of river, lake and reservoir water by nutrients, especially nitrogen (N) and phosphorus (P) that, together with potassium (K), are the main components of agricultural fertilizer. Together with municipal and industrial wastewater, agricultural runoff of N and P is a contributing factor to eutrophication of rivers and lakes across China.

FIGURE 1.2
Usual relationship in lakes and rivers between load (or concentration) of N & P, and amount of algae in the river or lake.

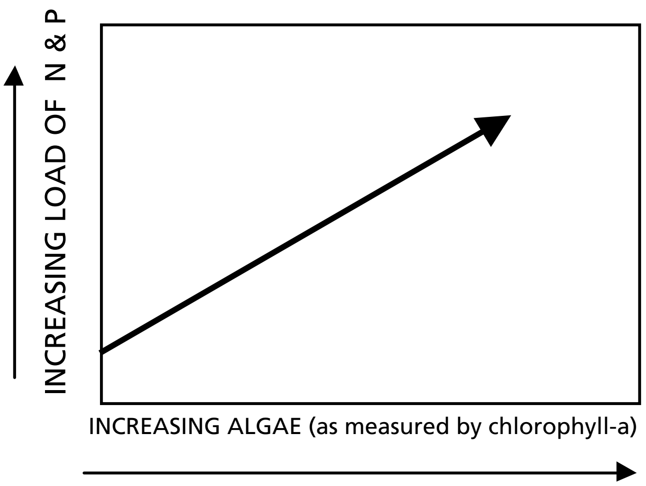


FIGURE 1.3
Algae bloom in a small river in an agricultural village in Sichuan province.

(Source: F. Andrews, Wilkipedia, with permission)

FIGURE 1.4
Thick algae on Taihu (lake Tai) in 2006. Nutrients are to blame.

(Photo: Pan, G. with permission)

Generally, as the load (or concentration) of N and P in a lake increases, the probability of algae growth also increases (Figures 1.2, 1.3). Many of China's large lakes, and most of its urban lakes, are enriched (Jin, 2002) to the point where many have occasional, or in some cases, prolonged annual blooms of blue-green (cyanobacteria) algae.

In many lakes and reservoirs, agriculture and aquaculture have been blamed for the poor quality of lake water. Some forms of blue-green algae produce toxins that attack the liver and nervous system of humans, domestic animals and wildlife. Algae blooms result in oxygen deficiency in lake water, which in turn causes fish to die from lack of oxygen.

Enrichment of surface water can be classified into various levels of eutrophication; one typical classification system is shown in Table 1.3. Typical characteristics of the lake, in each trophic class, are noted in Table 1.4. Jin (2002) found that of 50 Chinese lakes across the country, 44 percent were eutrophic and 22 percent were hypereutrophic with a rapidly increasing rate of change towards eutrophy and hypereutrophy. Recent and much publicized episodes of algae blooms in Taihu (Lake Tai – Figure 1.4) are caused not only by industrial and municipal wastewater that is discharged into tributary rivers to Taihu, but also by fertilizer runoff from agriculture in the Taihu basin and from aquaculture in the lake.

TABLE 1.3
Trophic classification

Trophic category	Mean total P (mg/m^3)	Annual mean chlorophyll (mg/m^3)	Chlorophyll maxima (mg/m^3)	Annual mean Secchi disk[1] transparency (m)	Secchi disk transparency minima (m)	Minimum oxygen (% sat^n) [2]
Ultra-oligotrophic	4.0	1.0	2.5	12.0	6.0	<90
Oligotrophic	10.0	2.5	8.0	6.0	3.0	<80
Mesotrophic	10 – 35	2.5 – 8	8 – 25	6 – 3	3 – 1.5	40 – 89
Eutrophic	35 – 100	8 – 25	25 – 75	3 – 1.5	1.5 – 0.7	40 – 0
Hypereutrophic	100.0	25.0	75.0	1.5	0.7	10 – 0

Source: (after Chapman, 1992)

1 Measurement of water transparency

2 % saturation in bottom waters depending on mean depth; Note: mg/m^3 = ug/litre

TABLE 1.4
Typical condition of lakes in each trophic category

Trophic category	Description of typical lakes[1]	Typical Chinese lakes[2]
Oligotrophic	Very low nutrient levels, low plankton productivity, no algae, very clear water (high transparency)	Tianshi (in Jilin)
Mesotrophic	This is a transitional stage between oligotrophic and eutrophic. Water is moderately clear; Secchi[3] disk depths and phosphorus and chlorophyll concentrations between those characteristic of oligotrophic and eutrophic lakes. Scattered weed beds and within these beds the weeds are usually sparse.	Poyang; Dongting; Taihu; Hongze; Qiandao; Erhai Miyun reservoir
Eutrophic	Relatively high N and P concentrations. Substantial phytoplankton (algae) with chlorophyll averaging about 14 mg/m^3 or higher with potential for algae blooms. Eutrophic lakes are often relatively shallow and often have extensive weed beds.	Chaohu; Baiyangdian Yuqiao reservoir
Hypereutrophic	High N and P concentrations. Abundant phytoplankton production (algae blooms), some of it toxic. Often anoxia in lake bottom.	Most of Dianchi; Yilong

1 Modified from Niles et al., 2009, and other sources.

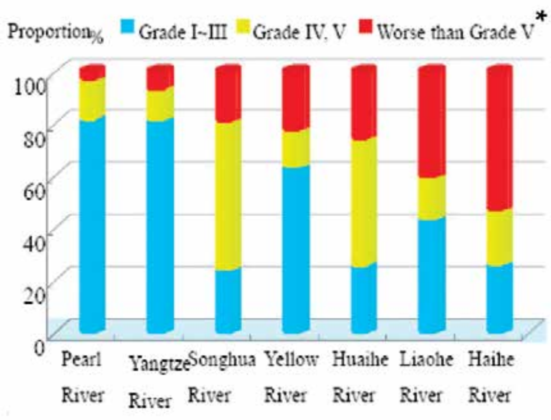
2 From Jin, 2002.

3 Measurement of water transparency

It does not help that Chinese farmers tend to use far more fertilizer than is required for optimum crop growth. The excess fertilizer that is not used by plants either runs off to surface water, or percolates downward thereby contaminating the groundwater (Figure 1.1). Algae growth requires, in particular, the nutrients N and P for optimum growth. In northern temperate lakes and reservoirs the ‘controlling’ (limiting) nutrient is usually phosphorus (P). Consequently, nutrient control policies in many Western countries focus on phosphorus control strategies both for wastewater and agriculture.

The situation in China is somewhat different insofar as many lakes and reservoirs are located in subtropical environments and for which the knowledge of the roles of N and P in lake eutrophication are less well known. In Taihu (lake Tai), for example, recent studies (McCarthy *et al.*, 2007) suggest that N may be the limiting nutrient, and not phosphorus. This is of considerable consequence to agriculture given the very large amount of urea fertilizer used by farmers. Irrespective of whether N or P is the limiting nutrient in Chinese lakes, Chinese scientists consider agriculture to be a significant contributor to the poor quality of lake water.

FIGURE 1.5
Status of water quality in major river basins in China, 2007.



**Unsuitable for any use*
(Photo: Pan, G. with permission)

Agriculture contribution to surface water pollution

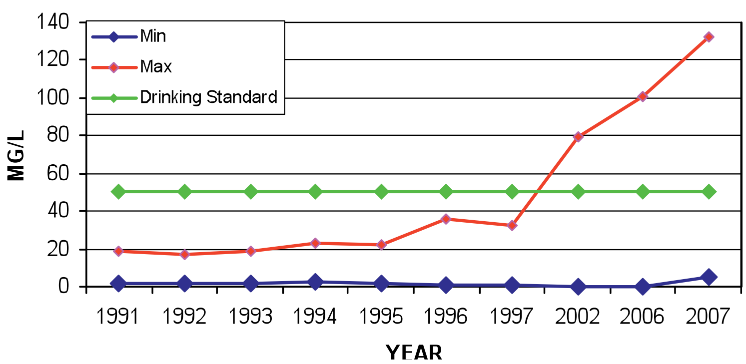
Water quality in Chinese rivers is, generally, very poor – more so in central and northern China where water is scarce as shown in Figure 1.5 for 2007. While it is true that much of the explanation for poor surface water quality lies in municipal and industrial wastewater discharged into rivers, Chinese scientists (Table 1.5) report that agriculture is becoming a major contributor to surface water pollution, especially from runoff of N and P from excessive use of fertilizer.

Scientists do not know exactly how much agriculture contributes to surface water pollution; however, published estimates are presented in Table 1.5 for major river basins in China. Many of these estimates are derived from models and probably over-estimate, to some extent, the actual role of agriculture in surface water pollution. Nevertheless, these various studies indicate that agriculture is a major contributor to nitrogen and phosphorus in surface water throughout China. Many studies do not differentiate between agriculture and rural living in their analysis; therefore, there is little information on the contribution of each type of rural activity.

Agriculture contribution to groundwater pollution

The effect of agricultural on groundwater pollution in China is substantial, but is not well documented. The Ministry of Water Resources (MWR, 2001) noted there is no systematic or consolidated database on groundwater contamination for China, because

FIGURE 1.6
Trend of nitrate in groundwater in Hebei province, 1991–2007[4]



(Graphic: Pan, G. with permission)

4 Data sources: 1991–1996, Bi *et al.*, (2001); 1992, Chen *et al.*, (2008); 2006–2007, Wang *et al.*, (2009).

data held by the many different ministries and organizations is not shared between them. There are however many studies in China and other countries that document the role of agriculture in groundwater pollution.

Agriculture is the main source of nitrogen in groundwater, which leaches from excessive fertilizer use. Figure 1.6 shows the change in nitrate (NO_3^-) concentration in groundwater at many sites in Hebei province. The chart shows that the range of NO_3^- concentration was relatively small in the early 1990s, but increased rapidly after 1997. According to the World Health Organization (WHO) there are only indirect links between nitrate in drinking water and human cancer, however high levels of nitrate can lead to methaemoglobinaemia – infants can turn blue because of lack of oxygen.

Therefore, the WHO and China (GB 5749–2006) have established safe drinking water guidelines of 50 mg/litre. As noted in Figure 1.6, maximum observed levels of nitrate in groundwater now greatly exceed safe drinking water standards. WHO also notes that when drinking water exceeds 50 mg/litre nitrate, drinking water is the major source of total (human) nitrate intake.

The situation in Hebei province is mirrored in other parts of China. Jiang *et al*. (2008) found that nitrate in groundwater, in the mainly agricultural Xiaojiang river basin of Yunnan province, exceeded drinking water standards in 2004 (the last year of their study). Jiang *et al*., note that agriculture has expanded by 132.7 percent in the past two decades and attribute the change in groundwater chemistry to a change in land use from forest to agricultural land.

TABLE 1.5

Reported agricultural contribution to surface water pollution in river basins in China[1].

Range of reported values as percentage of total water pollution						River basin
Total nitrogen		Total phosphorus		COD		
Total NPS (as % of total load)	Agricultural NPS (as % of total load)	Total NPS (as % of total load)	Agricultural NPS (as % of total load)	Total NPS (as % of total load)	Agricultural NPS (as % of total load)	
	52		76			Haihe
71	35	80	51			Yellow river
78	38	87	39	43		Songhua river
58-69		54				Xiaoqinghe, Shandong province; 1996–1999
81		88				Heihe river, Gansu province
>66		>90		87–90		Three Gorges area of Yangtze river
52		76				Large basin on North China Plain
58	43	93	85			Songhua river basin, 2000
47	38	92	84			Liao river basin, 2000
73	37	89	79			Yellow river
62	50	77	64			Yangtze river
70	53	66	56			Pearl river
	24		38			Taihu basin
				22–43		7 major river basins in China
				62	28	Suzhou creek basin

1 Modified from Ongley et al., 2010. Sources of data are cited Ongley et al., 2010.

1.6 WATER POLLUTION FROM DIFFERENT CATEGORIES OF AGRICULTURAL ACTIVITIES

From field studies in China, we can make some generalizations based on gross differences in climatic conditions (Table 1.6).

TABLE 1.6
Pollution potential of agricultural and rural activities in regions of China

Agricultural activity	Dry northeastern China & west China	Wet southern China	Large-scale irrigation areas	Mountainous areas in southwestern China
Cultivation (ploughing, fertilizing, etc.)	Low impact in surface water of N & P and pesticides because little rain and therefore little runoff. Nitrogen impacts groundwater	Large impact in surface water of N & P and pesticides because much rain and much runoff. Nitrogen impacts groundwater	Large impact of N, P & pesticides from irrigation return flows to canals and rivers. Nitrogen likely impacts groundwater	Large impact resulting from sloping land and runoff from rainfall. N impacts groundwater
Animal-raising – large animals (pigs, cows, etc.) (family farm + village and community feedlots)	*Dry manure:* relatively small impact if manure is stored properly. *Liquid waste:* major impact because of flushing into nearby canals.	*Dry manure:* large impact due to runoff from manure piles. *Liquid waste:* major impact because of flushing into nearby canals.	*Dry manure:* low impact due to low rainfall.	*Dry manure:* large impact due to runoff from manure piles. *Liquid waste:* major impact because of flushing into nearby canals.
Animal-raising – fowl	Low impact as manure is collected for fertilizer.			
(chickens, ducks)	Ducks in ponds are a problem for local water quality because of excreta.			
Rural villages	Low impact as these are not generally located on rivers or canals	High impact, as these are often located on rivers or canals.	Low impact. Few rivers or canals.	Not known but probably have impact because of steep slopes and runoff from seasonal rains.
	Can have high impact on local groundwater through contamination by poorly managed disposal of human excreta (latrines, toilets, seepage pits, etc.), especially around drinking water wells.			
Aquaculture	High impact in lakes and reservoirs where this activity is located. Land-based aquaculture ponds impact water quality when these are drained, or dredged to remove contaminated bottom sediments.			

Water pollution induced by cultivation

Cultivation practices are major contributors to water quality degradation throughout China. The nature of the impact depends on the climate and on local relief (flat, hilly or mountainous land). Generally, cultivation has two main types of impacts – one on surface water, and the second on groundwater quality. For surface water, two types of impacts are of most concern – the first is loss of topsoil as a result of erosion, then deposition in water courses and lakes; the second is runoff of nutrients (N and P) from excessive use of fertilizer. A lesser problem is pesticide runoff when these are applied incorrectly or when rain washes off the applied pesticide. Another more local water quality problem occurs when farmers desalinize irrigated fields by applying large amounts of water.

There is much misunderstanding about the degree to which fertilizer runoff affects surface water quality. Studies show that in humid parts of China such as Taihu and Chaohu, and on steep slopes such as in Yunnan, fertilizer runoff is definitely a major problem and leads directly to enrichment of lakes and rivers and contributes to the development of algae blooms. In dry areas, however, such as the North China Plain (NCP), there is relatively little runoff, indeed in parts of the NCP there has been virtually no runoff for more than a decade because of drought.

Under these circumstances, excessive fertilizer remains on the field because there is no mechanism (runoff) to remove the fertilizer. There has been relatively little study of the types of rainfall (intensity, duration) that can lead to fertilizer runoff under typical conditions on the NCP. In contrast, it is known that excessive use of nitrogenous fertilizers (e.g. urea) impacts groundwater quality throughout China. Nitrogen is mobile and can move easily from the soil down into the groundwater. In contrast with the NCP, humid parts of China receive abundant rainfall and have significant runoff. In such areas, excessive use of fertilizer has a direct and immediate impact on surface water quality.

Paddy rice is a major crop in China and studies of nutrient loss from paddy fields indicate that there is substantial loss from percolation to groundwater and to subsurface flow to nearby watercourses. Data on paddy losses from Guilin are shown in Table 1.7. This indicates a monthly loss from a 1 ha (15 mu, or 10 000 m^2) paddy field of between 3.19 and 5.53 kg of NH_4^+ in one month (August in this example), and between 0.03 and 1.12 kg PO_4^{3-}. Mao Zhi shows that different paddy irrigation schemes can greatly reduce both water loss and fertilizer loss.

TABLE 1.7

Fertilizer losses with percolation from late rice paddies under traditional irrigation regime (continuous deep flooding) at Guilin.

Nutrient	Rate of percolation (mm/day)	August (mean loss) mg/m^2	September (mean loss) mg/m^2
NH_4^+ (Nitrogenous fertilizer)	3	319	275
	6	553	422
PO_4^{3-} (Phosphate fertilizer)	*3*	*34*	*23*
	6	118	44

Adapted from Mao Zhi, No date.

Sedimentation caused by erosion of agricultural land, or conversion of forest to agriculture, is a major problem in many countries. In China, erosion from fields seems to be less of a problem than in other countries because of the water-conserving nature of Chinese agriculture (runoff is controlled by field edge berms, or paddy field berms), and extensive terracing in hilly areas. Historically, however, conversion of hilly land for agriculture has been a major problem in areas such as the Loess Plateau of the middle Yellow river. While this is now being controlled, land conversion in other parts of China is still ongoing. In the future, consolidation of small land holdings by farmers or agricultural entrepreneurs can easily lead to renewed erosion unless there is careful control by agricultural officials.

Water pollution in large-scale irrigation schemes

Large-scale irrigation impacts on surface and groundwater quality. Chemical runoff in irrigation return flows to the Yellow river, for example, has been studied by Chen *et al*., (2003) who found that agriculture has a significant impact on downstream water quality. In their study of Yinchuan plain, in Ningxia province the Australian Centre for International Agricultural Research (ACIAR, No date) reports that excessive seepage from the irrigation and drainage network causes saline, shallow water tables.

Subsequent evaporation from shallow water tables results in the accumulation of salts (salinization) in the soil surface layers. There is widespread pollution of groundwater from nutrients, pesticides and salts, and more than 50 percent of shallow groundwater on the Yinchuan plain has been polluted, especially with pesticides and fertilizers. This creates potential public health problems as most cities and villages on the Yinchuan plain rely on groundwater for drinking. Elsewhere, irrigated rice production has led to excessive sodium and other salt build up and higher pH in the shallow groundwaters of the Dongdapao area of the Songnen plain in northeastern China (ACIAR, No date).

Water pollution by animal raising

Livestock and poultry breeding in China produce huge amounts of manure. Only in 2007, pigs, cattle and poultry produced 1.08 billion tonnes. Untreated manure and wastewater from farms is the common situation in China, except for large commercial feedlots where animal waste is now considered an economic resource and is retained and converted to fertilizer, soil supplements and other commercial products. Animal and poultry waste enter surface and groundwater, both accidentally and deliberately, from family, village and communal farms and feedlots.

Without treatment, manure runoff from livestock and poultry farms is highly polluting to the environment. Manure runoff can lead to algae blooms in lakes, reservoirs and rivers throughout China, to nitrogen enrichment of groundwater, which can lead to human health problems. A wide variety of biological agents such as food additives, growth hormones and antibiotics collectively can collectively create serious human health concerns for the Chinese population if they enter the drinking water supply. This impact is often most severe for local farming families.

Water pollution from aquaculture

The role of aquaculture in water quality and environmental degradation is well known in China. In many lakes, such as Taihu, in-lake caged aquaculture is being removed because of large-scale pollution caused by excessive use of feed and by the volume of excreta from fish held in these cages. Generally, the caged fishery has been poorly regulated insofar as licenses are not linked to the carrying capacity of the lake, (its ability to support this activity without significant impact).

Other types of fishery, such as crabs, also have indirect impacts on water quality. Excessive crab densities destroy aquatic vegetation and leads to impoverished biodiversity. Ultimately, to ‘dead’ lakes that become eutrophic, and in which rooted aquatic plants are replaced by algae which, in turn, may form toxins in the water as well as fish kills, and taste and odour problems in drinking water.

1.7 INTERNATIONAL EXPERIENCE WITH AGRICULTURAL NPS POLLUTION

In North America, where point sources are well controlled, agriculture is considered to be the single largest source of pollution of surface waters, mainly from fertilizer and sediment eroded from fields. Nitrogen enrichment in groundwater is widely reported across the United States and is mainly from agriculture. Nitrate pollution of groundwater in Europe resulted in the European Union’s (EU) Nitrate Directive (1991, revised 2009); that specified manure spreading should be limited to 175 kg N/ha/yr (15 mu), which is equal to manure produced by two dairy cows and laid out. This is the basis for the Code of good agricultural practice (1996, revised in 2009), which has the force of law in EU countries. Each country in the EU has developed specific legislation to implement these EU requirements at the national level, which usually include provisions for inspection and enforcement, and financial arrangements for farmers. The 2009, *Good agricultural practice for protection of waters* (European Union, 2009) provides specific directions for manure and fertilizer management and agricultural practices to minimize water pollution (e.g. ploughing).

The United States has a very comprehensive national approach to non-point source pollution control and management involving three main agencies – the US-EPA, the United States Geological Survey (water quality monitoring), and the United States Department of Agriculture. To a large extent the activities of these three agencies are highly coordinated, consequently the amount of technical and guidance information on this subject is immense (e.g. US-EPA 2003).

There has been considerable success in reducing agricultural NPS, especially from animal-raising, erosion and fertilizer runoff. In part, this has been achieved by improved farmer education and the use of best management practices (BMPs), and partly because farmers recognize the economic benefits of reducing fertilizer costs, converting animal waste to fertilizer, improving soil fertility by controlling erosion, and reducing costs (fuel, etc.) by minimizing tillage.

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2. Pollution from soil erosion and sedimentation

LI Yong[1]

2.1 INTRODUCTION

China is among those countries that suffer most from soil loss resulting from water and wind erosion. Almost 40 percent of China's territory, or 3 569 200 km^2, is affected by soil erosion (MWR, 2002). Of the total area, water erosion accounts for 1.61 million km^2 with a further 1.96 million km^2 eroded by wind. Erosion occurs in almost every river basin and in every province. An estimated 4.52 billion tonnes of soil is eroded every year by water and wind, which exceeds that of India, Japan, the United States, Australia and many other countries.

Experts have warned that if soil erosion continues at this rate, grain production on 14 million mu (930 000 km^2) of farmland in northeastern China, one of the country's most productive areas, will be reduced by 40 percent in 50 years. Since 2000, erosion has caused a loss of at least RMB200 billion (US$29.4 billion). Associated with erosion is loss of soil organic carbon (SOC), which amounts to 1.595 x 10^8 tonne C/yr. Erosion induced CO_2 emissions[2], a greenhouse gas (GHG) that contributes to global warming, is about 3.19x10^7 tonne C/yr (Hu *et al.*, 2004).

Although soil erosion is a natural process, most erosion is induced by human activities and eroded soil originates from many sources including agricultural fields, woodlands, river banks, roads, construction and mining sites. Transported soil particles are referred to as **sediment**. Sediment in water is mainly comprised of small particles (clay, silt and fine sand) but in some river environments may include larger particles such as medium and coarse sand and river gravels. Sediment also includes organic material that is (i) eroded from soil and (ii) grows naturally in river and lakes (such as algae and bacteria).

Sediment in river systems is therefore a complex mixture of mineral and organic matter. Sediment transport in rivers is an important natural mechanism for maintaining hydraulic equilibrium in river channels, for the natural development of river levees, for fertilizing river flood plains with newly deposited sediment after floods, and for providing sediment to coastal shorelines that would otherwise erode.

In many Chinese rivers, however, the amount of sediment (***sediment load***) is greatly increased by accelerated erosion caused by human activities. Wind-blown soil from China has been identified as a major means of sediment transport in Japan and California. In this chapter, however, we focus on sediment in water.

1 Chinese Academy of Agricultural Sciences, Institute of Environment and Sustainable Development In Agriculture.

2 Assumes that 20 percent of SOC is oxidized.

2.2 SEDIMENT AS A WATER POLLUTANT

Sediment affects water quality physically, chemically, and biologically. Water-borne sediment is a ***physical pollutant*** when the sediment causes physical damage to the environment or poses a risk to biota or to human health. Damage caused by sediment is expensive both economically and environmentally in terms of prevention and restoration of degraded natural resources, damage to infrastructure and costs of water filtration.

Deposition of sediment covers and destroys fish spawning beds, reduces useful storage volume in reservoirs, damages watercourses and clogs streams and makes costly filtration necessary for municipal water supplies and for hydroelectric power, irrigation and industrial use. Suspended sediment can reduce aquatic plant life and alter a stream's ecology. (Cook *et al.*, 1994). Suspended sediment reduces light penetration into rivers and lakes and thereby inhibits the photosynthesis of aquatic plants. A key indicator of water quality, especially in lakes, is the depth of light penetration into the water column (turbidity).

Sediment is also a ***chemical pollutant*** because many types of chemicals are carried on the surfaces of sediment particles. Particles of clay and silt effectively adsorb (sequester) nutrients, heavy metals and persistent organic pollutants (POPs) including many (but not all) pesticides and herbicides, from the water column (Table 2.1).

TABLE 2.1
Contaminants in sediments

Contaminant	Characteristics
Nutrients	Includes phosphorous and nitrogen compounds such as ammonia. Phosphorus is of greatest concern because it is often transported by sediment in rivers. Elevated levels of phosphorous can promote the unwanted growth of algae in freshwater. This can lead to reduced levels of oxygen in the water as algae die and decay, and can cause fish kills. Species of algae that are common in algal blooms produce neurotoxins (affect nervous system) and hepatoxins (affect the liver). High concentrations of ammonia can be toxic to benthic organisms and fish.
Bulk organics	A class of hydrocarbons that includes oil and grease.
Halogenated hydrocarbons or persistent organics	A group of chemicals that are resistant to decay. DDT and PCBs are in this category and are hazardous to aquatic life.
Polycyclic aromatic hydrocarbons (PAHs)	A group of organic chemicals that includes several petroleum products and byproducts. These can be toxic to aquatic life.
Metals	Metals such as iron, manganese, lead, cadmium, zinc mercury, and metalloids such as arsenic and selenium. These can be toxic to aquatic life and are hazardous to human health.

Many sediments in our rivers, lakes and oceans have been contaminated by pollutants. Some of these pollutants, such as the pesticide DDT and the industrial chemicals known collectively as polychlorinated biphenyls (PCBs), were released into the environment long ago. Other contaminants enter the water every day, discharged as industrial and municipal waste, as polluted runoff from urban areas, and from fields and related agricultural activities. Other contaminants are carried through the air, landing in lakes and streams far from the factories and other facilities that produced them. Sediment may become a reservoir for contaminants and become, itself, a source of contamination.

Contaminated sediments affect small organisms such as worms, crustaceans, and insect larvae that inhabit the bottom of a water body in what is known as the ***benthic environment***. Some kinds of toxic sediments kill benthic organisms, reducing the food available to larger animals such as fish. Benthic organisms consume some of the carbon contained in some contaminants in the sediment as a food source, which results in ***bioaccumulation*** of toxins. When larger animals feed on these contaminated organisms, the toxins are taken into their bodies, moving up the food chain in increasing concentrations in a process known as ***biomagnification***.

As a result, contaminated sediments affect fish, shellfish, waterfowl, freshwater and marine mammals, as well as benthic organisms. Species that cannot tolerate the toxic contaminants, found in some sediments simply die, reducing the diversity of organisms. Animals that survive exposure to contaminated sediments may develop serious health problems, including fin rot, tumors and reproductive failure. When contaminants bioaccumulate in trout, salmon, ducks, and other food sources, they pose a threat to human health.

The most environmentally significant nutrient elements transported in water are nitrogen and phosphorus, which come chiefly from municipal and industrial wastewater and from mineral and organic (e.g. manure) fertilizers used in agriculture. **Nitrogen** is highly soluble and readily runs off in surface water and infiltrates through the soil to groundwater through ***leaching***. It can pose a human health risk (e.g. methemoglobinemia resulting from excessive ingestion of nitrate). Nitrogen, however, is not usually linked to sediment and therefore it will not be dealt with in this chapter.

FIGURE 2.1
Algae sludge from an algal bloom on a lake. This bloom is caused by soil erosion and fertilizer runoff from agriculture. Algal toxins are dangerous for cattle drinking this water.

Photo: E. Ongley

Phosphorus concentrates in the top few inches of most soils and is carried away with soil particles during soil erosion. Freshwater ecosystems develop under very low phosphorus conditions, but large additions of phosphorus increases its concentration in water, which leads to eutrophication and stimulates the production of algae blooms that can produce algal toxins that are dangerous to animals and people.

This has been a continuing problem in many Chinese lakes such as Taihu and Chaohu in recent years. As the algae die, organisms in the aquatic system decompose the algae as a food source. In the process, they also use significant amounts of oxygen. If the oxygen level is initially low, the decomposition process can further reduce it to a point where fish or other animal populations die because of inadequate oxygen. This is known as hypoxia.

2.3 STATUS AND CAUSES OF SOIL EROSION

Status of erosion

Serious soil erosion problems have existed in China for a very long time as a result of China's long agricultural history, combined with erosion-prone land-forms and climate. By 1990 about 3.67 million km^2 or 38.2 percent of the total national land area had been affected by some kind of soil erosion (Yang *et al*., 2002), which is equally distributed between water and wind erosion. Total annual soil loss was an estimated 5 billion tonnes in 1990 or 19.2 percent of the world's total soil loss, resulting in a decrease of 70 000 ha of croplands. It was found that over one-third of land in the seven major river basins was affected by soil erosion (Table 2.2).

TABLE 2.2
Soil erosion distribution by major river basins in China

Basin	Total land area (1 000 km^2)	Area subject to soil erosion (1 000 km^2)	Area affected by soil erosion (%)
Yangtze river	1 783.4	622.2	34.9
Yellow river	790.3	465.0	58.8
Haihe river	318.9	119.3	37.4
Huaihe river	266.8	59.4	22.3
Songhua and Liao rivers	772.4	281.6	36.5
Pearl river	441.7	58.5	13.2
Taihu lake	36.5	2.6	7.1
Subtotal	4 410.0	1 608.6	36.5
Other areas	5 190.0	2 061.4*	39.3
National total	**9 600.0**	**3 670.0**	**38.2**

** including 1 160 000 km^2 of desert*

Total soil loss in the Yangtze river basin was an estimated 2.4 billion tonnes, with over half the amount occurring in the upper tributaries. The Yellow river is regarded as the world's most sediment-laden river, with an average sediment concentration of up to 37.6 kg/m^3 (37 600 mg/litre), and a maximum value of 590 kg/m^3 (590 000 mg/litre). The total soil loss from the Yellow river basin was an estimated 1.6 billion tonnes primarily occurring in the middle and upper reaches.

Serious problems such as flooding and sedimentation resulting from soil erosion in those two major rivers greatly affect socio-economic development in the two regions, impacting the nation as a whole. Land degradation (mainly erosion) affects around 80 percent of China's dry lands (excluding extremely arid areas), which amounts to nearly one-third of the national territory (MWR, 2002).

There are three major agricultural soil groups in China that are susceptible to problems related to soil erosion.

The Loess Plateau – is in northern China and covers the drainage area surrounding the middle reaches of the Yellow river. The Plateau extends from the western piedmont of the Taihang mountains in the east, to the eastern slope of the Wushao and Riyue mountains in the west, and from the northern part of the Qinling mountains in the south to the Great Wall in the north. The region is extensively covered by Quaternary loess[3] with a thickness of 100–300 m. The Loess Plateau in China is well known as one of the world's most rapidly eroding areas. (CAI Qiang-guo, 2001). Within the plateau region lie the provinces of Shaanxi, Shanxi, Gansu, Ningxia, Qinghai and Inner Mongolia. The loess region covers 0.64 million km^2 of which 0.45 million km^2 (45 percent of the total area) are eroding. The area from Hekou town of Inner Mongolia to the Longmen of Shanxi and Shaanxi province is the most seriously eroded with an average soil loss of 3 720 tonnes km^{-2} yr^{-1} (Liu Guobin, 1999).

FIGURE 2.2
Loess plateau, Shaanxi province, China

The most severe contemporary erosion on the Loess Plateau is observed on the rolling hills, where sediment yields are in the range 10 000 ± 25 000 tonnes/km^2/yr (Gong and Xiong, 1979). The sediment is mainly from (i) erosion of the deep gullies that dissect the rolling plateau, (ii) from cultivated land on the steep slopes between the gullies, and (iii) land that has been overgrazed so that there is little protection from rainfall and runoff. Erosion has both on-site consequences in terms of soil loss from cultivated land, and severe off-site problems associated with sedimentation in rivers, lakes and reservoirs.

Black Soil Area – is located in the upper and middle reach of the Songhua river basin, with a water-eroded area of about 130 000 km^2. Loss under corn production is estimated at 4–45 tonne/ha/yr, with twice this amount under soybean cultivation and 8.3 million tonnes of topsoil from black soils in Jilin province alone. A close link can be observed between crop management practices and soil loss. Traditional intensive farming can accelerate the degradation of black soils, whereas conservation tillage has great potential to prevent losses related to rainfall erosion (Yang *et al*., 2003).

Red Soil Area – is mainly distributed in the middle and upper reaches of the Yangtze river, the middle and lower reaches of the Pearl river, as well as Zhejiang, Hainan and Taiwan provinces. Sloping (hilly) land accounts for more than 60 percent of total farmland and is intensively cultivated owing to a dense population and limited availability of land (Fanglong *et al*., 2007). Hilly areas in the Sichuan basin are one of the most severely eroded regions in the Upper Yangtze river basin. The area of water erosion accounts for 500 000 km^2 with sloping (hilly) farmland accounting for much of the estimated soil erosion rates of 3 000–5 000 tonne km^2/yr. Like the other two areas, the Red Soil Area demonstrates the close relationship between erosion and poor farming practices.

Elsewhere in China, and especially on sloping and mountainous land, soil erosion can be severe where poor farming practices and overgrazing lead to water and sediment runoff. Erosion is exacerbated everywhere when natural events, such as severe rains

3 Loess is a geological term that describes fine sediment blown by wind from areas surrounding melting glaciers and deposited far away from its source. In China, the most famous area of loess deposit is known as the Loess Plateau that was created during the Quaternary period in geological time.

overwhelm the protective measures provided by vegetation cover or terraced or bunded[4] (shuitian) fields, causing mud torrents and large-scale erosion as seen in many parts of China in 2010.

Causes of erosion

Erosion is a natural process, but has increased dramatically as a result of human land use. Agricultural activities are a major, but not the only, cause of erosion. This includes poor farming practices, deforestation, overgrazing by farm animals, and clearing of land for agriculture. Land clearance is particularly damaging; tree roots hold the soil, but root removal makes soil extremely vulnerable to erosion by running water (see Figure 2.3).

A similar problem occurs when farmers cut the natural vegetation on river banks and levees; floods quickly erode the unprotected banks causing loss of farmland, which changes the geometry of river channels so that flooding becomes more common. Soil loss is a major economic loss for farmers as this reduces soil fertility and lowers crop and livestock yields.

Agricultural land generally experiences a significantly greater rate of erosion than that of land under natural vegetation or well-managed rangeland, but this is greatly reduced when farmers employ sustainable agricultural practices. For example, the conventional

FIGURE 2.3
Accelerated soil erosion as a result of intensive tillage, overgrazing and irrational tillage practices on steep slopes.

Photo: Li Yong

4 Bunded field refers to low ridges (bunds) that typically surround fields on flat lands in China. The term ‘bunded’ may be applied to a variety of field and crop forms, from terraced agriculture to irrigated fields in dry areas.

activity of ploughing, especially on sloping fields, is a particular cause of disturbance of soil structure and hence soil erosion during medium to heavy rains and in areas subject to snowmelt and runoff in the spring.

While the type and rate of erosion depend on many factors, the most important are the degree of disturbance of the soil and natural vegetative cover as a result of agricultural activities (e.g. ploughing, land clearing and grazing), the slope of the land (the steeper the slope, the greater the erosion potential), the amount and intensity of rainfall and the type of soil. Sandy soils allow much higher rates of infiltration of rainwater into the soil, whereas clay soils have low infiltration capacity and produce greater runoff volumes than sandy soils. While nothing can be done about soil type and land slope, all the other factors associated with farming activities can be addressed largely (as discussed below) by good farming practices that can be collectively referred to as *best management practices*.

2.4 EROSION CONTROL AT FARM LEVEL

Agriculture may cause surface erosion, and small amounts of surface erosion can lead to gully erosion, which, at its most extreme, leaves the remaining agricultural surface unusable and inaccessible as shown in Figure 2.2. Slope is a critical factor, with steep, mountain slopes being most vulnerable to large-scale erosion from improper land use.

Hill-slope runoff and erosion processes are easily reduced by land-use changes. Increased vegetation cover in general leads to decreased runoff and reduced erosion. A small change in land-use practices (crop type, field size, ploughing, moving field boundaries away from streams, etc.) can significantly affect soil erosion rates (Van Rompaey *et al.*, 2002).

Presented below are a variety of land management approaches that farmers and

BOX 2.1

Role of vegetation in preventing erosion

This picture from Heilongjiang province shows the difference in erosion between de-vegetated sloping land and vegetated flat lands. The sloping land in the foreground has been de-vegetated and is now rapidly eroding. In contrast, continuous vegetative cover protects the flat land and the river banks are protected by a vegetative strip along each bank. There is no evidence of erosion on the flat land or in the river channels. Vegetative cover in agriculture can be natural (as in this example), or artificial such as straw or mulch that is left on the land by the farmer to protect the soil from rainfall. Straw and mulch have other benefits including retaining soil moisture in the soil.

cooperatives can apply to reduce soil erosion and soil loss from agricultural land. Extensive information on integrated soil management and conservation practices can be found in FAO (2000).

FIGURE 2.4
An effective combination of contour ploughing, terracing, and vegetated buffer strips to control erosion.

Photo: LIU, Z.

Conservation agriculture – combines minimum or no-till-systems with measures to optimize the protective cover of living vegetation (including cover crops), mulch and resulting litter layer, as well as crop diversification to make better use of the soil profile for moisture and nutrients through alternating species. It is characterized by three linked principles, namely: (i) minimum mechanical soil disturbance, (ii) permanent organic soil cover, and (iii) diversification of crop species grown in sequences and/or associations.

FIGURE 2.5
Crop residue is left on the field to restrict runoff and control soil erosion. In China, corn stalks and other crop residues can be harrowed and left on the field. This also increases soil carbon, a critical soil component.

Photo: USDA-NRCS

Conservation agriculture uses a variety of techniques to reduce soil erosion during all stages of ploughing, planting, harvesting and fallowing. This can include:

Contour farming – As shown in Figure 2.4, contour farming can be used for larger land holdings. Farmers should avoid ploughing up and down the slope on smaller plots on sloping land, but rather should plough parallel to the slope. This provides an effective barrier to runoff that would otherwise run downhill and carry eroded sediment. Experiments in Yunnan showed that erosion rates with contour cultivation were 31 percent less than downslope planting rates (Barton, 2004).

Mulching and crop residue – This is the practice of spreading straw, crop residue, or other organic matter over the soil. Use of mulch and crop residue has four major advantages for farmers: (i) it conserves water in the soil by reducing evaporation; (ii) organic mulch and crop residues add carbon to the soil; (iii) it reduces runoff and increases water infiltration into the soil and (iv) reduces erosion and soil loss. Mulch is usually organic material such as straw but in some cases, plastic mulch is used, especially for vegetables and fruits. Crop residues that remain after harvesting can be harrowed to chop the crop roots and stalks so they provide a more effective protective cover over the soil and are more readily broken down into litter and incorporated as soil organic matter by soil organisms (Figure 2.5).

BOX 2.2
Role of straw mulch in preventing erosion

Straw mulch is very effective in decreasing erosion rates. In 1993, 1994, 1995 and 1996, soil loss was 18, 66, 86 and 78 percent less than for conventionally tilled plots, respectively. Straw mulch maintained topsoil structure and encouraged infiltration, thus decreasing runoff and erosion rates. Conversely, erosion rates under conventional tillage were high. (Barton, 2004)

Conservation tillage – Is the minimum (or zero) use of hand or mechanical tillage practices for preparing the land and planting, leaving at least 30 percent residue cover on the ground. This excludes in general the use of mouldboard and disk ploughs. A subset of conservation tillage includes a 'no till' system, where, instead of mechanically tilling the land or hoeing, seeds are planted directly into the previous season's crop residue and weeds are controlled using herbicides with no soil engaging equipment (Figure 2.6) or with the use of cover crops.

FIGURE 2.6
'No-till' in which seeds are planted directly into the previous years crop residue.

Photo: USDA-NRCS

This simple, low-cost practice can have a huge impact on reducing soil erosion. Conservation tillage saves farmers large amounts of energy and labour and improves soil quality. Conservation tillage was widely adopted in the United States in the past decade because of cost savings, soil improvement and environmental benefits.

Terracing – has been carried out in China for millennia. Terracing on mountainous and steep land is the most effective way to control erosion. In many parts of semi-arid China, modern terracing is being used to combat erosion and create arable land on steep slopes (Figures 2.7 and 2.8). Detailed information on the effects of terracing on erosion are described in Dorren and Rey (2010).

FIGURE 2.7
Terracing on the Loess Plateau of Shaanxi province, China.

Photo: LI, Z.B.

Buffer strips and field borders – are vegetated strips of land used to prevent eroded soil from being carried off the field or from one field to the next. Buffer strips may be grass, or hedgerows of shrubs or bushes. Various types of buffer strip are illustrated in Figure 2.8. The value of borders in China has been evaluated by Chaowen *et al.*, (2009).

Grassed waterways – are broad, shallow channels, vegetated with grass or legumes. They are designed

FIGURE 2.8

Field borders of various types. On the right, the field border also serves as a terrace to control erosion on sloping land.

Photos: USDA-NRCS

to carry large volumes of water from parcels of land to nearby water bodies and to prevent rills and gully formation. Badly managed drainage channels cause large amounts of erosion and soil loss, whereas well-managed drainage channels minimize soil loss.

In China, where plots of land are very small, this may not be a major issue, however, as plots are consolidated and field surfaces become larger, farmers should pay attention to drainage channels, especially in southern and northern China. Recommendations for the maintenance of grassed waterways may include:

- Repair and reseed any bare or eroded spots as soon as possible. Check the waterway after spring runoff and heavy rains.
- Trim grass to promote a good, strong sod and to prevent the waterway from becoming blocked.
- Keep cattle out of the waterway. Their hooves can puncture the sod, giving erosion a place to start.
- Do not use your waterway as a road. Tyre ruts damage the sod where erosion can begin.
- Control ground burrowing animals that may live in the waterway. Their activities can create weak spots where new erosion problems can start.
- Keep an uncultivated strip, at least 3 m wide, on each side of the waterway for stability.
- Do not dump rocks, dead trees, old cars or other items into the waterway. Flowing water will swirl around these objects, increasing the water's ability to erode.

Figure 2.9 shows the contrast between poor versus good management practices to control erosion from drainage channels across fields.

2.5 LARGE-SCALE EROSION CONTROL

Hill-slope runoff and erosion processes are easily altered by land-use changes. Increased vegetation cover generally leads to decreased runoff and reduced erosion. A small change in land use (crop type, field size, farm practices such as ploughing,

FIGURE 2.9

On the left is a badly managed drainage channel. On the right are two well-managed drainage channels that prevent erosion.

Photos: USDA-NRCSS

moving field boundaries away from streams) can have a significant effect on soil erosion rates (Van Rompaey *et al.*, 2002).

Since the 1980s, large-scale watershed management and ecological reconstruction programmes have been implemented in key areas throughout China where there have been serious water erosion problems. Past efforts have focused on eight key regions and seven large river basins including the Yangtze and Yellow rivers that require taking immediate soil erosion control measures and environmental restoration. A comprehensive soil erosion control system was developed that is suited to the socio-economic conditions of China which applies the following principles:

- Systematic land planning should consider the inter-relationship between mountains, water, cropland and roads. Planning should be done at the county level.
- Erosion control measures should be implemented at the scale of the small watershed but within the overall framework of a large river basin.
- Erosion control measures should integrate engineering, biological, soil and water conservation tillage technologies.
- Erosion control measures should balance the ecological, economic and social benefits.

Specific measures on the Loess Plateau

Check-dams constructed on the Loess Plateau in China are excellent examples of efforts made to trap sediment, save water and develop more fertile farmland (Figure 2.10). The amount of sediment retained by these check-dams has been found to be the largest among all other measures, and high crop yields have been obtained on these sediment deposits because of the plentiful moisture and nutrients.

The Loess mesa ravine region and the loess hill ravine region, that encompass 200 000 km of the Loess Plateau, are among the areas having the highest erosion rates on Earth, and the most effective way to conserve soil and water in these areas is to build check-dam systems in the gullies. Currently, more than 100 000 check-dams have been built (Xu *et al.*, 2006).

FIGURE 2.10
Check-dams and terracing to prevent erosion, trap sediment and save water in the Loess Plateau in Shaanxi province.

Photo: LI, Z.

FIGURE 2.11
An effective combination of contour ploughing, terracing, and vegetated buffer strips to control erosion.

Photo: LUI, Z.

FIGURE 2.12
Combined use of engineering and biological measures to control slope collapse.

Photo: LUI, Z.

Specific measures in the Black Soil Area

The following activities can control soil erosion in the black soil area in the northeast:

- Planting trees in the upper part of the catchment building cutoff ditches on the slope for collection of runoff and sedimentation.
- Use of contour tillage on slopes (refer to Figure 2.11).
- Gully control with building of bank, small pond, check-dams, and the plantation of vegetation.
- Adaptive farming system: Better choice of enterprises (cereals, poultry and livestock, fruit and vegetables, forest) and better choice of locations for various farming activities improves the overall approach to erosion reduction and benefits farmers through increased and diversified income.

Specific measures in the red-soil hills in south China

Soil erosion can be controlled by a combination of:

- Rehabilitation by enclosing eroded land, terraces or vegetated field borders.
- Combined use of engineering and biological measures for control of slope erosion (Figure 2.12).
- Change to managed forests and trees used as cash crop for farmers.
- Provide local farmers with fuel resources in order to protect vegetative cover (forests, grasslands).

Specific measures in rocky mountains

The challenge on rocky, steep terrain is to stabilize sloping farmland to decrease erosion and increase farm production. Wasteland on mountain slopes can be rehabilitated and made productive by shifting farm production to managed grazing, orchards, fruits and forestry. Because of steep slopes, runoff needs to be controlled with check dams constructed in ditches, and with improved levees on rivers for flood management (Figure 2.13).

FIGURE 2.13

Examples of erosion control in mountainous areas. Terracing is effective on steep slopes. Bank protection and check-dams in small rivers draining mountainous areas also help control erosion and sediment transport. Note how clear the water is as it flows over the check-dam.

Photos: LUI, Z.

Specific measures in limestone areas in the southwest

Erosion in limestone areas is a particularly difficult problem, especially as much of the rainfall tends to disappear underground. Once limestone surfaces have been overgrazed by farm animals, or the soil has been eroded as a result of poor farm practices, there is little one can do to reclaim these slopes. One successful measure is to convert degraded farmland to forest or orchards (Figure 2.14). At the foot of limestone slopes the soil can be captured and converted into productive land.

FIGURE 2.14

On the left, eroded soil has been captured in a series of terraces, and the land converted to orchards using a minimum of tillage. On the right, the slope has been stripped of most of its soil cover and is marked by gullies so the land can no longer be used. This type of slope can only be reclaimed with the use of heavy equipment to re-engineer the slope. This is an expensive process but is the only way this type of slope can be reclaimed.

Photo: LUI, Z.

FIGURE 2.15
Grasses that are adapted to dry sandy soils are used to stabilize sand dunes and in areas where sand is windblown.

Photo: LUI, Z.

Specific measures in windy and sandy areas

Sandy areas can be successfully managed in China using a combination of forested windbreaks to reduce wind speed, planting of trees to stabilize the sandy, and use of grasses that withstand heat, cold, and lack of water. These grasses colonize sandy soils and their root structure stabilizes the soil against wind erosion.

Many grass species are used around the world for the use and restoration of drylands. Two grass species used in China are:

Vetiver grass (*Vetiveria zizanioides L.*) – is used in southern China for various applications in erosion and sediment control. Current applications include soil and water conservation on agricultural land, steep slope stabilization, rehabilitation of mined, contaminated and saline lands (Truong, 1999), and recently, for wastewater treatment (Truong and Hart, 2001). The Vetiver grass system was first developed by the World Bank in the 1980s for soil and water conservation in India. Research and development conducted in Queensland, Australia, and overseas since then have also shown this system to be effective in warm climates.

BOX 2.3
Technical results for Vetiver grass

In India on cropping land with 1.7 percent slope, Vetiver contour hedges reduced runoff (as percentage of rainfall) from 23.3 percent (control) to 15.5 percent, soil loss from 14.4 tonne/ha to 3.9 tonne/ha and sorghum yield increased from 2.52 tonne/ha to 2.88 tonne/ha over a 4-year period. The yield increase was attributed mainly to soil and water conservation under the Vetiver hedge system (Truong, 1993). Under small plot conditions at the International Crops Research Institute for the Semi-Arid Tropics, Vetiver hedges gave more effective runoff and soil loss control than lemon grass or stone bunds. Runoff from the Vetiver plots was only 44 percent of that from the control plots on 2.8 percent slope and 16 percent on 0.6 percent slope. Relative to control plots, it was recorded that on Vetiver plots average runoff was reduced by 69 percent and soil loss by 76 percent were recorded from Vetiver plots.

Jiji grass (*Achnatherum splendens (Trin), Nerski)* – is widely distributed in northern China. With its tough root system, it has been successfully used for erosion control in areas such as the Loess Plateau in Shanxi province. Jiji grass is a perennial grass in north China and has similar features to Vetiver grass. Jiji grass can also be used for weaving artisanal products and for paper-making. It tolerates drought, salt, cold and alkaline conditions. The biological characteristics, applications, propagation technology and its various applications on the Loess Plateau are summarized by Wang Ku (No date).

Specific measures for grasslands

Extensive areas of grassland, such as those of the Ruoergai marshes (Gansu and Sichuan provinces), the Qinghai plateau, and in Inner Mongolia, are widely threatened by overgrazing and consequent erosion. In the past, efforts to 'improve' grazing land by drainage have caused extensive erosion in, for example, part of the Ruoergai marshes.

FIGURE 2.16

Typical grassland in Qinghai province. Extensive draining in, for example, the Ruoergai marshes, carried out in years past by Agricultural Bureaus has proven to be very destructive, requiring infilling of ditches and restoration of gullied land. Overgrazing by yaks and cattle increases the problem of erosion.

Photo: LUI, Z.

Erosion control measures include: creating enclosures for farm animals by fencing, then grazing enclosed areas in sequence so that each enclosure alternates between grazing and vegetation recovery. Part of the problem is local culture insofar as herders define their family wealth in terms of number of farm animals. This requires extensive education and training of herders and their families, and often the provision of alternative livelihoods. Local Development and Reform Commissions also need to better appreciate that increasing the number of animals is not a long-term solution to poverty reduction and is ultimately destructive of local livelihoods through reduced carrying capacity of eroded grasslands.

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3. Pollution from fertilizers

LIU Rongle[1], WANG Yufeng[2], LIU Zhaohui[3], ZHANG Ying[4]
ZHANG Yufeng[3], WANG Zhigang[4], Christian NOLTE[5]

3.1 INTRODUCTION

Growing plants require nutrients, especially nitrogen and phosphorus. These are applied as fertilizers to compensate for soil deficits and to enhance plant growth. There are two main kinds of fertilizer – organic manure and chemical fertilizers. Organic manure includes animal manure, human waste, organic waste by-products from the food industry, and agricultural waste such as straw. Chemical fertilizers are manufactured by the chemical industry for agricultural use.

Fertilizer consumption in China has grown by almost 21 percent annually over the last two decades, with proportionally large production increases for grain, vegetables and fruit. China is the largest consumer of fertilizer and accounts for 77 percent of the global increase in use since 1981 (FAOSTAT, 2010). There is no doubt that fertilizer has played an essential role in assuring the nation's food security. China has 130 million hectares (ha) of arable land and consumes about 50 million tonnes of fertilizer nutrients ($N + P_2O_5 + K_2O$) each year.

On average, fertilizer application in China is approximately 330 kg/ha; this is much higher than the upper limit (225 kg/ha) recommended (Yan, X., *et al*., 2008) and greatly exceeds fertilizer use in developed countries. On the North China Plain the use of N and P fertilizer is reported to be 588 and 92 kg/ha/yr, which is 66 and 135 percent more than the crops can assimilate (Vitousek *et al*., 2009). This high rate of fertilizer use directly endangers the sustainable utilization of soil resources and causes environmental pollution (Chen, *et al*., 2003). This chapter reviews key facts and figures in China, the main factors driving water pollution from fertilizers as well as recommendations for a reasonable fertilization.

3.2 BASIC FACTS ABOUT FERTILIZER USE AND ECONOMIC LOSS

N-Fertilizer – Based on the annual N consumption of almost 23 million tonnes and an average 28.7 percent loss of crops (Yan, X., *et al*., 2008), it is estimated that the total N loss could be approximately 16.4 million tonnes nationally.

Control of N-Fertilizer loss – Excessive fertilizer use, beyond the requirement of a specific crop yield, is the main cause of N loss. On fertile soils fertilizer use can be reduced to the level of nutrient export by crop produce and thereby N loss can be

1 Graduate School of the Chinese Academy of Agricultural Sciences
2 Heilongjiang Academy of Agricultural Sciences
3 Shandong Academy of Agricultural Sciences
4 Northeast Agricultural University
5 FAO Plant Production and Protection Division

decreased. The combination of organic and mineral fertilizer increase nutrient use efficiency, thus decreasing N loss, e.g. by reducing volatile losses (Li, Z. *et al*., 2007) as well as by decreasing N loss from runoff after heavy rainfall or flood irrigation. Use of organic manure has other significant benefits – it reduces the cost of purchasing mineral fertilizer and improves soil fertility through the addition of organic matter (carbon) and other macro and micronutrients.

P-Fertilizer – Phosphorus moves into surface waters mainly during surface runoff and soil erosion. Phosphorus is the main cause of eutrophication in lakes and rivers. The ploughed layer in the Beijing region is rich in P because phosphate fertilizer has been over-used for many years and is now a potential threat to the environment (Su, *et al*., 1999). In paddy soils in Jiangsu province where phosphate fertilizers are applied, mobile and total P have significantly increased (Xie *et al*., 2007).

TABLE 3.1
Fertilizer use on major crops (kg/ha)

	Farmers' use rate			N surplus above recommendation
Crop	N	P_2O_5	K_2O	
Winter wheat	211.7	96.4	31.8	23.2
Summer maize	196.5	78.5	22.8	
Rice	215			22.0
Cotton	204.4	112.6	79.2	
Vegetables	352.9	229.2	105.9	75.4
Fruit trees	426.6	335.7	204.0	145.3

Control of P-Fertilizer loss – As for nitrogen, reduction of P-fertilizer is an immediate step that can be taken to reduce P loss and save farmers' money. Because soil loss is the main vector for P loss from fields, reduced use of P-fertilizer and control of soil erosion by mulching or maintaining a plant canopy cover for as long as possible, are the main ways to prevent off-farm impacts of phosphorus.

The cost to farmers of excessive fertilizer use can be shown by the 'Fertilizer use efficiency; (FUE) index that measures the amount of fertilizer taken up by crops vis-à-vis the amount fertilized. Ideally, FUE should be close to 100 percent, meaning that no fertilizer is being wasted. However, this is difficult to achieve on farmers' fields.

Field experiments in 1990s showed that the overall FUE for wheat, rice and maize was 10–25 percent for phosphorus and 28–41 percent for nitrogen. More recent trials with wheat, rice and maize indicate that the FUE averaged 13.1 percent for phosphorus and 28.7 percent for nitrogen. It should be noted that one-year experiments give a distorted picture of phosphorus use efficiency (PUE).

This is, because P is adsorbed onto soil components, and can be used later by subsequent crops. Long-term experiments show a PUE of up to 90 percent on temperate soils (Syers *et al*., 2008). On highly P-fixing tropical soils, such as ferralsols and some ultisols, however, such high PUEs cannot be achieved (Chien *et al*., 2012). Low FUEs are a tremendous and unnecessary cost to farmers and the environment.

TABLE 3.2

Fertilizer application rates, utilization rate and economic loss to farmers per hectare[1].

Kinds of crops		Fertilizer nutrient	Average application rate (kg/ha)	Utilization rate (%)	Utilization of nutrient in season (kg/ha)	Cost of fertilizer loss in RMB/ha	Total cost of fertilizer loss at end of season in RMB/ha
Food crops	**Rice**	N	205.6	45	92.5	452.3	630.5
		P_2O_5	52.8	25	13.2	178.2	
	Wheat	N	182.2	45	82.0	400.8	609.7
		P_2O_5	61.9	25	15.5	208.9	
	Corn	N	197.1	45	88.7	433.6	608.8
		P_2O_5	51.9	25	13.0	175.2	
Oil crops	**Peanut**	N	117.7	45	53.0	258.9	491.4
		P_2O_5	68.9	25	17.2	232.5	
	Rape	N	175.9	45	79.2	387.0	621.2
		P_2O_5	69.4	25	17.4	234.2	
Vegetables		N	304.4	30	101.1	813.2	1 312.7
		P_2O_5	148.0	25	37.0	499.5	

Calculation of utilization ratio is based on current studies.

Cost of fertilizer based on: N = 4 yuan/kg; P_2O_5 = 4.5 yuan/kg

Average application rate is the national average between 2000 and 2005

1 Adapted from: Yan, 2008; Li et al., 2000; Zhu, et al., 1992; Li et al., 2010.

The direct **economic cost to farmers** of excessive fertilizer use is shown in Table 3.2 and ranges from RMB491/ha (US$78/ha)[6] to RMB1 312/ha (US$208), depending on the crop and location. These economic losses are more on the North China Plain, where fertilizer application rates are well above the national average.

3.3 ENVIRONMENTAL IMPACTS OF FERTILIZER USE

Surface water – The Government of China, after a national pollution census published in 2010, found that agriculture contributes about half of COD and ammonia pollution to surface waters. Excessive nutrients in water cause eutrophication of lakes and rivers, produces serious problems of algae (lakes) and river-weeds (rivers and streams), and can lead to large-scale fish kills. The most serious eutrophication of surface waters exists in the larger and mid-sized cities and their suburbs, e.g. lakes Dianchi, Tai, Chao and East.

Recent unpublished research reports that in the Tai lake region of southern Jiangsu province, animal waste from large operations accounts for 28 percent of total N and 44 percent of total P input of pollutants, while the runoff and leachate from agricultural fields accounts for only 7 percent of N and 4 percent of P, indicating the increasing contribution of animal manure as a pollutant of surface water. Other significant sources of pollutants were human excretion (31 percent) and sewage (24 percent) for N and human excretion (24 percent) and aquaculture drainage (23 percent) for P.

6 At 6.3 RMB to US$1

According to Jin (2002) 66 percent of all Chinese lakes are eutrophic to hyper-eutrophic, meaning that they are enriched with N and P that produce algae blooms, causing among other problems fish kills. The present total N and P level of the lakes in high-yield cropping regions such as lakes Tai, Chao and Dianshe, is more than ten-times higher than in the 1980s (Xie *et al*., 2007).

Investigations by the Ministry of Environmental Protection in these lakes and the Three Gorges watershed showed that industrial effluent contributed only 10–16 percent to the total N and P load, while the remaining came from the non-point sources for N and P from farmland and household sewage. Xie *et al*., (2007) report that more than 50 percent of the N and P load originates in agricultural production.

Nitrogen applied in excess of crop requirements contributes to air pollution as a result of ammonia volatilization (up to 47 percent of N applied to fields; (Tian, *et al*., 1998), to contamination of groundwater from leaching of N through the soil, and to eutrophication of lakes and rivers from N runoff in irrigation runoff and rainfall that produces runoff from fields.

Air pollution – Mineral fertilizer and animal manure can lead to significant losses of N into the atmosphere, if applied in excess of plant needs. Some mineral N-fertilizer contains ammonium (NH_4^+), which quickly hydrolyzes to ammonia (NH_3) in the presence of water after application. Urea is prone to high losses. It contains N in the form of carbamide, a compound with the chemical formula $CO(NH_2)_2$, is rapidly transformed into NH_4^+ after application by the ubiquitous soil enzyme urease.

Therefore, covering the fertilizer with soil immediately after application is warranted and direct application of urea onto paddy rice fields should be avoided. This is because rice field water usually has a pH >7, leading to volatilization losses that rise to 50 percent of total N. One method of avoiding this is by treating urea chemically to delay or block hydrolysis. In 2004, Zhang *et al*., (2010), found that 54 percent of total N volatilization from agriculture was from mineral fertilizer, and 47 percent from animals (directly, or indirectly from manure). Zhang's results are typical of those reported in international literature.

Animal manure can contain large amounts of ammonia and will undergo significant ammonia volatilization when stored. The NH_3 volatilization loss can be from 2 to 53 percent of total N contained in animal manure in a 4-month period. Volatile loss of N from animal manure, whether fermented or not, varies considerably depending upon storage and fermentation facilities (Qian and Lu, l994).

Volatile loss of agricultural N also contributes to the total N balance on farmers' fields. Recent research indicates that annual deposition of N from the atmosphere could amount to 20–30 percent of total N use in the Yangtze river region (Yan WJ *et al*., 2001). Sixteen monitoring sites in China found that the annual N input from rainfall onto farmlands was 4–23 kg/ha, mainly in the form of NH_4^+-N (Shen, 1998). He *et al*., (2010) found that atmospheric N deposition on the North China Plain is from 50–76 kg/ha/yr, or up to 13 percent of total N fertilizer applied by farmers. A free fertilizer resource for farmers is atmospheric N, which should be taken into account when calculating the total amount of fertilizer required.

Groundwater – contamination by nitrate is widespread in China and can be a serious health problem, especially for infants, young children, pregnant women and the elderly.

The safe threshold for nitrate (as elemental N) in drinking water is 20 mg N/litre[7]. According to the China Geological Survey, nitrate pollution of shallow groundwater is widespread with almost 100 percent of water samples containing some level of nitrate and with 30–60 percent of samples containing N at levels above the national standard. NH_3-N was detectable even in samples from deep groundwater in some regions (e.g. in Yinchuan city of Ningxia Autonomous Region). The groundwater nitrate pollution survey in 43 counties of Henan province found that the average sample nitrate content of 537 sampling sites was 9.31 mg N·litre-1 and 31.4 percent, which exceeded the national health standard. Eighty-six percent of the sampling was from wells with depths < 30 m and are, therefore, vulnerable to pollution; these had nitrate concentrations up to 111.31 mg N·litre. Similar results have been reported in the intensive cropping and high fertilizer consumption regions of Hebei, Tianjin, Shandong, Shanxi, Shaanxi, Jiangsu, and Yunnan provinces (Zhang, 1995; Liu, 2002; Ma, *et al.*, 1997; Soil and Fertilizer Institute, 2003).

3.4 NUTRIENT CYCLING OF N & P ON FARMLAND

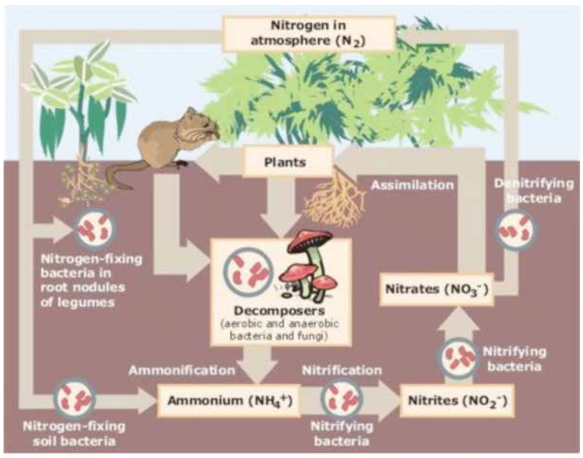
Plants absorb nutrients in ionic form from soil solutions through their root systems. Fertilizer application is to increase the capacity and intensity of nutrients available in the soil and to promote crop absorption and plant growth.

Nitrogen cycling

The soil nutrient cycle is shown in Figure 3.1. The **input** of N to a farmland system mainly includes:

- **Wet or dry deposition:** ammonia (NH_3) from the air in rainfall enters the soil, usually in the presence of SO_s, sulphur oxides, which are another air pollutant.
- **Biological fixation:** N-fixing bacteria in soil transform atmospheric N_2 into soluble soil-N forms.
- **Fertilizer and manure application:** chemical fertilizers and animal or green manure are usually used to increase soil N availability, to improve soil characteristics and crop growth and yield.
- **Irrigation:** N is usually found in irrigation water (from natural and human sources).

FIGURE 3.1
Soil nitrogen cycle



Source: US-EPA and US Dept. of Agriculture

The **loss** of soil N from a farmland system includes:

- **Crop removal:** The nutrients (N) contained in grain, vegetables, etc. are removed from the soil during harvesting or when crops and grasses are fed to animals and their manure is not returned to the soil.

7 The Chinese standard is two times lower than the WHO standard, which is 50 mg/litre NO_3 or 10 mg/litre nitrate-N.

- **Ammonia volatilization:** N in fertilizers applied to soil converts to ammonium ions (NH_4OH) in soil solution. NH_4OH is unstable at higher soil pH values and dissociates into NH_4^+ and OH-, and further into NH_3 and H_2O when the pH is 7 or higher. NH_3 then escapes into the atmosphere.
- **N denitrification:** The nitrate ions from nitrate fertilizer, together with soil nitrate that is oxidized from soil NH_4^+ through N nitrification, can be reduced to N_2, N_2O and other NOx compounds by denitrifying soil bacteria under anaerobic conditions. The resulting products are gaseous and can escape into the atmosphere.
- **Surface runoff:** NO_3^- is highly soluble and is easily lost in runoff from excess irrigation or from rainfall. N associated with particulate matter, including organic particles, is carried away with eroded topsoil. Excessive irrigation, rainfall and runoff that results in water and soil loss, are the main driving force of N surface loss.
- **Leaching loss:** Because NO_3^- is highly soluble; it is easily leached downwards through the matrix of most soils out of the root zone and into groundwater. However, on variable charge soils NO_3^- is bound to the soil matrix and not prone to leaching.

Phosphorus cycling

The characteristics of phosphorous cycling in farm systems are quite different from N cycling. Soil P is of low mobility, limited diffusion, and high reactivity with soil calcium, aluminum, iron, etc. to form phosphate compounds, which are of different solubility, but most are not very soluble. The main chemical process is the adsorption of water-soluble phosphate in soils, which results in low P use efficiency in the year of application. Because many farmers do not take into account the long-term availability of past P-fertilizer applications, overdose of phosphate fertilizers is common. The main soil P outputs include crop removal and surface runoff, because of the close chemical affinity of P with the soil's mineral and organic particles.

The topsoil of most farmland in China is rich in phosphorus as a result of intensive and large-scale use of phosphate fertilizers since the late 1960s. Scientists found that P loss from agricultural fields was about 1–8 kg/ha (Guo *et al*., 2004; Pan *et al*., 2003; Yan *et al*., 1999). FAO estimated the P transfer from farmland to water was up to 19.5 kg/ha in 1993 (Lu, 1998). Phosphorus loss is mainly in the form of particulate-P and accounts for 79–95 percent, while the soluble P component is very small (Yan *et al*., 1999; Shan, 2001).

Summary of nitrogen and phosphorus loss – Rainfall and runoff are the driving forces of N and P surface loss. When rainfall intensity exceeds the water infiltration rate on bare soil, surface runoff results in soil erosion. Because soil is enriched in N and P nutrients after long-term fertilizer application, the surface water and eroded soil particles carry N and P off the field and into surface waters. For nitrogen, rainfall and excessive irrigation carries nitrate in solution into the groundwater. Runoff dominates surface N loss on red soils under various farming systems (Yuan Dong-Hai *et al*., 2002). Soluble NH_4^+-N loss following application of fertilizer was the main form of N loss in the Tai lake region (Guo *et al*., 2003).

In conclusion, nutrient loss resulting from rainfall on unprotected soil and excess irrigation are the major mechanisms of surface water pollution from N and P fertilizers and of groundwater contamination. There is a great deal of room for improvement of resource-use efficiency, which can be achieved by integrated measures that require the broad cooperation of miners, fertilizer plants and agriculture.

3.5 FACTORS AFFECTING N & P LOSS

Management and utilization of nutrient resources

Unbalanced allocation among regions in China and excessive consumption of chemical fertilizers in some are a concern. In eastern regions, where agriculture and the economy is more developed, large amounts of fertilizer and over use are common. The average fertilizer application rate for field crops in Jiangsu, Shandong, Fujian and Shanghai was 376 kg/ha/yr in 2002, which exceeds the upper recommended limit of 345 kg/ha/yr.

In contrast, the average application in Guizhou, the Tibetan Autonomous Region of China, Gansu and Qinghai provinces was only 151 kg/ha/yr and is far less than the lower recommended limit of 255 kg/ha/yr (Li *et al*., 2001). Nutrient use between crops is also imbalanced. For example, in vegetable growing regions, N&P fertilizer application can be several times higher than the vegetable requirement (Wang *et al*., 2002) and up to 1 000 kg N/ha/yr have been reported.

Crops and cropping system – Crop seedlings and growing plants take up nutrients from the soil for early growth. When fertilizer is applied in the amount required by crops and at the time of highest nutrient uptake, N leaching and surface loss of N and P from runoff is greatly limited. Crops are an effective barrier to runoff, because they cover the soil and prevent aggregate destruction by raindrops, and they lower the nutrient concentration in the top soil layer by their nutrient uptake. The top layer is most prone to soil erosion. Different crops vary in their nutrient requirements and in their rooting patterns.

Field crops such as rice, wheat and maize develop extensive deep-root systems and can, therefore, exploit a large soil area. Vegetables have in general a poor root density, fewer root hairs (the main organs of nutrient uptake) and shallow roots. They require therefore a high concentration of soluble nutrients in the upper soil layer for high yields, which means that soil-N is leached out of vegetable fields to a much larger extent than out of cereal crop fields.

Paddy soils for rice are submerged during most of the rice growth period, so that anaerobic conditions prevail in the crop-growing season. This management system results in high denitrification rates and leads to substantial N leaching losses when the water is removed at harvest. Urea application onto standing water is of particular concern, as explained above, but is still farmers' conventional practice.

Paddy soils are less prone to P loss via surface runoff, because the P transfer rate from upland soils is often 100–200 percent higher.

Soil properties – Soil texture and the nature of the soil profile greatly influence soil nutrient loss. Sandy soil with low clay and organic matter content are well aerated and water infiltration is high. The low water and nutrient retention capacity result in higher leaching losses of soil N and P than in clayey soils. Clay-rich soils, however, often have spots where there are partial anaerobic conditions, favouring soil N denitrification.

If a clay layer lies underneath a sandy layer in a sandy-clay soil profile, water and nutrients are retained and nutrient leaching losses are reduced. A clay-sand soil profile in contrast, shows higher surface runoff and nutrient leaching losses because the sand layer is less able to retain nutrients.

BOX 3.1
Soil carbon and greenhouse gases in China

Chinese soils are, generally, low in carbon. With 12 million km^2 of farmland, increasing soil carbon by only 1 percent is the equivalent of storing (sequestering) 30.6 billion tonnes of CO_2 from the atmospheric. If only one billion tonnes per year is stored in the soil, this is equal to about 10 percent of estimated CO_2 production in China by 2025. Therefore, farmers can greatly assist China in meeting its CO_2 reduction targets and, at the same time, improve soil fertility – a win-win for farmers and the nation.

Source: Carbon Offsets, 2009

Soil pH and other chemical properties can affect N&P loss. Volatilization of ammonia (NH_3) is prominent on calcareous soils with higher pH in northern China. P fixation is a process that predominates in acid soils rich in iron and aluminum oxides.

Soil organic matter (OM) is an important index of soil fertility. Soil OM is usually measured as carbon in the soil (conversion factor C to OM = 1.72), yet Chinese soils are low in carbon from millennia of soil use and soil degradation.

In Heilongjiang, for example, one of the most fertile areas in China, the depth of fertile soil has diminished from 100 to 20–30 cm and organic matter content has been reduced from 12 to 1–2 percent in the last six to seven decades; furthermore, 85 percent of the soil is low in nutrients (Carbon Offsets, 2009).

There are similar patterns in Jilin province. The carbon/nitrogen (C/N) ratio of Chinese agricultural soils is currently 7:1 to 13:1 (Pan, 1999). Yet a suitable C/N ratio for soil microbial activities should range from 8:1 to 80:1, with optimal C/N close to 25:1. When organic manures or crop residues are applied to soils, the C/N ratio and microbial biomass is increased and some of the excess N would be immobilized into the soil biomass. Management of soil OM is an important technique to improve soil fertility, increase nutrient availability and control N&P loss.

Fertilizer and its application techniques

The chemical composition of N and P fertilizers affects their solubility and potential nutrient losses. Major N fertilizers used in China are urea and ammonium bicarbonate (for nitrogen), and ammonium phosphates such as di-ammonium phosphate (DAP), mono-ammonium phosphate (MAP) and simple superphosphate (SSP). Farm losses of N are especially important because of the potential volatile loss into the air of NH_3 from ammonium rich fertilizers, and leaching of NO_2 into groundwater after irrigation or rainfall. The order of nitrification of ammonium based N fertilizers is $NH_4(HCO_3)_2$ > $(NH_4)_2SO_4$)> NH_4Cl, and reflects the same order of nitrate leaching loss.

Nitrate based N fertilizers – include ammonium nitrate, potassium nitrate, and calcium nitrate. The soil N leaching loss is mainly due to nitrate leaching in soil water. Application of nitrate fertilizer into soil increases the potential N leaching loss. N leaching loss tends to be much higher when applied with ammonium nitrate than with urea and ammonium sulphate at the same rates (Zhang, F.Z. *et al.*, 1984).

Amide N fertilizer (Urea) – Urea is water-soluble and moves freely with soil water. Urea undergoes a decomposition process in soil with the help of soil urease after application, and is finally transformed to ammonium bicarbonate. Therefore urea behaves in the same way as ammonium bicarbonate except for the time lag required for decomposition.

Slow release fertilizers – mainly includes coated (sulphur coated, resin or other coatings) fertilizers and N fertilizers containing nitrification inhibitors. Coated fertilizer is used for controlling fertilizer N release. The low soluble or insoluble coatings fit N requirements in different periods of crop growth. Nitrification inhibitors are mixed with N fertilizers to slow the soil nitrification process and maintain more NH_4^+-N in the root zone for crop use. Studies have shown that slow release fertilizers have lower N leaching and volatile losses. For example, sulphur coated urea could delay N release for almost a week and reduce NO_3^--N leaching by 12 percent in a paddy soil.

It should be noted, however, that slow-release fertilizers are still much more expensive than the most common types of fertilizers, such as urea and DAP. It is still more economical for farmers to apply cheap urea, despite the losses they will incur, rather than their buying expensive sulphur-coated fertilizers with insignificant loss. Of course, in such cost/benefit calculations, environmental costs are treated as externalities, i.e. they do not enter into the economic equation, determining farmers' rational choice of inputs. Only if externalities are internalized, will that situation change.

Organic (green) fertilizer (manure) – Organic fertilizer has a much lower N and P content than commercial mineral fertilizers. This means transport costs per unit of nutrient are much higher than for mineral fertilizers. Since transport costs can make up one-third of the total fertilizer cost in countries with poor rural infrastructure farmers would face a substantial bill for applying organic fertilizers without substantial mechanization. Thus *in situ* production of green manure is often the better option, but farmers are generally reluctant to make the investment.

Since the release of N and P to plants is much slower with organic fertilizers, the combination of organic manure and mineral fertilizer is a common practice. Use tends to reduce NO_3^--N leaching because the N is in organic form, has a relatively low N release rate, and the microbial propagation and N immobilization associated with organic fertilizer helps retain N in the root zone. An additional benefit is the addition of carbon (organic matter) into the soil form organic manures.

The disadvantage is that there can be a substantial volatile loss of NH_3 into the atmosphere, unless the organic manure is quickly incorporated into the soil by disc harrowing. A study in the Taihu area demonstrates the benefits of using organic manure where, together with mineral (basal) fertilizer, loss resulting from N runoff was significantly diminished, reducing annual N leaching loss by 24.6 percent in paddy soils (Qiu *et al.*, 2004). Composting prior to manure application can help further decrease N leaching; composting also reduces manure volume, destroys weeds and pathogens and reduces odour.

There are limits, however, to the amount of organic fertilizer that can be used without causing serious N groundwater pollution. This limit may be exceeded in areas of high density animal-raising (e.g. large feedlots or large dairy operations) and application of large quantities of manure to small farm areas. The amount of manure applied to fields is determined by calculation of the nutrient balance in which the total amount of N (and P) that is applied (mineral and organic fertilizer) should not exceed the total of N up-take of crops + N stored in soil + N lost to the atmosphere. N that is in excess will runoff and leach into the groundwater. Farm agronomists can make this calculation for individual farms or farm areas having similar characteristics.

Fertilizer application techniques

This includes 'timing', 'placement', 'application rate' and 'nutrient ratio'.

- **Timing:** Basal fertilizers (applying fertilizers before sowing or transplanting), top-dressing (applied one or more times during crop growing periods), and basal-topdressing combinations.
- **Placement:** The application of fertilizers to the soil surface and to plant seedlings, and includes surface spreading (of fertilizers uniformly onto the soil surface), top plough down (top spreading and mix fertilizers with top soil by ploughing), deep placement (applying fertilizers below soil surface uniformly or in rows), fertigation (applying fertilizers with irrigation water).
- **Application rate and nutrient ratio:** This is the amount of fertilizer nutrient applied in a unit of cropping area and the ratios between nutrients (generally N-P-K).

Fertilizer application techniques are important when seeking to improve the efficiency of nutrient use and control nutrient loss. The key issues are placement and application rate for increasing the efficiency of fertilizer use.

3.6 REASONABLE FERTILIZATION

Crop fertilizer requirements

The fertilizer requirement of crops is the basis for developing fertilization programmes. In China, some requirements are:

Winter wheat – The growth period is long. For each 100 kg of wheat production, wheat needs to uptake 3 kg of nitrogen, 1–1.5 kg of phosphorus pentoxide (P_2O_5), and 2–4 kg of potassium oxide (K_2O). The absorption ratio of nitrogen, phosphorous and potassium is 3:1:3.

Rice – The amount of the three elements (N,P,K) required by rice depends upon the soil fertility level, yield, variety of rice, climatic conditions, cultivation and management measures. In general, 100 kg of produced rice needs to absorb 2.4 kg of nitrogen, 1 kg of phosphorous pentoxide, and 3.1 kg of potassium oxide. The absorption ratio of N: P_2O_5:K_2O is 1:0.52:1.29.

Soybean – uptake of N-P-K nutrients for seed production is higher than for cereal crops. An amount of 100 kg of soybean requires an uptake of about 6.5 kg of N, 1.9 kg of P_2O_5, and 3.2 kg of K_2O. In general, 50–70 percent of soybean N uptake is from soil and/or fertilizer, and the remaining portion is from air through nitrogen fixation in root nodules. The absorption ratio of N: P_2O_5:K_2O is 4:1:2.

Combined organic and chemical fertilizer use

In recent years, coordinated use of chemical and organic fertilizers is very popular in China. Although lower in nutrients, organic fertilizer releases nutrients more slowly and provides long-term nutrient supply not only of N and P but also of calcium, sulphur, boron, iron and other micronutrients required by crops. Because organic fertilizer is slow acting, its use alone may not satisfy all nutrient needs for the rapid growth of crops. Therefore the combination of organic and inorganic fertilizers makes excellent sense for farmers and reduces costs relative to use of only mineral fertilizers.

Balanced fertilization and economic benefits

Balanced fertilization refers to the combination of agronomic measures that support high levels of crop production, maintains soil fertility, minimizes nutrient losses to groundwater, surface water and to the air, and protects the ecological environment. Additionally, farmers can obtain economic benefits from balanced fertilization.

Balanced fertilization for corn production can increase production by 5.6 percent over that of conventional methods, with an additional benefit of more 714 yuan/ha[2] (Xing *et al.*, 2009). Balanced fertilization can enhance the nutrient utilization and quality of rice, increase production by 20.3 percent compared with conventional methods, and produce an additional 3 283 yuan/ha (Li *et al.*, 2008). Other economic benefits include reduced use of commercial fertilizer, when free organic fertilizer replaces mineral fertilizer and excessive fertilizer use is avoided.

Composting to produce organic fertilizer

Use of organic fertilizer is an important measure to increase crop production and income. Manure should not be applied before composting, especially for leaf vegetables because of the possible contamination of food with pathogens. Manure can be divided into three types – ‘fresh’ (non-composted), composted and aerobic or anaerobic digested manure. Composted manure should have a light, fluffy texture; anaerobic digested manure is handled as a semi-liquid (slurry).

FIGURE 3.2
A farmer uses slurry, the by-product of biogas production, which she has taken from the digester on her land, on this field of rice in Shuangliu, Sichuan province.

Photo: ©FAO/Florita Botts

Composting requires frequent turning of the composting manure (for aeration and to prevent overheating of the compost pile), a suitable C:N ratio (30:1), moisture content of about 50 percent (more than, or less than 50 percent slows decomposition). Composting produces heat (the optimal temperature is about 21.7 °C (71 °F), which is maintained by the compost pile through microbial action in the compost). The composting process can be easily seen to be finished when no further heat is produced and the composted pile is dark brown and odour-free. China is developing a Manure Composting Standard to illustrate specific requirements for composted manure.

Developing a fertilizer application programme at the farm level

Type of fertilizer – Nitrogen, phosphorus and potassium are the three important elements for crop growth. These are applied in a scientific way according to the actual needs of each type of crop, soil condition, and according to the farming system used. An important means of maintaining soil fertility is the use of organic fertilizer such as organic manure and crop residues (such as straw) in combination with mineral (commercial) fertilizers. Additionally, important trace elements in the soil need to be known and deficiencies rectified by adding these trace elements and micronutrients.

Fertilizer nutrient content – Commercial fertilizers are not 100 percent pure nutrient as these contain a variety of other substances that may include organic and inorganic matter, fillers and additives. For example, the amount of N in ammonium nitrate fertilizer is about 34 percent depending on the manufacturer and purity of the product (Alabama, 2008). Therefore the farmer must know the actual nutrient content in a fertilizer before its application so as to apply the appropriate amount of nutrient to the crops. The nutrient content of fertilizer is printed on the fertilizer bag as a formula N-P_2O_5-K_2O by weight. For example, 12-6-8 of one compound fertilizer indicates that it contains 12 percent of N, 6 percent of P_2O_5 and 8 percent of K_2O by weight.

Fertilizer application rate – Different methods are used to determine the rational application rates for nutrients on various crops. Generally speaking, the farmer determines the rational application rate of a specific nutrient according to the crop yield target, the soil nutrient content and the fertilizer used.

The farmer should also consider the following factors:

Crop and yield target – Different crops have varying nutrient needs for nitrogen, phosphate or potassium. The higher the crop-yield target, the higher the fertilizer rate because the crop needs more nutrient to achieve the higher yield. The nutrient requirements per unit of harvest yield listed in Table 3.3 could be used to estimate the total crop nutrient need when the target yield goal is set.

Soil nutrient content – Soil contains many essential nutrients required by crops. However, not all the nutrients in soil are available to crops; the amount of nutrient in soil that a crop can utilize is called 'available nutrients'. Available nutrients are determined by soil testing, which are then specified in 'milligram of nutrient per kilogram of soil'.

Therefore, when soil-testing values are given for a nutrient for a given soil, the total amount of available nutrient can be estimated by multiplying the soil test value and the soil volume. Soil volume is estimated using soil density and the rooting zone, usually the ploughing depth (20 cm). Soil testing information can be obtained from local government, from Soil and Fertilizer Stations, or by sending soil samples to a soil-testing laboratory for analysis.

Fertilizer nutrient recovery – The amount of fertilizer applied should be the difference between the amount of nutrient required by the crop and the amount of nutrient found in the soil. Fertilizer applied to soil is never fully used by crops; the percentage of fertilizer nutrients utilized is variable and is called '*nutrient recovery efficiency*'. Nutrient recovery efficiency is generally about 30–40 percent for nitrogen, 15–25 percent for phosphate and 60–80 percent for potash by the first field crop. Information on nutrient efficiency can be obtained from local agricultural bureaus.

Except for the small portion of fertilizer nutrients that are lost to the atmosphere and water, most unused nutrients are retained in the soil (especially P and K) and build up the soil testing value that will contribute to the following crops. The building up of nutrients in soils increases the risk of nutrient loss as a result of runoff and leaching. Farmers should develop suitable strategies for fertilizer application that aim to achieve maximum yield or to maintain soil fertility for reasonable yields in order to economically apply fertilizers and minimize the environmental impact of fertilizer use. Generally, the recommended fertilizer application rates are much higher with a maximum yield strategy than with a soil fertility maintenance strategy for an acceptable

TABLE 3.3

Crop nutrients required per 100 kg of economic output

Crop	Harvest	Total amount of N P & K (kg)		
		N	P_2O_5	K_2O
Rice	Paddy	2.1-2.4	1.25	3.13
Winter wheat	Grain	3.0	1.25	2.5
Spring wheat	Grain	3.0	1.0	2.5
Barley	Grain	2.7	0.9	2.2
Buckwheat	Grain	3.3	1.6	4.3
Corn	Grain	2.57	0.86	2.14
Millet	Grain	2.5	1.25	1.75
Sorghum	Grain	2.6	1.30	3.00
Sweet potato	Root	0.35	0.18	0.55
Potato	Tuber	0.5	0.20	1.06
Soybean	Beans	7.2	1.8	4.00
Pea	Beans	3.1	0.86	2.86
Peanut	Pod	6.8	1.30	3.8
Cotton	Seed cotton	5.0	1.8	4.00
Rape	Rapeseed	5.8	2.5	4.3
Sesame	Grain	8.2	2.07	4.41
Tobacco	Fresh leaves	4.1	0.70	1.10
Hemp	Fibre	8.0	2.30	5.00
Beet	Root	0.4	0.15	0.60
Grapes	Fruit	0.6	0.3	0.72
Cucumber	Fruit	0.4	0.35	0.55
Tomato	Fruit	0.45	0.50	0.50
Apple	Fruit	0.30	0.08	0.32
Cabbage	Leafy head	0.41	0.05	0.38
Eggplant	Fruit	0.30	0.10	0.40

Source: Compiled using data in: Plant nutrition and fertilizers (Ed. Zhejiang Agricultural University, 1991) and Soil testing and fertilization (Eds. Lv and Qin, 2002)

crop yield, depending on the type of the nutrients, crop value and other cultivation conditions.

- **Fertilization scheduling:** Crops require nutrients at specific times in their growth cycle. These are referred to as *'crop critical periods'*. If there is a deficit of nutrient at these critical periods, the crop suffers and usually cannot make up the loss with the later addition of extra nutrient. Therefore, scheduling fertilizer application in the correct amounts is an essential part of fertilizer management. Different crops have varying nutrient critical periods. The tilling stage is the critical value period for phosphorus on wheat and rice; for cotton and rape it is the seedling stage; for maize it is at the three-leaf stage. The critical period for nitrogen on rice is at the three-leaf stage and ear stage; for wheat it is at tillage stage and young ear formation. The critical period for potassium on rice is at the early tillage stage and young ear formation.

- **Fertilization method:** Fertilization methods vary based on crop species and scheduling requirements. Fertilizer application can be divided into (1) base fertilizer, (2) seed manure and (3) top dressing. Fertilizer application methods depend upon the amount of fertilizer required and the location of application. Therefore we speak of broadcast application (wide area application), spot application, and furrow application. Sometimes combinations of these are required to meet the crop needs at different times.
- **Soil characteristics:** Fertilization use must be based on to soil characteristics, including soil nutrient content. Some farmers do not pay attention to this point; this leads to 'blind' fertilization and results in excessive use of fertilizer and waste, or insufficient fertilizer that limits crop yields.

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4. Pollution from pesticides[1]

GENG Bing[2] and Edwin D. ONGLEY[3]

4.1 INTRODUCTION

The term 'pesticide' includes all chemicals of all types used to kill or control pests. In agriculture, this includes herbicides (weeds), insecticides (insects), fungicides (fungi), nematocides (nematodes) and rodenticides (vertebrate poisons).

A fundamental contributor to the Green Revolution has been the development and application of pesticides for the control of a wide variety of insectivorous and herbaceous pests that would otherwise diminish the quantity and quality of food produce. The use of pesticides coincides with the 'chemical age', which has transformed society since the 1950s. In areas where intensive monoculture is practised, pesticides are often used as a standard method for pest control.

Pesticides have contributed significantly to agricultural development and the production of fibres and food that feed and clothe the world's population. In the United States, crop yields for beet and soybean increased 175 and 91 percent as a result of the use of nematocides. Herbicides increased rice production in the Philippines by 50 percent and by 30 percent for sugarcane in Pakistan. In China, it is estimated that pesticides save 7 percent of food supplies and 18 percent of the cotton crop (Guo, 2010). This is critical in China, which has a large population with decreasing farmland. Pesticides also decrease the amount of labour and energy required for agriculture. In Japan, 330 hours/acre were required for weeding without pesticides; with pesticides there were only 29 hours of labour (Anon., 2008).

FIGURE 4.1
Spraying a rice field with powdered pesticide

Photo: ©FAO/Florita Botts

Unfortunately, with the benefits of chemistry have also come costs – some so serious that they now threaten the long-term survival of major ecosystems because of the disruption of predator-prey relationships and loss of biodiversity. Equally importantly, pesticides can significantly impact human health. This chapter describes these adverse effects of pesticides and identifies methods and approaches for impact mitigation.

1 Some of this chapter is taken from Ongley, 1996 (with permission).

2 Chinese Academy of Agricultural Sciences Institute of Environment and Sustainable Development in Agriculture.

3 Formerly, National Water Research Institute, Environment Canada (retired; currently international consultant).

4.2 IMPACTS OF PESTICIDE USE IN AGRICULTURE

Environmental characteristics of pesticides

In her 1962 book, Silent Spring, Rachel Carson was among the first to raise public concern about the environmental impact of pesticides. The ecological impacts of pesticides in water are determined using the criteria noted in Table 4.1.

TABLE 4.1
Criteria governing ecological impacts of pesticides

Toxicity	Mammalian and non-mammalian toxicity usually expressed as LD50 ('Lethal Dose': concentration of the pesticide that will kill half the test organisms over a specified test period). The lower the LD50, the greater the toxicity. Drinking water and food guidelines are determined by using a risk-based assessment. Generally, Risk = Exposure (amount and/or duration) × Toxicity. Toxic response (effect) can be acute (death) or chronic (an effect that does not cause death over the test period but which causes observable effects in the test organism such as cancers and tumours, reproductive failure, growth inhibition, teratogenic effects, etc.).
Persistence	Measured as half-life (time required for the ambient concentration to decrease by 50 %). Biotic and abiotic processes determine persistence. Biotic processes are biodegradation and metabolism; abiotic processes are mainly hydrolysis, photolysis and oxidation (Calamari and Barg, 1993). Modern pesticides tend to have short half-lives that reflect the period over which the pest needs to be controlled.
Degradates	The natural biochemical and photochemical degradation of pesticides can lead to formation of 'degradates' that may have greater, equal or lesser toxicity than the parent compound. As an example, DDT degrades to DDD and DDE.
Fate (Environmental)	The environmental fate (behaviour) of a pesticide is affected by the natural affinity of the chemical to one of four environmental compartments: solid matter (mineral matter and particulate organic carbon), liquid (solubility in surface and soil water), gaseous form (volatilization) and biota. This behaviour is often referred to as 'partitioning' and involves, respectively, the determination of: the soil sorption coefficient (K_{OC}); solubility; Henry's Constant (H); and the n-octanol/water partition coefficient (K_{OW}). These parameters are well known for pesticides and are used to predict the environmental fate of the pesticide. (Calamari and Barg, 1993)

Human health effects of pesticides

How pesticides enter humans or 'pathways':

- Skin contact: handling of pesticide products;
- Inhalation: breathing of dust or spray;
- Ingestion: pesticides eaten as a contaminant in/on food or in water.

Farm workers face particular risks when working with pesticides, which are associated with inhalation and skin contact during their preparation and application. However, for many in the population, ingesting food contaminated with pesticides is a principal pathway. This problem has become so pronounced that many consumers will pay extra to purchase certified organic products grown without toxic chemical pesticides. Many studies have demonstrated the impact of pesticides on, in particular, the health of farmers.

In Taiwan, Wang and Lin (1995), found that the substituted phenol, tetrachlorohydroquinone, a toxic metabolite of the biocide pentachlorophenol, produced 'significant and dose-dependent DNA damage'. Simoniello *et al.,* (2008) found similar DNA impairment in farmers who were exposed to agricultural pesticides. A study by Indian researchers found that cancer found in farmers working in the Punjab can be linked to pesticides used on their crops (Loyn, 2008). Elsewhere in India, agricultural soil that was contaminated with the pesticides carbaryl and α-napthol was shown to cause DNA damage.

One of the most detailed studies of linkages between pesticides and farmers' health in China is that of Huang *et al*., (2003) who studied 100 rice farmers in Zhejiang province. Nationwide it was reported that from 53 300 to 123 000 people are poisoned each year, with about half related to pesticide use for crops, about 300–500 deaths were caused by improper use of pesticides for crop production. In their study of 100 rice farmers in Zhejiang province they found the following typical health-related problems were associated with pesticide use: eye problems, headaches, skin irritation, impaired liver function (closely linked with pesticide use), kidney problems (also closely linked to pesticide use) and neurological problems (most pesticides are neurotoxins).

Health problems related to kidney function are mainly associated with category III and IV pesticides that are generally regarded as the most benign. It is estimated that each year approximately 7 000 die in China from exposure to pesticides (WHO, 2006). A more recent study by Zhou *et al*., (2011) determined that 67 percent of pesticide poisoning deaths in Hubei province were 'accidental' (exposure to pesticides by various means). Zhou notes that pesticides were the leading cause of poisoning deaths.

Degradation of water quality caused by pesticide runoff impacts human health in two ways. The first is the consumption of fish and shellfish contaminated by pesticides; this can be a particular problem for subsistence fish economies that lie downstream of major agricultural areas, or for consumers of fish raised in pens that received water contaminated by pesticides. The second is the direct consumption of pesticide-contaminated water. Many health and environmental protection agencies, including Chinese agencies, have established 'acceptable daily intake' (ADI) values that indicate maximum allowable daily ingestion, over a person's lifetime, without appreciable risk to the health of the individual.

Organophosphate and carbamate pesticides are highly toxic to target organisms, but can seriously impact birds. These pesticides are highly toxic and are associated with serious neurotoxic, carcinogenic (cancers), mutagenic and teratogenic (birth deformities) affect farmers who have had long-term exposure. Farmers' lack knowledge of treatment and some users' violation of relevant laws and regulations often result in acute poisoning. Recent studies concluded some pesticides can imitate natural hormones and can interfere, not only with the normal functioning of the endocrine system, but also with the immune, reproductive and nervous systems of people, animals and birds.

Impacts on the soil environment

According to Chinese statistics, every year over 180 million ha of farmland are polluted as a result of abuse of pesticides. Since the 1950s, more than 4 million tonnes of '666' and 50 million tonnes of DDT have been used for agriculture and 13.3 million ha of farmland have been contaminated. For many years DDT has been banned in China. DDT, however, like many other older (and mostly banned) organochlorine pesticides, is highly persistent in soil. Newer pesticides are formulated to break down relatively quickly so that they do not have the same long-term impacts on the soil as earlier pesticides. Today, however, a major cause of soil contamination is the disposal of used pesticide containers that can contaminate soil, groundwater and surface water.

Impacts on the water environment

Pesticides can be a significant water pollutant. The United States Environmental Protection Agency (USEPA) reports widespread contamination of waterways (rivers, lakes) by Atrazine, the second most commonly used herbicide in the United States. Direct runoff of pesticides into nearby drainage ditches, and drift from spraying, impacts nearby watercourses. In 1984, 12 kinds of high-concentration pesticides were measured in the groundwater in 18 states of the United States.

In 1986, 17 kinds of pesticides were detected in groundwater in 23 states. In Florida, dibromoethane concentration in groundwater was 64 times higher than the maximum allowable amount and resulted in more than 1 000 wells being closed. In a recent study on four major agricultural areas in the United States, the US Geological Survey (USGS) found that two classes of herbicides (triazines and chloroacetanilides) were commonly detected in shallow groundwater, but insecticides and fungicides were not found (Steele *et al.*, 2008). In Japan, pollution of water from pesticides is more serious. According to a monitoring report, during 1968 to 1969 content of DDT and its metabolites was 367 $\times 10^{-12}$ mg/litre in the main rivers, 666 to 923 $\times 10^{-12}$ mg/litre, significantly higher than in the United States (Chen and Zhao, 2002.)

From 1994 to 1998, more than 450 000 ha of fishing water was polluted and there were more than 800 accidents related to pollution in one province in southern China. Pesticides in water can be transferred and concentrated in the food chain by phytoplankton – zooplankton – fingerlings – grown fish, which when eaten by people, may accumulate in the body.

Impacts on aquatic biology

While modern pesticides are less dangerous to non-target organisms, and are formulated to break down relatively quickly, the impact of modern pesticides on biodiversity is now becoming clear. The widely used pesticide Atrazine causes male frogs to develop female characteristics (‘feminization’) at very low concentrations in water, which causes problems for frog reproduction. Glyphosate[4], another of the world's most common herbicides, is especially toxic to amphibians (e.g. frogs) and causes mortality, impaired growth and development[5]. This is a particular problem for wetlands near farms.

Certain pesticides, especially organochlorine pesticides, bio-accumulate in fish and other edible aquatic organisms, leading to potential human health problems, which are caused by eating contaminated seafood. In Yang’s 2005 study of fish and shellfish from markets in Tianjin, Dalian and Shanghai, a variety of chemical contaminants, including some pesticides, were found in edible fish tissue. Liu (2010) found similar results for fish and molluscs marketed in Liaoning province.

4 A recent comprehensive review of the environmental effects of Glyphosate herbicides is that of Govindarajulu, 2008.

5 There is some controversy about whether it is the active ingredient or the surfactant that carries the active ingredient when spraying that is toxic to amphibians.

4.3 REDUCING OFF-FARM WATER AND WATER-RELATED IMPACTS OF PESTICIDES

Guidelines for application of commonly-used pesticides

As noted above, the environmental and human-health impacts of pesticide abuse can be severe, with farmers' use of pesticides greatly exceeding the amount required to control pests. This is an unnecessary expense for farmers, is environmentally damaging and adds to farmers' health problems. Many studies indicate that environmental and food contamination from pesticides is widespread in China. Currently, many Chinese shoppers seek organically-grown fruit and vegetables as a way of maintaining family health. Nevertheless, it is farmers themselves who, as a group, are most affected by pesticides. Therefore, Table 4.1 provides guidelines for four commonly used pesticides for a variety of crops. Additional information can be obtained from local agricultural bureaus.

Farmers' knowledge

A study of 100 rice farmers in Jianxing and Anji counties of Zhejiang province revealed that:

> *'Although the kinds and amount of pesticide applied by farmers have increased significantly over the last two decades, farmers' knowledge of pest management was less than expected. Among 100 respondents, 34 farmers could not identify hazards caused by the pesticides they used. Those who replied they know the dangers of using pesticides (66 farmers) had minimal knowledge/ About two-thirds (65) did not know pests have (natural) 'enemies', and about half had never heard about integrated pest management (IPM). This was surprising, since Anji and Jiaxing have been sites for ecology-agricultural production experiments for a long time.'* (Huang *et al*., 2003).

This study is revealing both because it demonstrates how little Chinese farmers know about the hazards of pesticides, but also that efforts to introduce integrated pest management (IPM, see below) into farm systems appears not to have been very successful.

Huang *et al*., also examined the efficacy of pesticide use and found that:

> *'While pesticides contributed significantly to rice production by limiting yield losses, the marginal contributions of pesticide use declined considerably with increase in pesticide use, and approached zero at current average pesticide use level by the rice farmers.'*

Part of the overuse problem is because farmers perceive loss of yield from pest diseases and incorrectly conclude that more pesticides would produce better yield. This implies that farmers need to be educated about the reality of yield loss caused by pests. They need better information about the effectiveness of pesticides and to improve pesticide application practices (amounts, timing, etc.). This would decrease farmers' costs, improve their health, and reduce surrounding environmental damage, without reducing yield.

Know what you buy

China is the world's largest producer, exporter and user of pesticides and hundreds of companies produce pesticides. Complaints both inside and outside of China about fake, badly formulated and unregistered pesticides have been substantial and are undoubtedly linked to an unknown number of illegal manufacturers who market both overseas and directly to local farmers.

These contraband pesticides are particular hazardous to farmers and include pesticides that are cheap, but have been officially banned in China because they are toxic to the environment and can severely affect health. As part of the Twelfth Five-year Plan, the Chinese Government plans to reduce the number of manufacturers to 300 by 2015, with 50 percent of total sales limited to about 20 large producers.

While this will greatly assist the control of pesticide quality, it will not directly deal with the problem of farm gate sales by salespeople selling inferior or illegal pesticides, usually packaged to look like legitimate pesticide products from reliable manufacturers. Farmers need to consider the reliability of the source of the chemicals purchased from sales representatives, and should always check that the salesperson, and the company he/she represents, can be found if the chemicals prove to be dangerous or illegal.

Local agricultural bureaus play an important role in pesticide sales and sales management through inspection and enforcement of pesticide regulations. Actions include:

- Pesticide wholesale enterprises should be required to offer information about varieties, name and registration certificate; this is basic information contained on the pesticide label required by the agricultural administrative law enforcement unit.
- Supervision of wholesalers' purchase of pesticides. This inhibits entry of counterfeit pesticides into the market and reduces the number of agricultural accidents related to pesticides.
- Pesticide stores must display information about legitimate pesticides in a prominent location to increase farmers' understanding of legitimate pesticides and their safe use.
- Sales accounts and records of pesticide shops in townships should be checked regularly. A complaint should be lodged against shops with incomplete accounts and no sales records. They should be encouraged to create an adequate record-keeping system. Control of pesticide movement from wholesalers to retailers and farmers can be more effectively controlled by supervision, including the inspection of business accounts, pesticide product quality, purchase sources and destination.

4.4 MODERN APPROACHES TO PEST MANAGEMENT

Improvement of modern pesticides

Long-term use of highly toxic pesticides has led to the destruction of China's agro-ecological environment, has significantly decreased the number of natural enemies of pests, and contributed to the rapid development of pests' resistance to pesticides. As a result, the Chinese government is promoting the modernization of pesticides. In December 2003, the Ministry of Agriculture decreed that the registration of five kinds of highly toxic organophosphorus pesticides, including methamidophos, parathion, parathion-methyl, monocrotophos, and phosphorus amine products would be terminated.

Further, from 1 January 2007 onwards, five kinds of highly toxic pesticides, containing methamidophos, will be banned for use in agricultural and two newer replacements for these highly toxic pesticides have been released onto the market. Farmers need to ensure that the newer form of these pesticides is used, because they are more effective and safer than the older formulations both for farmers and the environment.

Organic farming

Organic farming is the form of agriculture that relies on crop rotation; green manure, compost; biological pest control; pesticides made from natural products; and mechanical cultivation to maintain soil productivity and control pests. Generally, synthetic fertilizers and pesticides, plant growth regulators, livestock feed additives and genetically modified organisms are not allowed. Since 1990, the global market for organic products has grown at a rapid pace, reaching US$46 billion in 2007. Organic farming is still insignificant in China and much of the produce is exported, yet concerns about food safety are resulting in rapid growth of the organic farm business with direct sale to consumers, also through some large food distributors.

Integrated pest management (IPM)

IPM is a pest control strategy that uses a variety of complementary strategies that together, reduce pests, costs and the use of chemical pesticides. Farmers practising IPM follow four steps (USEPA, 2010):

- Set action thresholds: Before taking any pest control action, IPM first sets an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not mean control is needed. The level at which pests will become an economic threat is critical to guide future pest control decisions.
- Monitor and identify pests: Not all insects, weeds or other living organisms require control. Many organisms are innocuous, some even beneficial. IPM programmes work to monitor and accurately identify pests, so appropriate decisions can be made for their control in conjunction with action thresholds. This monitoring and identification ensures that pesticides will be used only when they are needed and that only the right pesticide will be used.
- Prevention: The first step in an IPM programme is to take preventative measures such as rotating between different crops, selecting pest-resistant varieties and planting pest-free rootstock. These control methods can be effective and cost-efficient and present little to no risk to people or the environment.
- Control: Once monitoring, identification, and action thresholds indicate that pest control is required, and preventive methods are no longer effective or available, IPM programmes evaluate the proper control method both for effectiveness and risk. Effective, less risky pest controls are chosen first, including highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identification, and action thresholds indicate that less risky controls are not working, then additional pest control methods would be employed, such as targeted spraying of pesticides. Broadcast spraying of non-specific pesticides is a last resort.

In China, as in other rice-growing countries, beneficial insects ('beneficials'), especially spiders, are extremely effective in controlling major rice pests. Typically, beneficials enter the rice field before pests and feed on them as they invade the rice. Chemical pesticides disrupt this balance, often producing rather than controlling pest outbreaks. Farmers implement IPM using a technique known as the Farmer Field School model in which farmers are taught to recognize and make pesticide application decisions based on the numbers and types of beneficials. Mangan & Mangan (1998) report that rice farmers in Sichuan and Jiangxi who practiced IPM saw increases in farm income per mu of rice production. FAO (Ooi *et al*., 2005) found that cotton farmers who practiced IPM in Anhui, Hubei and Shandong also saw significant increases in farm income as well as reduced pesticide and healthcare costs.

An excellent example of the 'prevention' principle (above) is the development of cotton pest management practices in China. Since the introduction of transgenic cotton (Bt cotton) in 1997, which is resistant to some insects, together with mixed planting systems of cotton, corn, soybean and peanut on small farms that conserve the natural refuges of beneficial insects, the use of pesticides on cotton have fallen drammatically since the unprecedented pest densities of the early 1990s (Wu and Guo, 2005). Other publications from China also indicate an improvement in economic benefits for farmers using IPM[6].

Another example of IPM is the 'pollution-free cabbage demonstration station' in Haiyan in Zhejiang province where 300 acres of cabbage have been managed using a combination of sexual attractant control techniques on cruciferous vegetable pests, cultivation, management, fertilizer, plant protection, mechanized farming and harvesting. Rice brown planthopper, planthopper, stripe blight and other major diseases were controlled effectively, pesticide use declined by 22.3 percent, pest control efficiency increased by 15 percent and nitrogen fertilizer use decreased by 25 percent.

4.5 DISPOSAL OF PESTICIDES AND PESTICIDE CONTAINERS[7]

Storage and disposal of pesticide waste and empty containers is a major source both of environmental pollution and impacts on farmers' health. This is a particular problem in developing countries an in China. The key factors include:

Storage:

- Unused pesticides should be kept in their original packaging, sealed and stored in a locked, secure location to prevent accidental use by unqualified people, especially children.
- Pesticides should never be stored in other containers. It is strictly prohibited to use empty drinking bottles to store pesticides.

Disposal

- Never dispose of old or unused pesticides near wells, watercourses, ponds or irrigation channels and follow label instructions.
- Old pesticide containers should never be used for other purposes.
- Obsolete pesticides should be recovered by government, sales store, or manufacturers. Consult your local agricultural station for information.

6 Further information on IPM can be obtained from The State Key Laboratory of Integrated Management of Pest Insects and Rodents, Chinese Academy of Science, Beijing.

7 Full Guidelines on safe disposal of pesticide containers are found in FAO, 2008.

- Follow *'The regulation for safe application of pesticides'*.
- Use recycling facilities if these exist; otherwise:
  - glass containers should be washed three times then smashed and buried. Burial sites should be far away from homes and farm buildings;
  - metal cans and containers should be rinsed three times then pressed flat and buried;
  - plastic containers should be rinsed three times, smashed, flattened or cut up, then buried.
  - paper containers should be washed three times and then burned or buried. Burning should be carried out far away from homes and farm buildings; farmers and family members should stay far away from the smoke.
- Areas contaminated by pesticide spillage must be contained to ensure children or animals cannot enter. Consult with the local agricultural station for the correct method for managing the contaminated site.

4.6 SOURCES OF INFORMATION ON PESTICIDES AVAILABLE TO CHINESE FARMERS

Technical departments – (Plant Protection Stations, Plant Protection and Quarantine Station, Agricultural Technology Promotion Centers, Agricultural Technology Stations): provide most information on pesticides available to Chinese farmers. Many Plant Protection Stations have established pesticide distribution stations to consolidate pesticides sales and technical services.

Internet-based information – Much information is available on the Chinese Internet and accessible to agricultural professionals and farmers. These include:

www.chinapesticide.gov.cn	China Pesticides Information Network
natesc.agri.gov.cn	China Agricultural Technology Extension Network
www.sdica.com	Shandong platform for pesticides information
www.nyxxw.cn	Pesticides Information network
www.agrichem.cn	China Pesticides Network
www.hbsannong.com.cn	Hebei Rural Issues Information Network
www.ny114.cn	China Pesticides Consultation Network
www.fao.org/agriculture/crops/core-themes/theme/pests/en/	FAO Pest and pesticide management news, updates and references

Currently, many regions and counties have built 'Agriculture 110' integrated information service centres to achieve 'three-in-one' information modes: computer, telephone and television to provide science, technology and market information services to local farmers. These could, however, be used more effectively to explain the use and misuse of pesticides to farmers.

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5. Pollution from irrigation and drainage

LI Jiusheng[1], PENG Shizhang[2], HAO Weiping[3]

5.1 INTRODUCTION

With almost 63 million ha equipped for irrigation (FAO, 2012), China accounts for 22 percent of the world's irrigation area. The development of large irrigation projects has been an important factor in increasing food security, but it has often been associated with water quality problems caused by salt and fertilizer runoff as well as other pollutants such as pesticides. These have exposed aquatic ecosystems and human health to serious risks and have presented a major challenge requiring urgent attention. This chapter reviews the main causes and effects of water quality degradation induced by irrigation and suggests preventive and remedial actions.

5.2 MAIN PRESSURES AND IMPACTS ON WATER QUALITY

Salt runoff

Salinization of farmland from irrigation is common in many parts of China. This is linked to water quality problems caused by the high salt concentration of farmland drainage discharged into rivers and lakes. The Xinjiang Tarim river is an example; in the period 1993–2000 the salinity in the main stream and source region of the Tarim river was less than 1 g/litre, yet was up to 6~13 g/litre in the middle and lower reaches and the water quality is worse than Class V. (Song *et al*., 2000; Ji *et al*., 1998; 2000).

During the irrigation season, the irrigation return water that discharges into the main stream of the Tarim river is high in salt and is the main reason for increased salinity. Not only has water quality deteriorated but agricultural production has suffered from lower yields, and people's lives in this area have been seriously affected by salinization of the Tarim river.

Fertilizer runoff

Overuse of fertilizers by Chinese farmers is well known and has been reported by many researchers. Because many field crops are irrigated, including paddy rice, irrigation runoff is a major source of nutrients and contaminants (from pesticides used by farmers) in China's rivers and lakes. Box 5.1 illustrates the very large increase in fertilizer use and the loads of N, P and K in large lakes in China. More than 50 percent of nitrogen (N) and phosphorus (P) in Chinese lakes come from agricultural sources. In Taihu lake, N and P from agriculture is up to 77 and 33.4 percent respectively of the total load of N and P to that lake.

1 China Institute of Water Resources and Hydropower Research

2 Hoha University

3 Chinese Academy of Agricultural Sciences, Institute of Environment and Sustainable Development in Agriculture

BOX 5.1

Examples of overuse of fertilizer

N- and P-loads from different sources to arable land in main watersheds in China since 1960s

	1960s		1980s		2000-2001	
Source	N ($kg \cdot ha^{-1}$)	P_2O_5 ($kg \cdot ha^{-1}$)	N ($kg \cdot ha^{-1}$)	P_2O_5 ($kg \cdot ha^{-1}$)	N ($kg \cdot ha^{-1}$)	P_2O_5 ($kg \cdot ha^{-1}$)
Fertilizers	5	1	135	22	368	154
Animal husbandry	19	11	101	56	128	74
Rural life	29	8	49	13	56	15
Fertilizers: Livestock raising: Rural life	1:4:5	1:5:4	5:4:2	2:6:2	7:2:1	6:3:1

Calculated using summarized data from the lakes Dianchi, Taihu, Chaohu, Poyanghu, Hongzehu, Dongtinghu, Baiyangdian in Hebei province, Nansihu lake in Shandong province, Yilonghu lake in Yunnan province and the Three Gorges reservoir area. N- and P-loads mean the input from fertilizers, animal husbandry. Source: Zhang *et al.,* 2004

Impact on groundwater quality

Agricultural drainage leaches to groundwater, carrying excess nitrogen and phosphorus. Since 1994 the Chinese Academy of Agricultural Sciences has monitored more than 600 groundwater sampling points in 20 counties of Beijing, Shanghai, Hebei, Tianjin and other locations. The results show that 45 percent of the sampled groundwater exceeds the safe limit of 50 mg/litre used for drinking water standards in developed countries. In fact, nitrate content in groundwater can exceed 500 mg/litre at individual sites (Zhang *et al.*, 2004).

Groundwater nitrate content in seven Bohai sea provinces (municipalities) of north China show that the average nitrate content of groundwater is up to 11.9 mg/litre and about 34.1 percent of groundwater samples do not meet the drinking water quality standard of the World Health Organization (WHO). The impact of crop type on groundwater is significant; higher use of fertilizer on vegetable and orchard crops results in higher levels of N (average of 21.4 mg/litre) in groundwater than for grain crops (14.3 mg/litre). Based on 205 water source wells the Beijing Environment Protection Agency has declared that the over-standard number of wells is 23.4 percent, representing 146.8 km^2. Because about 50 percent of Beijing drinking water is from groundwater, nitrate pollution has become a health threat to drinking water safety in Beijing (Zhang *et al.*, 2004).

5.3 RICE – OPTIMIZATION OF IRRIGATION AND DRAINAGE

Rice is the main food crop in China and accounts for more than 60 percent of total irrigation water (Guo *et al.*, 2006). Most paddy rice is located in the south of China. Although water resources in the south are much more abundant than the north, water scarcity is also increasing and is exacerbated by serious waste of water in agriculture. The utilization coefficient of irrigation water is only about 0.45 (Wang, 2005). In developed countries this is >0.8; therefore, this is a serious problem for China. The pollution load of nitrogen and phosphorus for paddy rice is four times higher per unit area than for dryland farming and is caused by leakage and runoff from paddy fields (Hu *et al.*, 2000).

Controlled paddy irrigation

Since the 1990s many different water-saving irrigation techniques have been applied to paddy rice in large areas of China. The one common point is that field water conditions are different from those of traditional paddy irrigation in that at certain times in the growing cycle there is little or no submerged water over the rice. Controlled paddy irrigation is determined according to the soil moisture in the root layer. The procedures for controlled paddy irrigation are too lengthy and complex to include in this document but can be easily obtained from local agricultural bureaus. Field experiments show that the combination of controlled irrigation and drainage technology not only saves water and increases rice yield, but also reduces water discharge, and nitrogen and phosphorus loss from the paddy field (Gao *et al*., 2009). Compared with conventional irrigation, water savings are 16.7 percent with an increase of 7.1 percent in yield. Similarly, drainage from controlled paddy irrigation is reduced by 54 percent and with decreases in NO_3^--N, NH_4^+ and total-P of 38 percent, 82 percent and 52 percent respectively.

Paddy drainage

Controlled paddy drainage is a relatively new technology. It can regulate and control the amount and rate of drainage and reduces the chemical loss from the field, thereby improving the farmers' profit and drainage water quality.

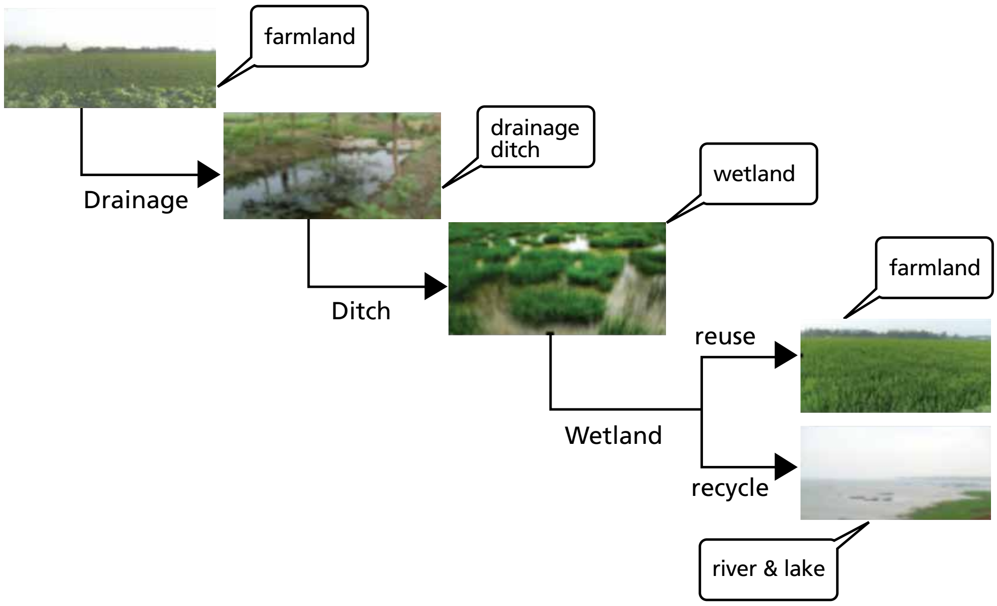
Underground pipe drainage – Pervious pipe is buried under the field to reduce excessive soil moisture. Use of pipe drainage reduces losses from both paddy runoff and nitrogen and phosphorus runoff.

Mole drainage – is performed by cutting the soil with a mole plough; subsequently, cracks appear in the soil after the dehydration of cohesive soils and water drains off. This technology is suitable for sticky-heavy soil. The mole plough was used in Jiangsu province in 1974 on an initial drainage area of 7 000 hm^2 and subsequently has been widely applied. The mole plough is often used in other countries to cut a trench into which subsurface drainage pipe is laid then covered with gravel and soil.

Controlled drainage – requires drainage management at the outlet of the field drainage system. Drainage control allows adjustment of underground water levels in the field. This, then, achieves the purpose of reusing drainage water, managing damage from waterlogging and reducing surrounding water pollution caused by drainage. It reduces loss of nitrogen and phosphorus from farmland and improves the quality of water in farm drainage. This technique has had a significant impact on farmland hydrology and on the surrounding water environment.

Integrated drainage and wetland management – this system combines irrigation, drainage and wetland as shown in Figure 5.1. The irrigated area is higher than the pond; field drainage is through pipes or ditches to the wetland where nitrogen and phosphorus are biodegraded by wetland plants. Water from the wetland can be reused in the field, or discharged to nearby watercourses. Compared with conventional irrigation and drainage, research shows that total nitrogen TN, NH_4^+-N and NO_3^--N concentrations at the outlet of the wetland were lowered by 17 percent, 14 percent and 51 percent respectively compared with the field drainage water. (Peng *et al*., 2009).

FIGURE 5.1
The system of farmland – ditch – wetland – reuse or recycle



5.4 WATER USE EFFICIENCY IN IRRIGATION SYSTEMS

In northern China, controlled irrigation covers two-thirds of the total irrigation area. Every year, there is up to 150 billion m^3 of leakage. Therefore, anti-seepage technology should be expanded vigorously. Lining of channels can cut losses from leakage by 50–90 percent; prevent secondary soil salinization and mitigate pollution of surface and groundwater. Canals can be lined with a wide variety of impermeable materials as noted in Table 5.1. These are described in the *Anti-seepage of Channels Project Technical Regulation* (Ministry of Water Resources) in 2004.

TABLE 5.1
Seepage characteristics of different canal lining materials

Impermeable linings	Seepage characteristics
Clay	Clay has anti-seepage and impermeable properties and can reduce the amount of seepage by up to 60 %; it cannot be used at higher flow rates
Cement/concrete	Seepage can be decreased by 80–90 %
Stone masonry	Seepage can be decreased by 70–80 % with dry stone masonry. Anti-seepage characteristics are improved when used with mortar cement, however it is difficult to guarantee the results
Film material	Can reduce seepage by > 90 %
Asphalt	Seepage is related to porosity of asphalt. The less the porosity, the less water seepage. Seepage can be reduced by >90 %
Polymer fibre concrete	Seepage can be further decreased by 13–26 % when used with ordinary concrete lining
Geo-synthetic clay liner	The functions of anti-seepage and anti-hydrostatic pressure are improved

Source: Yu *et al.*, 2010

Water-saving irrigation technology

Popular field irrigation techniques in China include many types of surface irrigation and pressurized irrigation. Water-saving and water-use efficiency are important reasons for irrigation water management, which can improve the water and nutrient utilization ratio, reduce waterlogging, water loss, and nutrient leaching to groundwater runoff from irrigation drainage.

Surface irrigation is the most widely used irrigation technique in China, practised on > 95 percent of irrigation areas. Surface irrigation includes strip irrigation, furrow irrigation, and flood irrigation. Irrigation efficiency is usually calculated as:

$$E_a \pounds \tfrac{1}{2} \frac{100Z_s}{Z_{avg}}$$

Where: Ea — Irrigation efficiency (%)

Zavg — Average irrigation depth (mm)

Zs — Average irrigation depth in crop root zone after irrigating.

Chinese fields are often referred to as irrigation ‘borders’. Borders are long, uniformly graded strips of land separated by earth bunds (mounds). In contrast with basin irrigation these bunds are intended to guide the water as it flows down the field. Borders are irrigated by diverting a stream of water from the irrigation supply channel to the upper end of the border. The water flows down the slope and, when the desired amount of water has been delivered to the border, the stream is turned off. This may occur before the water has reached the end of the border. There are no specific rules controlling this decision. However, if the flow is stopped too soon there may not be enough water in the border to complete the irrigation at the far end. If the water is left running for too long, then it may run off the end of the border and be lost in the drainage system.

As a guideline[4], the inflow to the border can be stopped as follows so that the accumulated water in the border reaches the end without loss:

- On **clay soils**, the inflow is stopped when the irrigation water covers 60 percent of the border. If, for example, the border is 100 m long a stick is placed 60 m from the farm channel. When the waterfront reaches the stick, the inflow is stopped.
- On **loamy soils** inflow is stopped when 70 to 80 percent of the border is covered with water.
- On **sandy soils** the irrigation water must cover the entire border before the flow is stopped.

Standards used for irrigation ditches are important in determining irrigation efficiency. Field experiments on the North China Plain show that the longer the irrigation ditch (L), the lower the irrigation efficiency (Pereira *et al.*, 1998). Tables 5.2 and 5.3 show the recommended values for improved irrigation efficiency border, irrigation ditch standard and technical parameters for different soil and terrain conditions (Ministry of Water Resources, 2011).

4 From: FAO, 1988. Chapter 4: Border Irrigation. In: *Irrigation water management*

In areas where rainfall carries organic waste (straw, mulch, manure) from the fields into watercourses, the increase of COD becomes a problem. Other types of plant production pressures on water quality include flushing of salt from farmland that has been salinized by irrigation practices, and improper disposal of pesticide containers, which can contaminate surface and groundwater.

Amount, timing and evenness are easy to regulate with pressurized irrigation (i.e. sprinkling and drip irrigation), thus reducing the leaching loss of water and fertilizer. With sprinkler irrigation for winter wheat on the North China Plain, loss of soil nitrate nitrogen because of leaching was only about 3 percent compared with surface irrigation under the same fertilizer application (Sun *et al*., 2007). Xi and Zhou (2003) showed that compared with traditional surface irrigation, urea-N, NO_3^--N, NH_4^+-N, and total-N leaching loss in drip irrigation was reduced by 19, 51, 43 and 25 percent respectively.

According to the absorption characteristic of water and fertilizer in different growing stages, the fertigation (irrigation water containing N and/or P) amount, timing and uniformity can be determined. Irrigation is usually determined by calculating crop evapotranspiration and real-time monitoring of soil moisture. Irrigation can be further optimized by practising deficit irrigation (see below) at specific growing stages (Kang

TABLE 5.2

Border length and unit width discharge under different conditions

Soil permeability coefficient ($m.h^{-1}$)	Border slope (%)	Border length (m)	Unit width discharge ($L.s^{-1}.m^{-1}$)
>0.15	<2	40-60	5-8
	2-5	50-70	5-6
	>5	60-100	3-6
0.10~0.15	<2	50-70	5-7
	2-5	70-100	3-6
	>5	80-120	3-5
<0.10	<2	70-90	4-5
	2-5	80-100	3-4
	>5	100-150	3-4

TABLE 5.3

Irrigation ditch length and flow rate under different conditions

Soil permeability coefficient ($m.h^{-1}$)	Furrow slope (%)	Ditch length (m)	Inflow discharge of furrow ($litre.s^{-1}$)
>0.15	<2	30~40	1.0~1.5
	2~5	40~60	0.7~1.0
	>5	50~100	0.7~1.0
0.10~0.15	<2	40~80	0.6~1.0
	2~5	60~90	0.6~0.8
	>5	70~100	0.4~0.6
<0.10	<2	60~80	0.4~0.6
	2~5	80~100	0.3~0.5
	>5	90~150	0.2~0.4

and Cai, 2002) resulting in increased water savings, yield improvement, and reduced loss of water and fertilizer from leaching.

Fertilization amount is also a key factor in affecting the fertilizer leaching; excessive fertilizer cannot improve yield; it only increases the leaching losses of water and fertilizer. For example, when nitrogen application increased from 150 kg/ha to 200 kg/ha under sprinkler irrigation condition, there was no significant difference in corn yield, but nitrate leaching increased by 59 percent (Mohammad *et al.*, 2002).

To determine the scheduling and amount of fertigation the farmer should consider the nutrient demand at different growing stages, and should follow the principle of 'little but more times'. Research shows that by increasing the frequency of drip irrigation frequency from 1 to 8 times per day the leaching loss of NO_3^--N can be reduced by 37 to 66 percent (Table 5.4).

TABLE 5.4
The effect of irrigation frequencies and irrigation amount on nitrogen leaching

Treatments		Nitrate leaching (kg/N/ha^2)	
Irrigation frequencies		2001	2002
Once per day	1.0 ET*	172	194
Once per day	0.8 ET*	194	233
Eight times per day	0.8 ET*	122	80

*ET: Potential evapotranspiration
From Vázquez *et al.*, 2006

Deficit irrigation

A deficit irrigation strategy is used when there is insufficient water for full irrigation requirements. During non-critical growing periods, little or no water is added to the crop. Water is added during critical growth periods; this has a significantly beneficial impact on yield that would otherwise be seriously reduced when there is water scarcity. Deficit irrigation follows from much research in the United States, Japan and elsewhere, where it has been proven that deficit irrigation has beneficial effects on yield of a variety of crops, from wheat to oranges.

Deficit irrigation experiments over three years for winter wheat in southwest Shandong province showed that water-use efficiency of wheat is highest at the jointing and grouting stages. With only two water applications, during the winter wheat growing season, yield reduction is 2.5 percent, but water saving is 26 percent (Zhang *et al.*, 2003). A single application of water at the jointing stage has a yield reduction of 15 percent and a water savings of 31 percent. Similar observations are made with winter wheat in Xinjiang province (Cheng *et al.*, 2009). Deficit irrigation has been practised only in the past few years in large areas of China, and there are significant possibilities for improving water-use efficiency in agriculture.

5.5 ECONOMIC CONSIDERATIONS

Investing in water saving improves water quality

Water-saving irrigation techniques improve the utilization ratio of water and fertilizer, reduce water loss and drainage and minimize the negative effects of irrigation drainage on nearby watercourses. The investment per unit area and investment cost per unit of saved water for different irrigation technologies in more than 20 provinces in China are shown in Table 5.5.

TABLE 5.5
Survey results on investment per unit area of different water-saving irrigation projects and investment cost per unit of saved water

Water saving irrigation engineering types	Investment in water-saving irrigation project		Investment cost per unit of saved water		
	Range (RMB/ha)	Average (RMB/ha)		Range (RMB/m^3)	Average (RMB/m^3)
Channel seepage prevention control			Irrigation area is > 33 300 ha	0.02~2.16	0.29
			Irrigation area is 20 000 – 33 300 ha	0.01~1.97	0.17
			Irrigation area is < 20 000 ha	0.01~0.40	0.14
Low pressure pipe irrigation	1 675~1 4818	7 910		0.05~1.45	0.55
Improved surface irrigation	232~7548	1 705		0.19~5.47	0.87
Sprinkling irrigation	4 873~2 9801	10 750		0.18~2.64	0.51
Micro-irrigation	8 750~32 402	13 523		0.20~6.83	0.51

Note: These data are obtained from the China Irrigation and Drainage Development Center: Integrated water-saving irrigation technology Lecture Series documentation.

The effects of water price on water quality

The cost of water for agriculture is generally low in China with an average price of RMB0.0357/m^3 in 1998 (Table 5.6), rising to a nationwide average price of RMB0.0733/m^3 in 2009 (Ministry of Water Resources, 2009). Although the cost has doubled since 1998 it remains very low, and ten times less than the RMB0.7~0.8/m^3 in developed countries. Because the cost to farmers is so low, the result is that the cost of irrigation infrastructure maintenance, management and equipment renewal is always in deficit.

Leakage in some irrigated areas is caused by lack of canal repair and maintenance. In fact, more than half of agricultural water is wasted during delivery and distribution, and field irrigation. This wastage results both in economic loss to farmers and to the government, and environmental damage is caused by surface runoff and seepage to groundwater. Fertilizers and pesticides, not utilized by crops, runoff to nearby watercourses and create about half of the nation's water pollution. For example, the cost of water to farmers in the Yellow river irrigation area in Ningxia was only RMB 0.002–0.012/m^3 for the period 1991~2000. According to the Ningxia Environmental Water Monitoring Centre in December, 2010, the water quality in seven drains in this irrigation district were all Class V (extremely polluted).

Mineralization and ammonia nitrogen in other channels also exceed the standards. This situation has resulted in monitoring of 25 drainage sections at the boundaries of the Ningxia Yellow river irrigation area, launched in November 2010. Monitoring will provide specific evidence of the amount of pollution caused by irrigation and will document the impact of steps made to counteract pollution from irrigation runoff. Comprehensive monitoring of the irrigation return flows can provide the necessary data for regulating agricultural non-point source pollution.

TABLE 5.6

The price of water used for agricultural in some provinces and municipalities in China at the end of 1998 (RMB0.01/m^3)

Regions	Water price	Regions	Water price	Regions	Water price	Regions	Water price
Beijing	2	Tianjin	4	Hebei	7.5	Shanxi	6.18
Inner Mongolia	2.3	Liaoning	3	Jilin	3 (Integrated)	Heilongjiang	2.4
Shanghai	1.5	Jiangsu	1 (Integrated)	Zhejiang	1.5*	Anhui	4.2*
Fujian	3.5*	Jiangxi	1.6*	Shandong	3.22	Henan	4
Hubei	4*	Hunan	3.2*	Guangxi	3*	Hainan	1.7
Sichuan	3.1	Guizhou	2*	Yunnan	2 (Integrated)		
Shanxi	3.9	Gansu	3	Qinghai	4*		
Xinjiang	1.8	Chongqing	3 (Integrated)	Ningxia	0.6 (Gravity flow)		

Data source: China Water Resources, 1998 (1), p. 6.

* These values are the equivalent price for water even though farmers paid for water in grain, not cash.

5.6 CONCLUSIONS

As practiced in China, irrigation has been shown to be wasteful of both water and agricultural chemicals, which negatively impacts the farmer and the environment. There is widespread water scarcity in the north and west of China, and the low price of water for agriculture promotes waste, provides no incentive to farmers to save water, and results in excessive cost to the national budget. Modern irrigation techniques reduce (i) the quantity of water used for irrigation, (ii) the amount of water that runs off to surface and groundwater, and (iii) the impact of agrochemicals on water in the environment. Modern irrigation techniques also improve yield and increase farmers' incomes.

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6. Pollution from livestock and crop waste

ZHANG Ke-qiang[1], ZHAO Run[1], HUANG Zhi-ping[1],
YANG Peng[1], WANG Feng[1], DU Lian-zhu[1]

6.1 INTRODUCTION

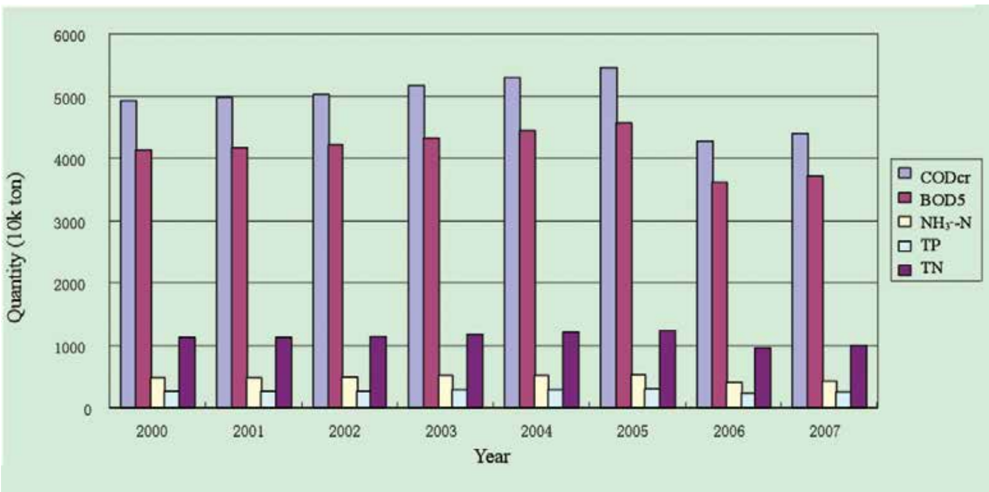
With the recent rapid development of livestock in China, the sector has become a new growth point in the rural economy and an important pillar industry. However, with the increasing scale of breeding and the continuing intensification and mechanization of this agro-activity, the pollution caused by livestock rearing has become the main source of non-point source (NPS) pollution in the Chinese countryside. The Ministry of Environmental Protection and Ministry of Agriculture, after several years of study, considers that in 2010 agriculture accounted for about half of all water pollution in China and, of this amount, the major contributor is animal waste. This chapter shows how important the problem is in China and suggests good management practices for manure and straw that can revert this situation.

6.2 OVERVIEW OF AGRICULTURAL WASTE POLLUTION

Animal waste

The problem of water quality in the livestock industry is from solid and liquid waste (manure). Liquid manure is urine, or any manure to which water is added in the collection, storage or treatment processes. The main pollutants in animal waste

FIGURE 6.1
Total pollution loads released to the environment from pigs, cattle and poultry, from 2000 to 2007.



Source: China Animal Husbandry Yearbook, 2008

1 Ministry of Agriculture, Agro-Environmental Protection Institute, China

are chemical oxygen demand (COD), biological oxygen demand (BOD), ammonia nitrogen (NH_3-N), total phosphorus (TP), total nitrogen (TN) and metals. Animal wastes often contain growth hormones and antibiotics. Livestock breeding in China produces huge amounts of manure (Figure 6.1).

In 2007, pigs, cattle and poultry produced 1.08 billion tonnes of manure. The composition of this manure in terms of pollutants is shown in Table 6.1.

TABLE 6.1

Pollution loads from livestock breeding in China, 2007

Livestock	Source and specific pollutants (10 000 tonnes)						
	Dung	Urine	COD_{cr}	BOD_5	NH_3-N	TP	TN
Pigs	17 507	28 888	1 171	1 143	91.1	74.8	198.4
Cattle	77 342	38 671	2 630	2 052	266.5	106.7	647.3
Poultry	13 200	—	585	509	62.7	57.7	138.0
Total	**108 049**	**67 559**	**4 385**	**3 704**	**420.3**	**239.2**	**983.7**

Source: China Animal Husbandry Yearbook, 2008

Livestock breeding causes many environmental problems such as atmospheric pollution, soil, surface and groundwater pollution and public health problems. This has negatively impacted the livestock industry itself and the rural eco-environment as noted in Table 6.2.

TABLE 6.2

Environmental pollution caused by livestock

Pollution category	Pollution impacts
Odour contamination	Clay has anti-seepage and impermeable properties and can reduce the amount of seepage by up to 60 %; it cannot be used at higher flow rates.
(NH_3, H_2S, CO_2, CH_4, N_2, Methanol, etc.)	Produces noxious odours that can threaten animal growth and disturb neighbouring communities. Some of these (highlighted) are greenhouse gases that cause global warming.
Nitrogen and phosphorus pollution in wastewater	Causes eutrophication of rivers and lakes and endangers aquatic organisms when severe eutrophication causes oxygen depletion in surface water. Nitrogen is a serious groundwater pollutant that threatens human health.
Mineral elements (calcium, copper, zinc, manganese, cobalt, iodine)	Pollutes water and soil, and endangers human health.
Heavy metal (arsenic, mercury, selenium, etc.)	Pollutes water and soil and endangers human health.
Residues of veterinary drugs (antibiotics, hormones, etc.)	Contaminates food and may be harmful to humans and wildlife.
Micro-organisms (anthrax, avian flu, tuberculosis, etc.)	Spreads pathogens and causes animal disease as well as impacting human health.
Other pollutants (animal corpses, burning waste, etc.)	Pollutes the atmosphere and spreads pathogens that can impact human health.

In China, the usual contaminant is untreated wastewater from farms. Large commercial feedlots, however, consider animal waste to be an economic resource. The waste is retained and converted to fertilizer, soil supplements and other commercial products. Animal waste can enter surface and groundwater both accidentally and deliberately from family, village and communal farms and feedlots (Figures 6.2 and 6.3). Rainfall causes animal waste to runoff into surface streams and groundwater. Also, farmers deliberately clean their animal pens directly into rivers and canals as a means of waste disposal. Without treatment, manure runoff from livestock farms can drastically pollute the environment.

FIGURE 6.2
Pollution of surface water from manure runoff.

Photo: ZHANG Ke-qiang

FIGURE 6.3
Runoff from a manure pile outside a pigsty runs directly into a canal.

Photo: E. Ongley

Nutrients, eutrophication and hypoxia

Nitrogen and phosphorus are important nutritional elements in animal diets. A good part of these nutrients are excreted and are found in manure. Animal manure contributes to much of the water pollution that is attributed to crop production in China. The enrichment of surface water by nitrogen, phosphorus and other nutrients leads to accelerated eutrophication (nutrient enrichment) of lakes, reservoirs, rivers and estuaries, leading to algal blooms and, in serious situations such as Taihu in recent years, to algal toxins that can dangerously impact human and animal health.

Algal blooms also deplete the dissolved oxygen (hypoxia) in water leading to death of fish and other aquatic organisms. In the absence of oxygen in lake water, the lake sediments generate hydrogen sulfide, ammonia and other malodorous substances. A particular problem is nitrogen, because it passes easily through the soil into the groundwater. Pollution of groundwater by nitrogen is a growing threat to human health, especially to infants and young children. Drinking nitrogen-rich groundwater can cause methemoglobinemia (red blood cells are less able to release oxygen to tissues), among other diseases.

Feed additives, hormones, antibiotics and heavy metals

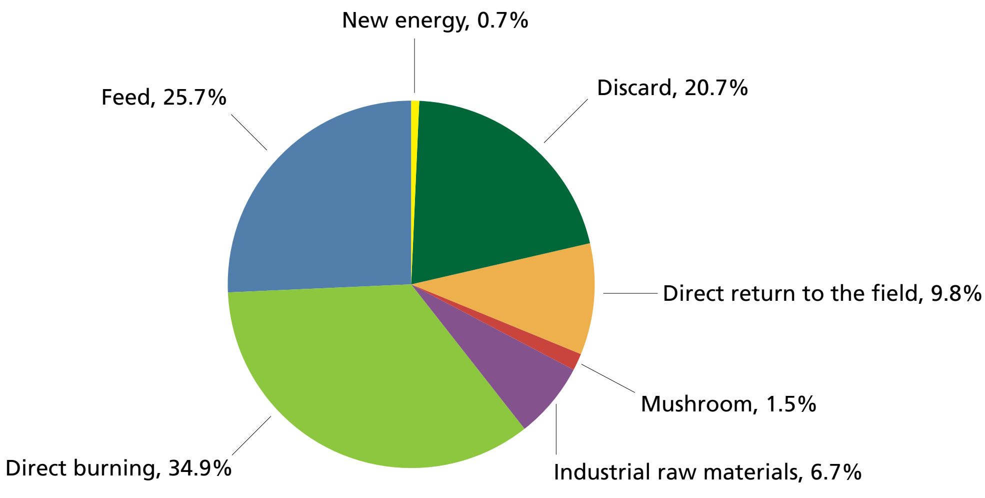
A huge amount of feed additives and antibiotics are consumed in China, the average annual consumption of antibiotics is approximately 6 000 tonnes. As a result of the excessive and inappropriate use, more than 75 percent of antibiotics, including the original drug and its metabolites, are discharged into the environment in animal manure. Studies show that a variety of animal antibiotics could be detected in the septic tanks of large-scale pig and poultry farms (at concentrations >100 µg/litre) and the same antibiotics could be detected in nearby surface water and groundwater.

The use of feed additives, together with feed manufacturing, results in relatively high heavy metal content in livestock and poultry manure. When the untreated manure is discharged into the aquatic environment the self-purification ability of the water is lowered and water quality deteriorates. An investigation of the surrounding environment and nearby farmland of 15 large-scale pig farms where PAPAA[2] was used as a feed additive for many years, found that the arsenic content in most fishponds exceeded the fishing water quality standard (0.05 mg/litre). Also, because of the impact of faecal waste from pig farms, the contents of Cu, Zn, Cd and Pb in the nearby reservoir are higher than the background water quality value by ten to hundred times (Zhang and Ji, 2007). More than 80 percent of livestock and poultry farms in China do not have waste treatment and recycling facilities, thus resulting in the pollution of surface and groundwater.

Crop residue: straw

Straw waste is an immense problem in China. There is little use of crop residue and a large amount is wasted. Poor treatment and disposal of straw seriously pollutes the atmosphere, soil and water and is a major waste of this resource. The annual production of straw has slowly increased since 2000, and in 2008 the annual production was 780 million tonnes. Straw utilization is shown in Figure 6.4. Use rate is low, direct combustion and discard amount to 55.6 percent of the total amount of straw residue.

FIGURE 6.4
Use of straw residue in China.



There are a few environmental, economic, human health and public safety concerns related to the burning of straw waste across China:

- pollutes the atmosphere and endangers human health;
- destroys soil structure and results in reduced soil quality resulting in economic loss to farmers;

2 Para aminophenylarsonic acid

- triggers fires, threatening life and property safety of rural populations and also of urban populations when large forest fires are caused by straw burning;
- air pollution results in traffic accidents and threatens aviation security because of poor visibility caused by smoke from burning straw.

FIGURE 6.5
Water body contaminated by straw.

Photo: YANG Peng

Straw is now a major source of pollution both for farmland and the aquatic environment. In harvest season a large amount of straw is dumped in drains, rivers or piled on river banks. When wet, and over periods of weeks to months, straw decomposes causing loss of oxygen, adding decay products to the water and turning the water black (Figure 6.5). This negatively impacts the aquatic environment and spoils drinking water sources. Best management practices for managing straw residue are noted in Section 6.4 of this chapter.

6.3 GOOD MANAGEMENT PRACTICES FOR MANURE

The storage, processing, handling and spreading of manure play an important role both in reducing water pollution and increasing economic benefits to farmers, especially as manure adds organic fertilizer and carbon to the soil and promotes good soil texture.

Storage

The volume (V) of manure storage (in m^3) at the farm level can be calculated as follows:

Formula 1

$$V = \frac{MW \bullet D}{MD} + BF + WW \bullet D$$

Where:

MW is the daily amount of manure produced on a livestock or poultry farm (kg/day);
D is storage days;

MD is the density of manure (kg/m^3);

WW is the volume of daily wastewater production (m^3);

BF is the volume of bedding (m3) calculated using Formula (2):

Formula 2

$$BF = VR(\frac{N \bullet B \bullet D}{BD})$$

VR is a proportional coefficient that is generally between 0.3 and 0.5; N is the number of animals;

B is the bedding straw consumed per head per day (kg/day); and

BD is the packing density of bedding (kg/m^3).

TABLE 6.3
Fresh manure production and characteristics per 1 000 kg live animal mass, per day

Parameter	Animal species										
	Cow	Cattle	Calves	Swine	Sheep	Goat	Horse	Chicken Layers	Chicken Broilers	Turkey	Duck
Fresh manure/ kg	86	58	62	84	40	41	51	64	85	47	110
Urine / kg	26	18	**	39	15	**	10	**	**	**	**
Density/ $kg \cdot m^{-3}$	990	1 000	1 000	990	1 000	1 000	1 000	970	1 000	1 000	**
Volatile solids (VS)/kg	10	7.2	2.3	8.5	9.2	**	10	12	17	9.1	19

The shape and size of manure storage facilities is important. Increasing the height of storage facilities reduces the surface area required and reduces odour. Increasing the height of anaerobic storage can reduce nutrient loss, improve the anaerobic environment and enhance the effect of treatment. The height of underground septic tanks should be 1.8~3.6 m. Storage space needs to accommodate rainfall, or rainfall runoff should be separated from the manure stream, so that the storage facility does not overflow. Generally the maximum rainfall over a 24-hour period that has occurred over the past 25 years is used to design storage facilities. An additional 0.3 m should be added to the design of anaerobic oxidation ponds without covers, for safety. Ponds or lagoons must be constructed so they minimize seepage to groundwater.

FIGURE 6.6
Large-scale composting

Photo: HUANG Hongying

Processing and handling

The health and safety of the farmer and crop products, comprehensive use and prevention of environmental pollution are the basic requirements for manure processing and handling. The following are options for manure processing:

Compost fermentation

Composting technology is the traditional method for reducing and processing farm waste. Under natural environmental conditions, straw and farm manure are mixed together, composted and then used as fertilizer. Composting technology varies according to compost materials, product to be produced by composting, and local conditions that determine the rate of fermentation such as temperature and moisture content. With the development of advanced mechanical composting technologies, composting can now be carried out on an industrial scale as shown in Figure 6.6. High-temperature aerobic fermentation can shorten the composting time and kill pathogenic bacteria and Ascaris eggs in manure to produce a safe product.

Anaerobic fermentation

There are a variety of technologies using 'bio-reactors'; these use anaerobic digestion and produce methane (biogas) and digested sludge as the end reaction products. The principal difference in these various technologies is the internal design of the bioreactor (Figure 6.7). Large-scale anaerobic fermentation reactors are increasingly common in commercial-scale animal raising and in agro-food manufacturing because the digester eliminates animal waste discharges and produces commercial products. Small-scale bioreactors are being installed in many counties on individual farms. These inexpensive bioreactors process household and toilet waste, and a limited amount of animal waste and produce methane that is used by the household for cooking, light and heat. Methane fermentation products should follow the *Sanitary standard for the non-hazardous treatment of night soil* (GB7959-87). Because methane is a greenhouse gas, it should never be released into the environment without burning it.

FIGURE 6.7
Bio-organic reactors at household scale

Photo: YANG Peng

Bioorganic fertilizer

Animal manure is the main raw material and is inoculated with a microbial additive that promotes biochemical decomposition in which pathogenic bacteria and parasite eggs are destroyed and odour is eliminated. Bioorganic fertilizer (Figure 6.8) has excellent physical properties, a moderate amount of carbon and nitrogen, and excellent fertilization efficiency.

FIGURE 6.8
Industrial scale preparation of bio-organic fertilizer

Photo: HUANG Hongying

Spreading manure

Although most crops require some inorganic fertilizer at critical growing periods, organic manure is part of the total fertilizer regime. Therefore, the amount of manure used must be part of a comprehensive fertilizer management plan. This is more fully discussed in Chapter 3. Excessive use of manure leads to a situation where the soil and crops cannot fully adsorb the nutritive components in manure and leads to surface and groundwater pollution. Scheduling of manure spreading on fields is also discussed in Chapter 3; however the following points are important for both solid and liquid manure:

- Runoff from snowmelt carries manure directly into rivers, therefore spreading of manure on frozen ground and on snow should be avoided. In some western countries the spreading of manure in winter on frozen ground is forbidden.
- Spreading of manure should be avoided when heavy rain is forecast and when there are physical or soil limitations that create the potential for runoff of manure, or leaching to groundwater.
- Because fertilization and irrigation is carried out at defined periods in the growing season of specific crops, the volume of the total designed manure storage facility should not be less than the total volume of manure produced during the intervals between manure use; generally, there should be enough storage for a minimum of 90 days although this may be longer depending on local circumstances.

BOX 6.1

Pig breeding and manure treatment by the Xiang Hua Company, Baodi district, Tianjin

FIGURE 6.9

Biogas facilities at the Xiang Hua Company pig farm. *(Photo: ZHAO Run)*

Tianjin Xiang Hua Co., Ltd. covers 40 acres and has 200 boars, (Landrace, Large White and Duroc), 50 back-up breeding hogs, 300 multiparous sows and 50 back-up sows. There are 2 500 pigs and an annual sale volume of 6 000 pigs. The company designed and constructed a plug-flowing methane tank with a total volume of 246 m^3. The fermentation room is 140 m^3, water pressure room is 36 m^3 and daily methane output is about 15~25 m^3 with more gas production in the summer because of the higher temperatures. Pig manure and wastewater are the raw materials, and the methane tank can produce 3 600 m^3/yr with a 60 percent utilization rate of the tank (Figure 6.9). This saves 20 tonne of coal in the winter for a saving of RMB 20 000. After fermentation the biogas residues are applied to the company's eco-garden and some farmland to replace fertilizer. So far farm wastes have not been discharged into the environment. Compared with manure used as fertilizer and integrated treatment, the nutrient utilization has been improved by 40 percent and use of bioenergy has increased by 30 percent or more.

6.4 GOOD MANAGEMENT PRACTICES FOR STRAW

Poor management of straw residue leads to excessive air pollution and is a waste of a valuable resource, and is being addressed by the Chinese government. In recent years, under national policy guidance and support, comprehensive straw utilization technologies continue to be improved and utilized, with the result that the comprehensive utilization rate increases each year. The straw use pattern is shown in Figure 6.11.

BOX 6.2

Bailong biobreeding farm in Wuling district, Changde city, Hunan province

This farm has ten employees and covers 5 acres. There are 240 stocking pigs and 600 are sold annually; total income is RMB1.2 million. The company introduced the pig-breeding biofermentation bed technique, using micro-ecology and biofermentation in which cotton-seed husks, sawdust, pulverized straw and fermenting ingredients are mixed into an organic litter inside the pig shelter. Pigs are bred on the mixed litter. Pig manure and urine are quickly degraded in the organic litter so that there is no need to wash the pigsty, no odour, and no emissions of pollutants. Labour savings are above 50 percent relative to conventional pig breeding. The average feeding period is shortened by 10–15 days. Each pig can save up to 20 percent feed per day; with a 75–90 percent water saving. On average, savings are made in veterinary medicine, electricity and feed costs of 50 to 80 RMB (~US$ 7–12) per pig.

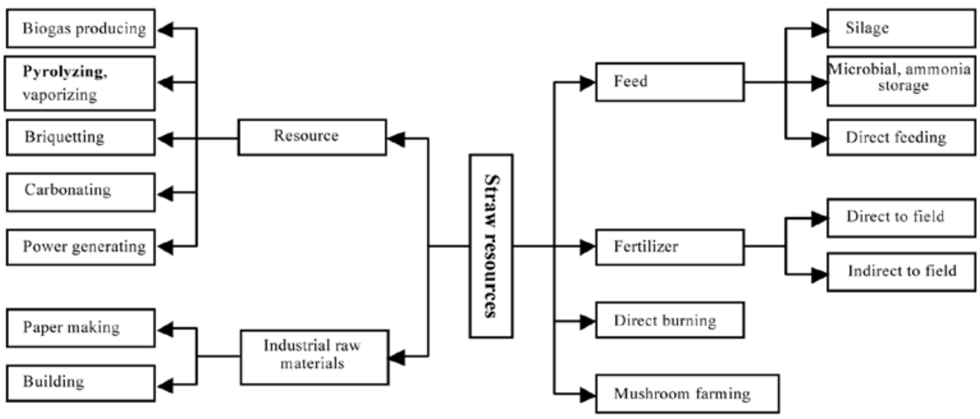
FIGURE 6.10

Pigs at the Bailong biobreeding farm

(Photo: ZHAO Run)

FIGURE 6.11

Illustration of the many different ways straw can be used



Currently there are many different techniques for using straw in China. Incorporating straw directly into the soil (Figure 6.12) and straw silage not only meet the needs for developing the rural circular economy, but are relatively simple and popular. Production of biogas with straw fermentation provides a clean source of energy and the fermented products can be applied to the field and thus save on fertilizers and increase food production. Straw use has great development potential and can effectively use straw resources in rural areas.

FIGURE 6.12
Straw mulch is returned directly to the soil

Source: Baidu

FIGURE 6.13
Increasing area where straw is recycled back to the soil

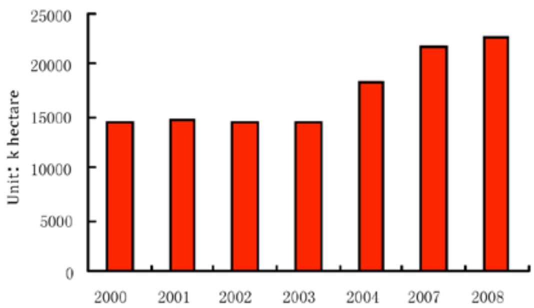


FIGURE 6.14A
Piling straw for silage.

Photo: ZHAO Run

Recycling straw directly to field soil

When crops are harvested, the stalks are shredded by machine to 5~10 cm; the shredded stalks are then evenly scattered on the field and are directly incorporated into the soil by shallow ploughing, or by pressing into the surface as shown in Figure 6.11. Pressing is preferable to ploughing insofar as pressing does not leave the soil vulnerable to erosion. Use of straw mulch in this way enhances soil quality and the ability of the soil to retain moisture. It also increases the organic and carbon content of the soil, is cost-effective and suitable for use on a large-scale in the main producing areas of wheat, rice and maize.

In the Eighth and Ninth Five-Year planning periods, technical studies on recycling of straw to the field achieved major breakthroughs for China. Recycling of wheat straw and corn stalks were studied in north and southwest China, the Yangtze river midstream area, the paddy-upland crop rotation areas of Jiangsu and the three cropping areas of Zhejiang. The effect of returning straw to the field became evident after three consecutive years of operation, soil organic matter increased by 0.2~0.4 percent, which is equivalent to an additional 255 kg standard nitrogen, 225 kg super phosphate, and 285 kg potassium chloride. Grain yield increased by 10~20 percent; farm income increased by 2.67~4 RMB/ha, fertilizer costs were reduced by 4.67~5 RMB/ha.

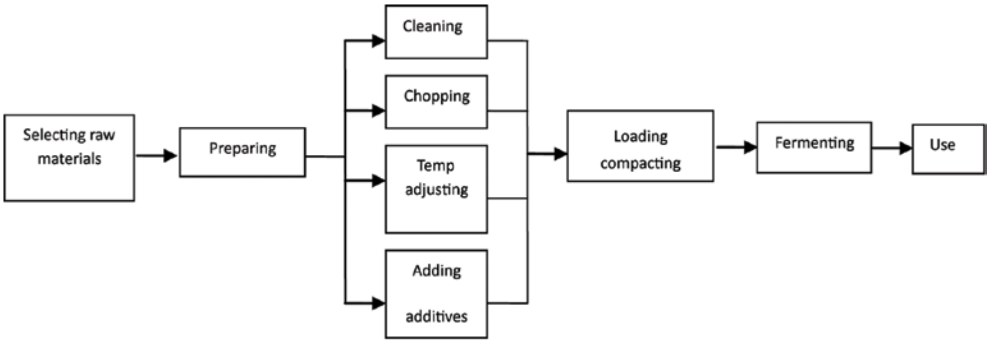
Recently, as this technology has matured, in 2008 the area of implementation was 227 333 ha (Figure 6.13) and plays an important role in improving grain production and reducing water pollution.

Straw silage

Straw silage is made by fermenting shredded green straw (Figure 6.14a) in packed tanks in which anaerobic fermentation by lactobacillus and other micro-organisms takes place. Straw silage fodder has an aromatic, sour and sweet taste that is palatable to livestock. This improves the nutritional intake of animals resulting in improved livestock products and breeding efficiency.

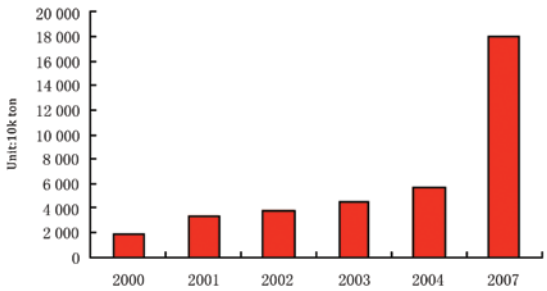
The straw silage process is illustrated in Figure 6.14b. The manure can be converted to organic fertilizer and returned to the field, or it can provide the raw material for biogas production. This technology is suitable for the main corn and other crop-producing areas.

FIGURE 6.14B
Flow chart for straw silage



In recent years, straw silage technology has developed rapidly as shown in Figure 6.15. The straw feed manufacturing, and marketing industry in, for example, Hebei, Henan, and Shandong are now of substantial scale and can continuously meet the needs of cattle and other animals. According to the China Agricultural Yearbook of 2008, 220 million tonnes of straw was used for animal husbandry in 2007, which accounted for 25.7 percent of total straw resources. Of this total amount, straw silage accounted for more than 180 million tonnes (fresh weight). With the continuous development of animal husbandry and aquaculture in China, there is great potential for the use of straw silage as feed.

FIGURE 6.15
Growth in use of straw silage in China



Straw biogas

The generation of straw biogas is the process whereby straw is transformed into biogas to provide energy for daily use by farmers on the small scale, and for industrial use such as electricity generation at a larger scale. The fermentation sludge residue is processed into a high-quality organic fertilizer for crop production. Straw and animal manure are the raw materials. These are pretreated, for example, by crushing, and then digested during anaerobic fermentation to produce methane biogas. Many types of fermentation technologies are available that can be used to create biogas from straw. In 2007, the Ministry of Agriculture listed straw biogas producing technology as the primary agricultural and rural technology.

FIGURE 6.16
Biogas fermentation and biogas capture tank using straw fermentation on an industrial scale in Jinghai, Tianjin.

Photo: DU Lian-zhu

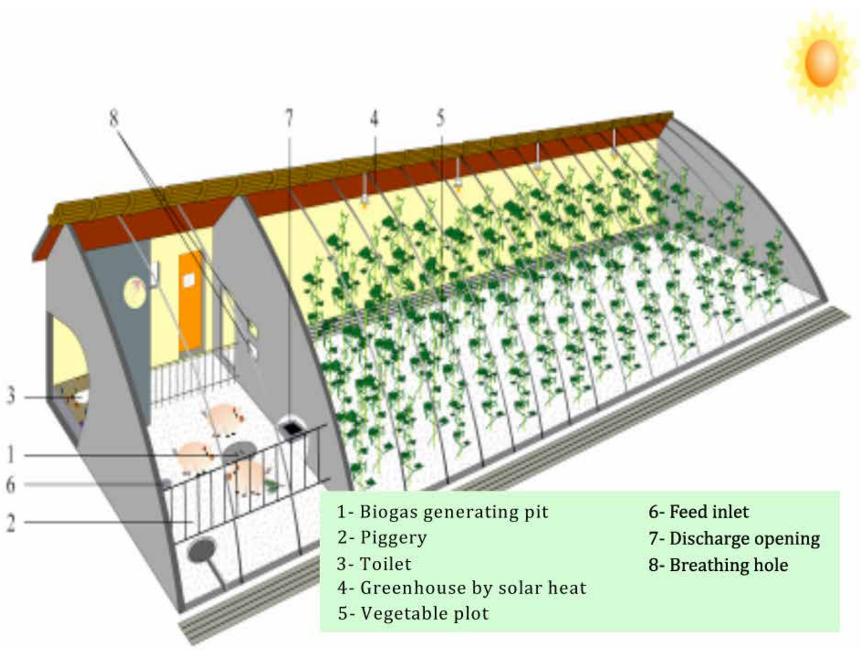
Straw biogas technology was being used by 138 000 households by the end of 2008 and there were 150 concentrated straw biogas supply projects. The promotion of straw biogas improves the comprehensive use of straw and the rural environment.

6.5 INTEGRATED REUSE AND RECYCLING

'Four-in-one' ecological greenhouse system

This refers to the combination of pigs, vegetables, waste and solar energy. Manure in pig-pens, household waste and toilets flow (Figure 6.17) to an underground biogas reactor (tank) through pipelines and produce biogas (methane) during anaerobic fermentation. The biogas is used for cooking and lighting; reactor liquid and sludge are used as fertilizer in the solar-heated vegetable greenhouse. The tank volume is designed based on the amount of manure produced by the farm, and the area of the vegetable greenhouse so that all sludge can be utilized. This type of system has substantial economic benefits for farmers because the reduced energy and fertilizer costs can virtually eliminate environmental pollution.

FIGURE 6.17
Illustration of the 'Four-in-one' method. Source: Baidu



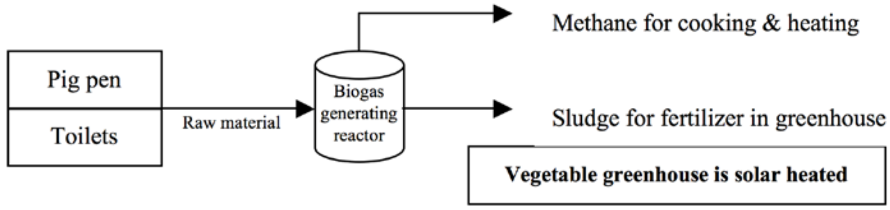
The 'Pig – biogas – fruit – vegetables' mode is a variation of the 'Quaternity' method; farmers integrate pig breeding with household waste to produce biogas and sludge. The gas is used for fuel and the sludge is used for fertilizer not only for greenhouses but also for field crops, paddy rice, fish production and orchards.

Mushroom cultivation with cow manure and crop straw

Crop straw and cow manure are the main raw materials used to produce edible mushrooms. After the mushroom crop, the substrate can be used to plant peas (without pesticides and fertilizers); finally, the substrate can be separated into two

FIGURE 6.18

Flow diagram of the Quaternity system. This is an example of comprehensive utilization of farm waste.



parts: the mycorrhiza[3], after drying and grinding, is then used to seed the next mushroom crop; and the remainder is used as highly efficient organic orchard fertilizer. This model achieves the transformation of agricultural production and waste recycling, and improves farmers' income, business efficiency and the environment.

FIGURE 6.19

Mushroom cultivation using manure and straw

Photo: LIANG Jun-feng

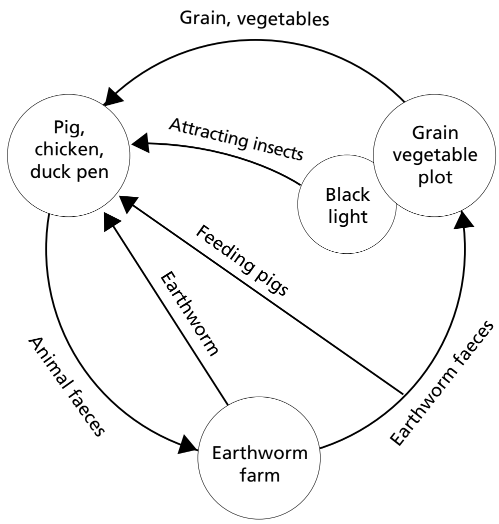
Multi-dimensional recycling of straw

Multi-dimensional recycling involves the combination of several recycling technologies into an integrated production system. For example, straw – livestock – biogas – mushroom – earthworm – chicken – pig – fish methodologies can be integrated into a single production system. Straw silage is used for animal feed. Animal manure and bedding straw are used to produce methane gas or for mushroom cultivation. The byproducts of mushroom cultivation are used to breed earthworms and raise chickens.

The chicken manure is fermented, the fermentation sludge and breeding manure are used to raise earthworms, and the residues are used to raise fish or are returned to the field. There are many combinations of these basic processes that can be integrated at the farm level into cost-savings for energy and fertilizer, and to increase farmer income. Multi-dimensional recycling promotes an effective circular economy in rural areas and the sustainable development of agriculture.

FIGURE 6.20

Industry chain comprises livestock + poultry earthworm–grain and vegetable



Source: Baidu

Industrial chain and economies of scale

Small farms usually do not have the economies of scale to adequately develop economic

3 In this case, the product of the symbiotic relationship between the mycelium of the mushroom and plant roots.

methods of processing their waste. However, by organizing several livestock or poultry enterprises into a cooperative enterprise, economies of scale can be achieved so that each farmer can benefit economically while, at the same time, producing high-quality livestock as well as other products developed from animal waste. This forms a chain in which each part of the production process is linked to another. This is shown in Figure 6.20. Earthworms are used to reduce waste, which is then used for grain and vegetable production.

6.6 CRITERIA FOR SITE SELECTION FOR LIVESTOCK AND POULTRY FARMS

China has introduced a number of management regulations to address environmental pollution caused by the livestock breeding industry, such as Regulations for the prevention and control of pollution from livestock breeding; Pollutants discharge standards for the livestock and poultry breeding industry; Technical specifications for pollution prevention for the livestock and poultry breeding industry, in which requirements for site selection and the required facilities for livestock and poultry farms are identified. In general, the following are important considerations:

- Animal breeding must be located in areas that conform to the legal requirements for this type of activity.
- Local conditions such as soil, terrain, water, etc. must be taken into account when establishing animal breeding facilities. Enough land needs to be available for manure spreading.
- Animal pens should be far from rivers, canals or creeks. Legal requirements exist to prevent water pollution. Farmers should not clean animal pens directly into nearby watercourses.
- Drainage should separate sewage and rainwater, and sewage should be in pipes, not in open ditches.
- Manure storage and disposal facilities are to be built to eliminate rainwater entry into the facility, and to prevent seepage to surface and groundwater.

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7. Pollution from freshwater aquaculture

LI Xuxing[1] and SHEN Gongming[1]

7.1 INTRODUCTION

Aquaculture is the process of farming aquatic organisms in inland and coastal areas. It involves intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated. It embraces the entire range of activities from the breeding of seeds to the harvesting of aquatic products.

Although aquaculture is a major source of protein and income in China it can also contribute significantly to water pollution. Fed and intensive aquaculture can result in excess of feaces, un-eaten feed and drugs released to water bodies. Some types of non-fed aquaculture (e.g. mussel farming) can filter and clean waters but other types (e.g. intensive caged crab culture) may disrupt natural nutrient cycles and result in the degradation of water quality. This chapter provides an overview of the types of aquaculture and their pressures and impacts on water quality, the chapter also suggests measures to prevent and remedy these impacts.

FIGURE 7.1
Fish ponds for aquaculture, Shang Nong Jie, Yunnan province

Photo: ©FAO/Antonello Proto

7.2 TYPES OF AQUACULTURE

Aquaculture includes extensive, intensive, and high-density intensive methods. In extensive aquaculture stock density is low and the feedstock (such as algae, aquatic weeds, small fish, etc.) occurs naturally in the water body (non-fed aquaculture). Examples of extensive aquaculture in China include fish and crab culture in many small and medium-sized lakes. Intensive aquaculture cultivates aquatic products in relatively small water bodies or in contained facilities normally with water treatment, disease control, feeding (fed-aquaculture) and fertilization. High-density intensive aquaculture uses water, temperature, oxygen and high-quality organisms to maximize the yield of fish, shrimp and other intensively raised organisms.

Non-fed aquaculture – In this form of aquaculture naturally occurring nutrients, plants and animals in the water are used as feedstock to produce aquatic organisms for harvest and sale. This type of aquaculture is often practiced on floating rafts containing aquatic plants or nylon bags used to grow mussels (such as *Hyriopsis Cumingii*, which is commonly used in China for freshwater pearls), and fenced (caged) areas in lakes to produce crabs that feed on naturally occurring vegetation.

1 Chinese Academy of Fishery Sciences

FIGURE 7.2
Fisherfolk learn new aquaculture techniques at the Freshwater Fisheries Research and Training Centre, near Canton.

Photo: ©FAO/Florita Botts

Rafts are commonly used in China to control water pollution, especially in urban lakes, to reduce the concentration of nutrients in the water (Liu, S. and Xiong, Y., 2007). Another form of non-fed aquaculture is the raising of fish in rice paddies. The benefits include increased fish production, feeding fish reduce pests and weeds in the rice fields, and soil is loosened and fertilized by fish excreta, promoting increased rice yield.

Fed aquaculture – most common methods are pond and cage culture. External feed, known as bait in China, is the main source of nutrients for fed aquaculture organisms. A particular disadvantage is that under current culture techniques, farmed fish do not completely consume the minced fish (prepared by grinding small raw fish) or other artificial feedstock. This can cause direct pollution of natural water bodies as a result of the excess feed plus fish faeces deposited on the bottom of the water body. In fish ponds created on land, the chemically enriched water from fish excreta and suspended food and excreted solids, as well as bottom sediments that have been contaminated by excess food (bait) and excreted solids, is pumped out, usually into nearby waterbodies, which causes pollution.

7.3 MAIN SOURCES OF POLLUTION FROM AQUACULTURE

Large amounts of artificial feed are released into aquaculture water to increase production. In some cases, fertilizers are released into aquaculture water to increase growth of food organisms. Often, drugs are used to control diseases. The waste produced by these processes includes un-eaten feed, excretions and secretions of the aquaculture organisms, and excess chemicals and pharmaceutical agents. Pollutants produced by aquaculture chiefly originate from the use of various inputs and the excreta of the aquaculture organism.

Feed conversion ratios (FCR) vary significantly between species and farming systems. In China's typical culture processes, 10-20 percent of feed is not eaten by the fish and is dissipated in the water. For that part of the feed that is eaten by the fish, 20-25 percent of nitrogen and 25-40 percent of phosphorus are used for growing, in other words, 75-80 percent of nitrogen and 60-75 percent of phosphorus are excreted into the surrounding water as fish faeces and urine (Jianping Wang, Jigang Chen, Liegang Si, Lin Chen and Xiongfei Wu. 2008). Gradual accumulation of excreta and residual feed in farming waters increase the nitrogen and phosphorus concentrations. At the same time, the physical and chemical indicies and biological factors in the water have changed. Finally, the water's capacity for self-purification is reduced, which leads to water eutrophication or deterioration of the water quality.

7.4 MAJOR POLLUTANTS AND POLLUTION INDICATORS

Ammonia nitrogen – in aquaculture water includes non-ionic toxic ammonia (NH_3) and the ammonium ion (NH_4^+), which is non-toxic. Major sources are faeces of aquatic organisms, feed residues and dead algae. Increased ammonia nitrogen concentration can be a major environmental factor that can trigger eutrophication in the water body when nitrogen is the limiting factor.

Nitrite – is an intermediate product during the conversion of ammonia into nitrate.

Phosphorus – the major source, during aquaculture production, is phosphorus in feed. However, since the digestibility of phosphorus differs greatly among different species of fish, the amount of phosphorus added to commercial feed is usually quite high, leading to the release of a large amount of phosphorus into the water body. Phosphorus is considered to be the controlling (limiting) nutrient in the process of eutrophication in non-tropical waters in China and elsewhere.

Other chemical residues – are chemical compounds released in aquaculture. These are (i) bactericides, fungicides and parasite-killing agents for controlling disease; (ii) chemicals used to control algae and herbicides to control excessive growth of aquatic plants; (iii) pesticides and molluscicides to control other pests; (iv) growth hormones; and (v) other chemicals used to 'improve' water quality.

Turbidity – is mainly caused by suspended particles (including phytoplankton) in the water, usually smaller than 200 µm. It is an important physical indicator of water quality and can indirectly indicate the abundance of solid particles and organic matter that, in turn, can be vectors for pathogens and viruses.

Chemical oxygen demand (COD) – indicates the abundance of organic matter that causes poor water quality. High values of COD are a threat to aquaculture organisms because of the oxygen-consuming substances that can lead to oxygen deficiency, which can kill fish, and can cause the release of poisonous or harmful substances, such as ammonia and hydrogen sulfide.

pH – is a measure of the hydrogen ion content in water. Most aquatic organisms grow best in a neutral pH environment (around pH 7). Chemical contamination, often from industrial pollution, can cause very high or very low pH, which can kill cultured organisms.

7.5 TOXICITY AND IMPACTS ON ECOSYSTEMS

pH value – When the pH value is below 6.5, the pH value of the fish blood decreases and causes disruption in the oxygen-carrying function of hemoglobin; this leads to oxygen deficiency in fish tissue. Even if the dissolved oxygen value is normal in the water, the fish will show symptoms of hypoxia at low pH level. Also, at low pH values, the anions in the water body such as S^{2-}, CN^-, HCO^{3-} are converted to highly toxic H_2S, HCN, CO_2 whereas heavy metal ions such as Cu^{2+}, Pb^{2+} are converted to complex compounds, significantly reducing their toxicity to the aquatic organisms. At high pH values, the NH_4^+ ion is converted to non-ionic ammonia NH_3, with increased toxicity. Strongly alkaline (high pH) water can cause fish gill tissue to corrode, leading to respiratory disorder or hypoxia. Strongly alkaline water affects microbial activity and leads to reduced microbial degradation of organic substances.

Dissolved oxygen – concentration in aquaculture water should be around 5–8 mg/litre and should always be kept above 4 mg/litre. When oxygen levels are low, hypoxia and rapid breathing are observed in fish, which tends to aggregate in the surface water to access oxygen from the air. At levels of severe oxygen deficiency, large quantities of fish are found floating, unable to swim, some dying of asphyxia.

The supersaturation of dissolved oxygen in water usually causes no harm; sometimes it will cause gas bubble disease in fish, especially at the breeding stage. Sufficient dissolved oxygen in water can inhibit the formation and reduce the concentration of toxic substances. When the dissolved oxygen is deficient, conversion of ammonia and hydrogen sulfide is impeded and the healthy growth of fish can be endangered, depending on the species.

Ammonia – Non-ionic ammonia is strongly toxic to fish. and when the concentration of non-ionic ammonia reaches 0.02 mg/litre, it can cause chronic stress to fish. When the concentration reaches 0.05 mg/litre, it can cause acute stress to fish, and fish will die when the concentration reaches 0.4 mg/litre (Xuefeng Cai, Lin Luo and Biwen Xie. 2001).

In general, ammonia nitrogen enters the aquatic ecosystem in three ways: one is the product of fish protein metabolism; another is the product of decomposition of organic matter by bacteria in water; the last is from nitrogen fertilizer in the water. The equilibrium relationship between non-ionic ammonia and ionic ammonium is directly adjusted by the pH and temperature. When the pH value and temperature rise, the percentage of non-ionic ammonia will increase. For instance, when the pH value rises from 8 to 9, non-ionic ammonia will increase by 7 times. Non-ionic ammonia is strongly toxic to fish. When the concentration of non-ionic ammonia is 0.02 mg/litre, it can cause chronic stress to fish. When the concentration reaches 0.05 mg/litre, it can cause acute stress and fish will die when the concentration reaches 0.4 mg/litre (Xuefeng Cai, Lin Luo and Biwen Xie. 2001).

Nitrite – if the concentration in the water body is too high, nitrite can enter the blood of the fish via osmosis and absorption, and can cause blood to lose its oxygen transport function. Usually, Nitrite poisoning of fishes can be divided into two kinds.

The first is chronic poisoning: the symptom is not obvious. In general, it is hard to observe, but it seriously affects the growth and life of the fish. When the poisoning is serious, it reduces food intake and activity, which leads the fish to lose weight. If the water quality returns to normal, the symptoms will gradually disappear. But if water quality is not adjusted in time, it the survival rate of the fish will be affected, which will result in great losses, especially in severe weather or disease invasion.

The second is acute poisoning, which generally in general this occurs in the early morning. The symptom is the same as that of hypoxia using macroscopic observation and is often associated with hypoxia, which occurs at the same time. Sometimes it is difficult to tell the difference between nitrite poisoning and hypoxia. Hypoxia often causes fish to cluster together. Nitrite poisoning is different, fish distribute themselves unevenly and throughout the pond. Symptoms will not disappear even if the sun comes out. The symptoms will become worsen as time progresses and can cause mass death.

Sulfide – toxicity refers to that caused by hydrogen sulfide gas (H_2S), which is naturally produced in bottom sediments lacking oxygen. This is a naturally occurring phenomenon when bottom sediments are enriched with nutrients, faecal matter from fish and other organic waste. Hydrogen sulfide causes respiratory paralysis and death. According to China fishery water quality standards, the concentration of sulfide (calculated as S) should not be over 0.2 mg/litre. For the culture of some special species of fish or fish eggs, the concentration of sulfide should be controlled to less than 0.1 mg/litre.

The toxic effects of different pollutants can lead to the higher mortality of different species, which may cause the disruption of the aquatic ecosystem. Also, nutrients in feed and excreta from aquacultural organisms can lead to eutrophication of the water body leading to the excessive growth of algae and/or to the formation of algae blooms. Excess algae increases turbidity (loss of water clarity), which causes loss of submerged plants. This not only decreases the habitat for aquatic organisms but also causes loss of food for cultured organisms such as crabs. Algae blooms can cause the death of aquaculture organisms because of the lack of oxygen during or after the bloom period, which may also lead to broader impacts on ecosystems. Sometimes the blooming algae are toxic which excacerbates the impacts.

Escaped species may breed with wild species introducing unwanted genetic strains and parasites into the wild aquatic stock. Escaped cultured fish may be much larger and more aggressive than wild fish and can out-compete wild fish for food thereby severely impacting the normal population of wild fish stock. Use of introduced or exotic species, construction of ponds that modify the habitat, water diversion, changes in benthos biogeochemistry resulting from organic and inorganic matter in the water can also affect biodiversity.

7.6 MEASURES TO PREVENT AND REMEDY WATER POLLUTION FROM AQUACULTURE

Prevention: Best management practices for aquaculture

Good aquaculture management practices include (i) selecting healthy fish eggs; (ii) releasing the eggs using correct procedures; (iii) choosing reasonable farming densities within the natural carrying capacity of the ecosystem; and (iv) releasing suitable combinations of various fish species. A good aquaculture operator will make full use of natural feeds when appropriate and take advantage of the interactions between fish species.

Best management practices ensure both development of the fishery and protection of the surrounding aquatic environment. Best management practices include:

- Establishment of a suitable production biomass based on the environmental capacity of the water body.
- Rational planning of cage aquaculture to prevent eutrophication of local waters. When fish are grown in cages, the bottom under the cage and the water body will be cleaned naturally when the cage is removed if the current is strong enough, or there are adequate water exchange rates.
- Standardized feed inputs to prevent pollution of the surrounding water, which is usually caused by excess feed. This is achieved by: (i) selection of the correct type of feed; (ii) carrying out feeding according to the aquaculture manual and or technical guidance, for example feeding tables or use simple sensors that inform when the fish are not eating anymore; and (iii) not using excessive amounts of feed. Waste feed pollutes water quality and is an extra expense for the operator. FAO has a complete guide on aquaculture feeds and feeding (e.g. FAO, 2009).
- Prevention of water pollution by correct use of fish drugs for prevention and control of fish diseases. Do not use prohibited substances (see Table 7.1), select the appropriate fish drugs and use these correctly. Most important, measures should be taken to prevent disease. For example, avoid stressing the fish by maintaining reasonable fish densities and ensuring a biosecurity framework is in place.

- Creation of non-infected aquaculture areas. This involves the combination of modern breeding techniques and control of fish diseases that minimize or avoid the use of drugs. This may include the use of biological and ecological control techniques to control fish diseases.
- Developing industrial-scale aquaculture based on water recycling. Uncontrolled, large-scale aquaculture can lead to severe water pollution. This is why, in recent years, aquaculture has been banned or severely restricted in many lakes in China. In contrast, industrial fish farming is at a scale that aquaculture wastewater can be treated cost-effectively using treatment facilities. The treated wastewater is recycled back to the rearing pond for repeated use. Treating, then recycling wastewater significantly reduces the pollution load in the aquatic environment.

Remediate: Removing pollutants from the aquaculture system

- It is possible to ***precipitate nutrients*** and suspended particles from fishponds using salts containing cations such as iron, calcium and aluminum. These combine with the inorganic phosphorus or phosphorus-rich particles in the water and precipitate these to the bottom of the pond or cage. Commonly, chemical additives used for this purpose include ferric chloride, aluminum salts, clay and lime. With lime, however, care must be taken to ensure that the pH does not become excessively basic (high pH). When the pond is drained the accumulated sludge on the bottom of the pond is removed and may be placed on the field as a source of organic fertilizer. These techniques require, however, special knowledge and skills that are beyond the subject matter in this publication.
- On the other hand it is well known that ***aquatic vegetation*** is very effective in removing nutrients from water. For example, macrophytes in lakes and ponds can assimilate large quantities of nutrients. However, at the time of year when these plants begin to die, they must be taken out of the water to ensure that the nutrients are not re-released back into the water during plant decay.
- Another technique is to use ***floating rafts for biocleaning***. Plants are grown on rafts; their roots in the water absorb phosphorus and nitrogen. These plants can be commercially harvested and can include flowers and some types of vegetables.
- An additional way to control water quality, especially in ponds where algae is a problem, is by adjusting the ***biological community structure***. For example, excessive growth of algae can be controlled by adjusting the fish community structure and by increasing the number of large filter-feeding fish such as chub and bighead carp.
- The use of ***micro-ecological agents*** can improve the ecological conditions of the water body. The application of probiotics of compound micro-organisms such as photosynthetic bacteria, *Bacillus subtilis*, actinomycetes, lactobacilli, yeast and streptococci can significantly reduce the concentration of sulfide, nitrate and nitrite and increase the dissolved oxygen in the water body. It therefore fundamentally improves the aquaculture environment and enhances disease resistance and immunity of aquatic animals. These types of application require special skills and training that are not included in this publication.
- Where there is aquaculture, the sediment at the bottom of many lakes and ponds forms a grey-black sludge that is rich in organic substances and nutrients. This bottom sediment is easily resuspended by waves and currents and may become a large internal nutrient load that results in large-scale algae blooms. ***Dredging*** removes nutrient-enriched sediments from the bottom of a lake, reservoir or large pond. Dredging has been used extensively in China, but is very expensive

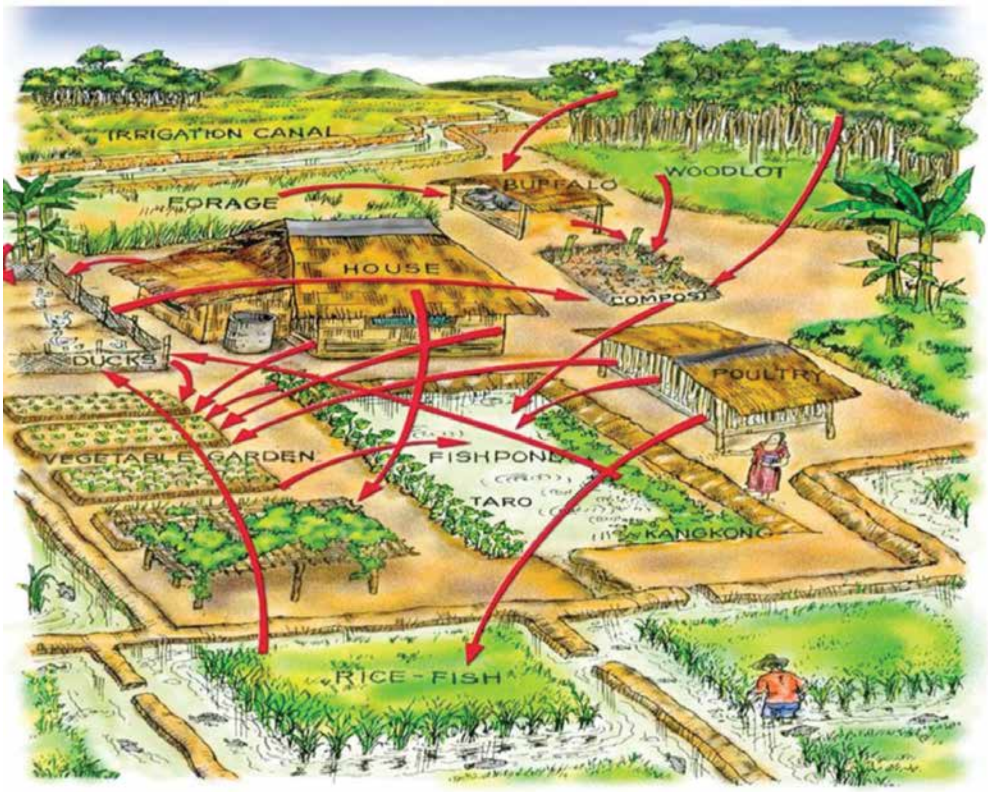
and many lake restoration experts believe that the cost does not merit the expense, and the resulting improved water quality may only be temporary.

- *'Modified local soil induced ecological restoration' (MLS-IER) technology* – was developed in China to restore degraded shallow lakes. It prevents algal blooms, improves water quality, and simultaneously restores submerged macrophytes in shallow lakes. As local soils are used it is safe, efficient and cost-effective. It is applied mechanically to large areas and does not require dredging of bottom sediments (Pan, 2011).

Promoting integrated systems for reuse and recycling

Integrated aquaculture-agriculture (FAO, 2001, 2009) is a good example of an integrated system (Figure 7.3). This promotes the integration of crops, vegetables, livestock, trees and fish for more stability in production, efficiency in resource use and conservation of the environment. Integrated farming ensures that waste from one enterprise becomes inputs to another and, thus, the use of resources is optimized and pollution reduced.

FIGURE 7.3
Integrated agriculture-aquaculture



Source: FAO, 2001

The same principle applies to integrated multi-trophic aquaculture (IMTA) by farming of different aquaculture species together in a way that allows one species' waste to be recycled as feed for another. Integrated systems can be a cost-effective way of minimizing water pollution.

7.7 ENVIRONMENTAL LAWS AND PROHIBITED DRUGS IN AQUACULTURE

A variety of Chinese Laws apply to the aquaculture industry. Important aspects include:

- The quality of the water body should be controlled to maintain fishery water standards during the whole aquaculture process.
- People who wish to engage in aquaculture require permission.
- Standards for aquaculture include: standardized transportation and releasing of fish eggs; measures to prevent the spread of disease; and use of drugs according to standards and the prohibition of specified drugs.
- Measures that control pollution of the aquaculture environment include preventing the leakage of oil from machinery into water; preventing discarded waste materials such as fishing nets and fishing gear, and human waste from entering the water near the fishery; and the timely removal of dead fish.

Good aquaculture practices require improvement of the technical and legal education of aquaculture farmers. The legitimate rights of law-abiding aquaculture farmers need to be protected, the authorities must be informed of illegal aquaculture practices so that there is both healthy development of fisheries and the environment is protected.

Unfortunately, aquaculture farms often use prohibited drugs, in part because aquaculture farmers do not understand the dangers posed by these drugs and farmers are influenced by others and salespeople. Below is a guide to some commonly used but prohibited drugs used for aquaculture. The full list of prohibited chemicals appears in Table 7.1.

- Although green malachite controls saprolegniasis, branchiomycosis and ichthyophthiriasis in various aquatic animals, it is a carcinogenic, teratogenic drug that is potentially dangerous to humans. Therefore this drug has been listed as prohibited for use in aquaculture.
- Chloromycetin is a broad-spectrum antibiotic. This drug is toxic to humans and inhibits the hematopoietic function of bone marrow, causing hyper-susceptibility, which can lead to regenerative anemia disorder. This drug has therefore been prohibited.
- Aeromonas sp. (a bacteria) is sensitive to Erythromycin and Tylosin. Therefore, these antibiotics are often used to control bacterial gill-rot disease in fish. Some of this drug remains in the fish and can lead to drug-resistant bacteria. When people eat the fish containing the drug, drug-resistant bacteria can appear in the human body. This drug has therefore been prohibited.
- Lindane and toxaphene are part of a group known as organochlorine pesticides. The major feature is bioaccumulation, and cancer-forming and the residue remains active over time. These are banned or prohibited in most countries, including China.
- Olaquindox is often added as a growth stimulant to feed for aquatic animals. Its antibiotic function is secondary. Long-term addition of this drug causes damage to the liver and kidneys of aquaculture animals, including enlargement of the liver, ascites (accumulation of fluids in the stomach lining) in aquaculture animals and can lead to death. Long-term use can lead to drug-resistance in aquatic animals and cause the prevalence of Enterococci, which can severely endanger human health. The use of this drug is prohibited.

TABLE 7.1
Drugs prohibited for use in aquaculture in China

Name of drug	Remarks
Diethylstilbestrol	Including derivatives
Zeranol	Dihydroxybenzoic acid lactones including preparation
Trenbolone	Including preparation
Mengestrol Acetate	Including preparation
Clenbuterol	(βadrenergic agonists) including salts, esters and preparation
Salbutamol	Including salts, esters and preparation
Cimaterol	Including salts, esters and preparation
Terbutaline	Including salts, esters and preparation
Ractopamine	Including salts, esters and preparation
Carbaryl	Carbamate
Thiamazole	Thyroid inhibitors
Dimetridazole	
Metronidazole	Including salts, esters and preparation
Ronidazole	
Dimetronidazole	Including salts, esters and preparation
Chloramphenicol	Including salts, esters and preparation
Chloramphenicol Succinate	Including salts, esters and preparation
Furazolidone	Including preparation
Furaltadone	Including preparation
Nifurstyrenate Sodium	Including preparation
Carbofuran	
Ciprofloxacin	
Erythromycin	
Tylosinum	
Bacitracin	
Chlorpromazine	Including salts, esters and preparation
Colchicine	
Diazepam	Including salts, esters and preparation
Methaqulone	Including preparation
Dapsone	Including preparation
Anticoccidials(Clopidol)	
Sulfaquinoxaline	
Sulfaguanidine	
sulfathiazole	
Lindane	
Camahechlor	
Chlordimeform	
Amitraz	
Pentachlorophenol Sodium	
Pcp—Na	
Sodium nitropenolate	Including preparation
Nitrovin	Including preparation
Calomel	
Mercurous nitrate	
Pyridyl mercurous acetate	

Name of drug	Remarks
Mercurous acetate	
Antimony potassium tartrate	
Tryparsamide	
Methyltestosterone	Including similar androgens
Oestrol including similar estrogens	
Olaguindox	
Fenbendazole	
Malachite green	
BHC	
DDT	
Hexachlorbenzene	
PCBS	
Fldoroguinolones	
Glycoptides	
Diazinon	
Dichlorvos	
Other steroid hormones	
Other organochlorine pesticides	
Pyrethroids	Except deltamethrin
Other mercury preparation	
Fonofos	

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8. Pollution from agricultural villages and towns

ZHAO Lixin[1], XU Zhe[1], LIU Dongsheng[1], LI Xiang[1], DENG Yu[2], Javier MATEO-SAGASTA[3]

8.1 INTRODUCTION

With the rapid development of the economy and of living standards in rural areas domestic rural pollution has become increasingly prominent as a cause of water pollution. According to estimates, the annual output of rural domestic waste in China is around 280 million tonnes and rural sewage is about 9 billion tonnes (Shen *et al.*, 2011). Much of this sewage is discharged to the roadside, farmyards and watercourses without treatment; solid waste is scattered on farmland and at roadsides. When it rains, the sewage and waste flow to nearby water bodies and to groundwater, causing serious environmental pollution.

Rural domestic pollution is an important part of agricultural non-point source (NPS) pollution yet is difficult to monitor and control. In 2008, the Ministry of Agriculture, together with the Ministry of Environmental Protection, carried out the first National Pollution Sources Census in agriculture. For the first time, the survey investigated the nature and importance of large-scale sources of rural domestic pollution. The Census was limited to 68 counties representative of regions within the four major river basins of lakes Taihu, Chaohu, Dianchi and the Three Gorges reservoir area.

The Census revealed significant differences between the different regions for solid waste and domestic sewage production (Table 8.1). These differences are related to variations in natural conditions, level of economic development, rural lifestyle and other factors. Further, within individual regions, the output of rural domestic sewage and solid waste can change significantly over time. In most rural regions, sewage is at a maximum in the morning and evening and less during the day and minimal at night.

TABLE 8.1
Waste production in lake Taihu and the Three Gorges reservoir area (2008)

Region		Amount of domestic sewage production (Litres/person/day)	Amount of domestic waste production (kg/person/day)
Taihu lake basin	Plain river network areas	42.36	0.2
	Hilly and mountainous areas	22.19	0.28
Three Gorges reservoir area		18.97	0.51

1 Chinese Academy of Agricultural Engineering
2 Biogas Institute of the Ministry of Agriculture
3 FAO Land and Water Division

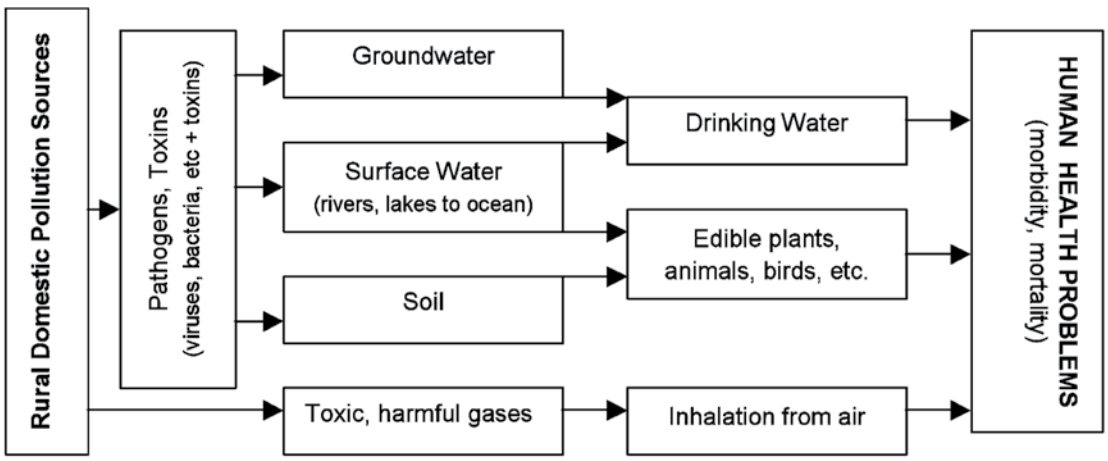
The quantity and characteristics of solid waste fluctuate significantly depending on the season. For example, solid waste increases in China around the Spring Festival and from July to August. Rural domestic sewage and solid waste change significantly with the seasons in villages visited by tourists, reflecting the impact of tourism.

8.2 HAZARDS AND HEALTH IMPACTS

Rural domestic sewage includes effluents from toilets (black water), kitchens and bathrooms (grey water). Raw sewage contains various types of inorganic and organic pollutants and pathogens including helminthes and helminthes eggs, parasitic protozoa, pathogenic bacteria and virus. Sewage also contains other pollutants including large amounts of dissolved nitrogen and phosphorus. If discharged untreated, sewage can pose serious risks to human health and the environment.

Rural solid waste comprises organic waste from kitchens including fruit peel, vegetable leaves, inorganic waste (such as cinders, paper, rubber, plastic and glass), as well as hazardous waste (such as used batteries, fluorescent tubes, discarded appliances and paint drums). Uncontrolled organic waste disposal leads to the growth of various pathogens and disease vectors. Additionally, hazardous waste, if not disposed of correctly, leaches hazardous chemicals into surface and groundwater. All this can pose specific health risks to rural families, especially to children. These risks can translate into infections and diseases that can arise after direct contact with solid waste, drinking contaminated water, inhaling the vapours produced by some kinds of waste products, and by ingestion when (especially children) transfer pathogens and hazardous chemicals directly to their mouths when eating, without first having washed their hands.

FIGURE 8.1
Causal chain linking rural domestic pollution to human health. Some of these mainly impact rural populations; others such as contaminated food impact everyone.



Source: Zhang, 2006

8.3 RURAL SANITATION

The main objective of a sanitation system is to protect and promote human health by providing a clean environment and breaking the cycle of disease transmission. In order to be sustainable, a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and natural resources (SuSanA, 2008). A system, contrary to a sanitation technology, considers all components required for the adequate management of human excreta. This includes its collection, transport, treatment and reuse/disposal.

Decentralized/on-site sanitation – are small-scale systems for one or several adjacent villages where sewage transport is minimum. These systems are flexible and easily constructed but require the implementation of multiple, simple and small-scale sewage treatment plants to serve a given population. This method is suitable for remote or small villages with complex terrain where sewage is difficult to collect and transport.

Centralized/off-site sanitation – are mid- to large-scale systems that include a collection system such as pipes, ditches, tunnels and pumps to transport sewage to a centralized treatment plant. This requires significant investment in construction and it is therefore more suitable for a large village or several close villages with a large population and good economic conditions. Under the right conditions one single central wastewater treatment plant can be easier to manage than multiple, small-scale plants.

The selection between sanitation systems needs to be based on the sustainability criteria mentioned above.

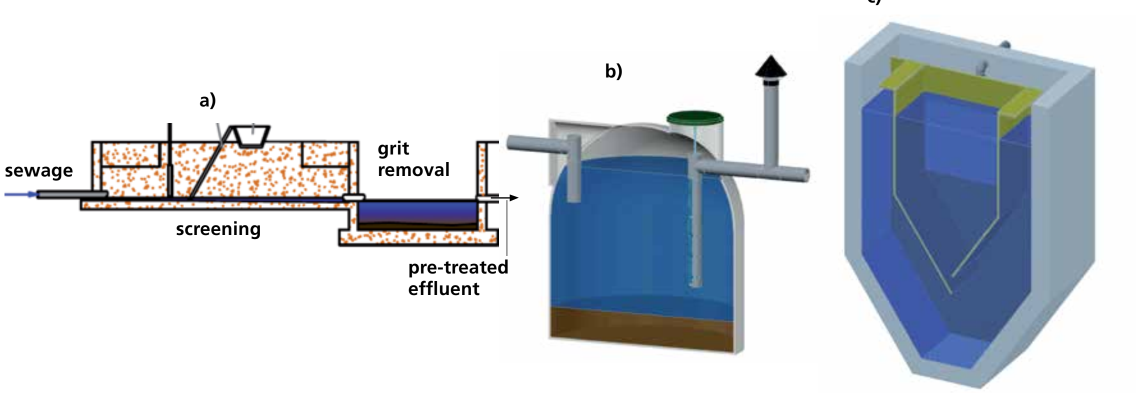
8.4 RURAL SEWAGE TREATMENT

While there are many treatment options that could potentially treat rural sewage this section briefly describes, those that are most commonly used or promising and lists their key advantages and drawbacks.

Pre-treatment and primary treatment

Before being treated, sewage usually goes through pre-treatment to remove grit, grease and gross solids that could hinder subsequent treatment stages. Later, primary treatment aims to settle and remove suspended solids; although organic pollution is reduced as some suspended solids are organic particles. The most common treatments in rural villages are primary settlers, septic and Imhoff tanks (Figure 8.2).

FIGURE 8.2
(a) Grit removal system (b) Septic tank (c) Imhoff tank.



Source: CEDEX-CENTA, 2010

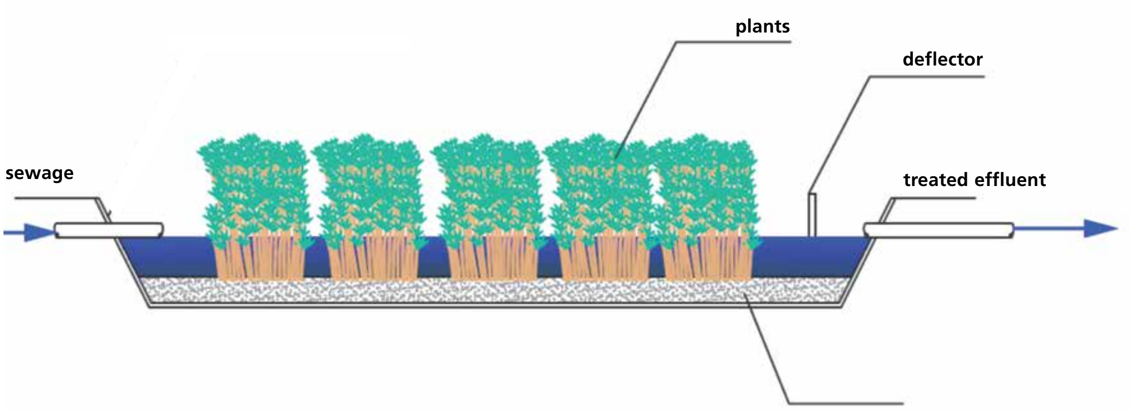
The performance of pre- and primary treatment technologies strongly affects the subsequent treatment steps. Furthermore, in rural villages these may be the only treatment of sewage before its disposal. This is why correct design, operation and maintenance of these technologies is imperative.

Extensive technologies

Extensive technologies are characterized by a treatment process that takes place at 'natural' rates, with no energy supply, and in one single reactor-system (Mecalf and Eddy, 2000). Energy savings are compensated by increased surface needs.

Constructed wetlands – are treatment systems that emulate the pollutant removal process that takes place in natural wetlands. These artificial systems are confined, using impermeable materials, and use selected substrates and plants. Pollutant removal takes place during physical, chemical and biological processes. Key advantages of these systems are low operation and maintenance costs, good landscape integration, minimum odours production and potential for biomass generation for animal feed or ornamental use. Key drawbacks include significant surface requirements, siltation risks, water loss during evapotranspiration that increases effluent salinity, little flexibility in operation and possible increased breeding of mosquitoes (Figure 8.3).

FIGURE 8.3
Constructed wetland (surface flow).



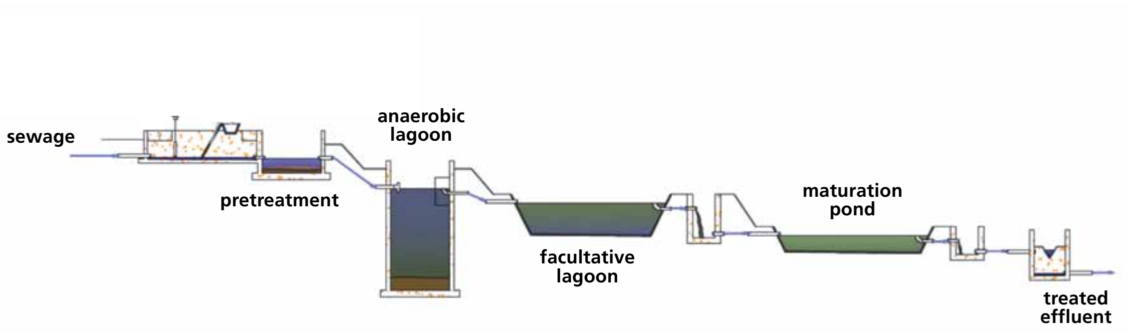
Source: CEDEX-CENTA, 2010

Intermittent sand filters – are shallow beds (0.6–1.1 m) with a surface water distribution system and a drainage system on the bottom to collect treated effluent. Pollution is removed during biological treatment in the mass of sand, physical filtering and adsorption. The biological treatment takes place in the first 15 cm of the filtering material, where aerobic biofilms develop. The main advantages of this system include its quick start up, its capacity to remove relevant pathogens, low operation and maintenance costs and low or moderate energy requirements. Key drawbacks are the moderate surface requirements, clogging risks and there is little flexibility of operation.

Stabilization ponds – are shallow constructed basins comprising single or several anaerobic, facultative or maturation ponds. The primary treatment takes place in the anaerobic pond, which is mainly designed to remove suspended solids and some soluble organic matter. During the secondary stage in the facultative pond most of the remaining BOD is removed during the coordinated activity of algae and heterotrophic bacteria. The main function of the tertiary treatment in the *maturation pond* is the removal of pathogens and nutrients, especially nitrogen.

The key advantages are: easy construction, no energy requirements, no electronic or mechanical devices needed, very low operation and maintenance costs, highly robust, relevant disinfection capacity, good landscape integration and low sludge production (Figure 8.4).

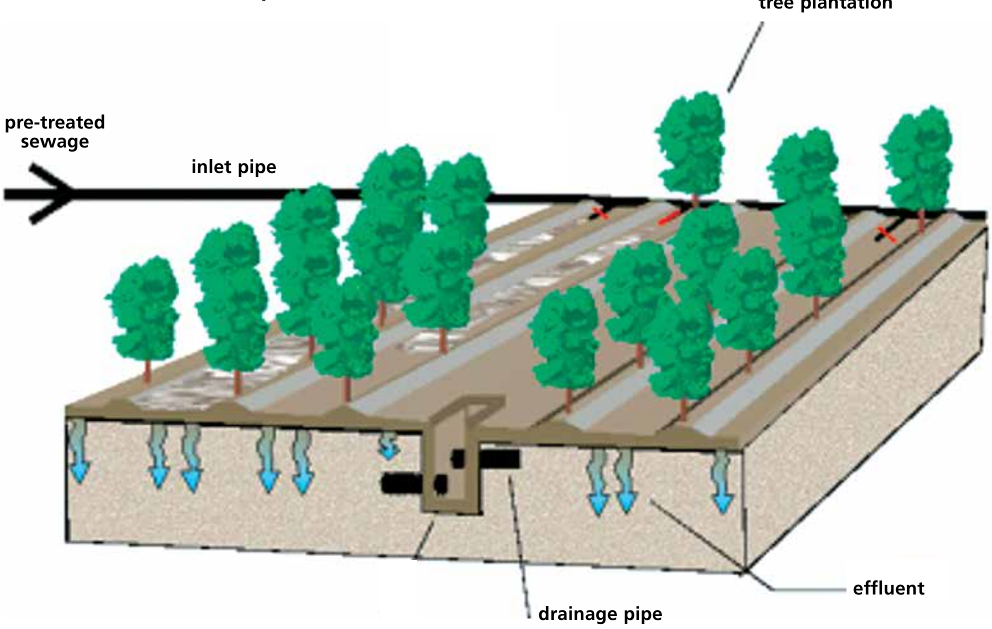
FIGURE 8.4
Stabilization ponds: a combination of pre-treatment and anaerobic, facultative and maturation ponds.



Source: CEDEX-CENTA, 2010

The main drawbacks include very high surface requirements, likely increased breeding of mosquitoes, loss of water during evapotranspiration, which increases the salinity of the effluent, algae proliferation leading to high concentration of suspended solids in the final effluent and risk of groundwater pollution.

FIGURE 8.5
Green filter with wood production.



Source: CEDEX-CENTA, 2010

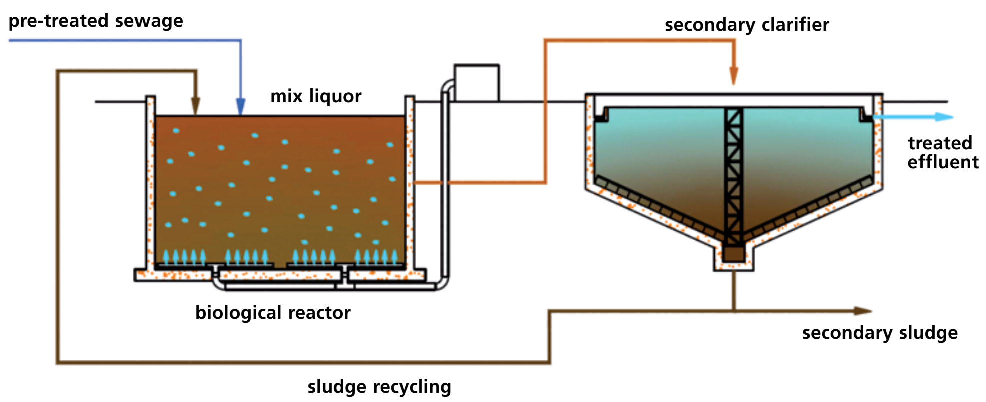
Green filter – is irrigated land where one or more plant species have been planted. The irrigation method is normally intermittent surface irrigation, where irrigation and natural soil re-oxygenation alternate to ensure the development of aerobic micro-organisms in the soil and to prevent undesired fermentation. The plant species used should meet the following requirements: high rates of uptake of water and nutrients, tolerance to waterlogging, fast growth rates and minimum management requirements. The main advantages of this method are: no energy requirements, no electronic or mechanical devices needed, good landscape integration and production of biomass (e.g. wood, fibres or animal feed). Its main drawback includes: high surface requirements, risk of groundwater pollution, possible foul odours (Figure 8.5).

Compact technologies

Compact technologies are characterized by a process that takes place in tanks or reactors that accelerates treatment. Frequently, these technologies are aerobic and require a supply of oxygen and the use of electromechanical devices. Some relevant examples are:

Activated sludge reactors – treat sewage using air and biological flocks, which are composed of aerobic bacteria and protozoa. After pre-treatment, wastewater enters the bioreactor where mechanical aerators keep the aerobic flocks in suspension. Normally, secondary settlers accompany these bioreactors to separate liquids from solids. The main advantages are: minimal space requirements, high potential for nitrogen removal, very flexible operation and minimal odour. The main drawbacks include: high-energy consumption and operation costs; qualified staff are required for operation and maintenance; continuous sludge production; noise and sensitivity to hydraulic overloads (Figure 8.6).

FIGURE 8.6
Activated sludge reactor, the case of prolonged aeration system.



Source: CEDEX-CENTA, 2010

Trickle filters – are aerobic biofilm reactors. After pre-treatment, wastewater percolates through a packing material where micro-organisms develop and form biofilms. The main advantages are: minimal space is required, robustness and resilience to load variability, relatively simple and low cost of operation and low energy consumption. Some drawbacks include the system's more complex construction, operation and maintenance as compared to extensive systems; unstable sludge production, noise and it is difficult to integrate into the landscape (Figure 8.7).

Rotating biological contactors (RBC) – are aerobic biofilm reactors, where micro-organisms grow on the surface of discs or cylinders that rotate semi-submerged in wastewater. The discs rotate slowly, at 1 to 2 revolutions per minute, which allows the discs to be exposed alternatively to water and air, which leads to the growth of an aerobic biofilm on the discs' surface. This biofilm removes soluble biodegradable organic matter from the wastewater.

Relevant advantages of these reactors include: little space is required; easy gradual and modular construction; robustness and resilience to load variability; low operation cost and low energy consumption.

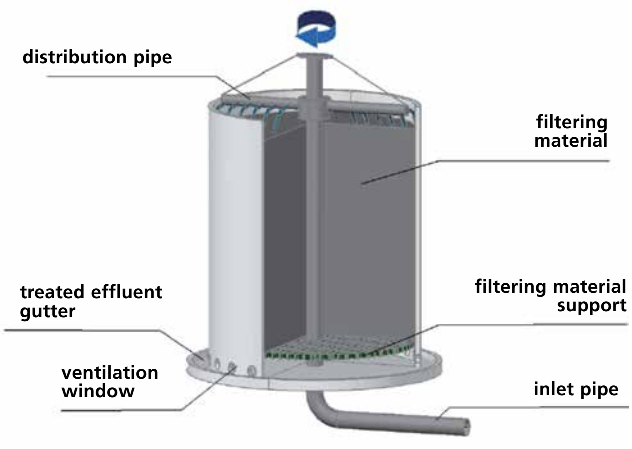
The main drawbacks include the relatively high implementation costs and production of unstable sludge. Most commercial RBCs are patented and more complex to construct, operate and maintain as compared to extensive systems (Figure 8.8).

Up-flow anaerobic sludge blanket reactors (UASB) – form a blanket of anaerobic (preferably granular) suspended sludge in the tank. Wastewater flows upwards through the sludge blanket and is processed (degraded) by the anaerobic micro-organisms. UASB are equipped with a liquid-solid-gas separator on the top.

Key advantages include: production of methane for energy recovery, minimal space requirements and lower sludge production, which is better stabilized than for aerobic systems.

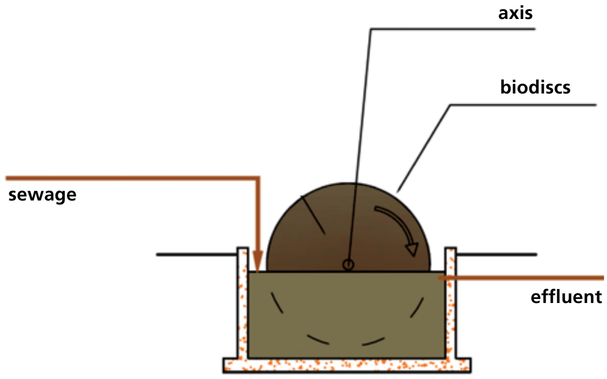
The main drawbacks are: slow start up, sensitivity to low temperatures and toxicity as compared to aerobic systems. The system is more complex to construct, operate and maintain in comparison to extensive systems (Figure 8.9).

FIGURE 8.7
Tricking filter.



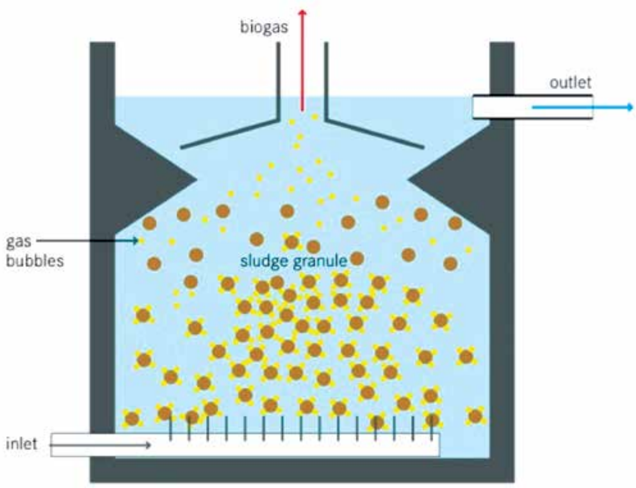
Source: CEDEX-CENTA, 2010

FIGURE 8.8
Rotating Biological Contactor.



Source: CEDEX-CENTA, 2010

FIGURE 8.9
Upflow Anaerobic Sludge Blanket Reactor



Selection and combination of technologies

Several methods are usually combined, including pre-treatment, primary and secondary treatments, to ensure the effective removal of pollutants from rural sewage. Literally hundreds of technologies and combinations of technologies can be used. Selection of the best combination should be based on technical, environmental and economic criteria.

Technical criteria include – the efficiency of pollution removal to meet standards for discharged water quality; size of the village to be served (Table 8.2); land availability and characteristics; types and concentration of pollutants in wastewater; climate conditions (particularly temperatures); sludge production and complexity of operation and maintenance.

TABLE 8.2

Recommended population range for different sewage treatment technologies*

Region	Population range (p-e)				
	10–200	200–500	500–1 000	1 000–2 000	>2 000
Septic tank					
Inhoff tank					
Primary settler					
Green filters					
Maturation ponds					
Constructed wetlands					
Intermittent sand filter					
RBC					
UASB					

* p-e (population equivalent)

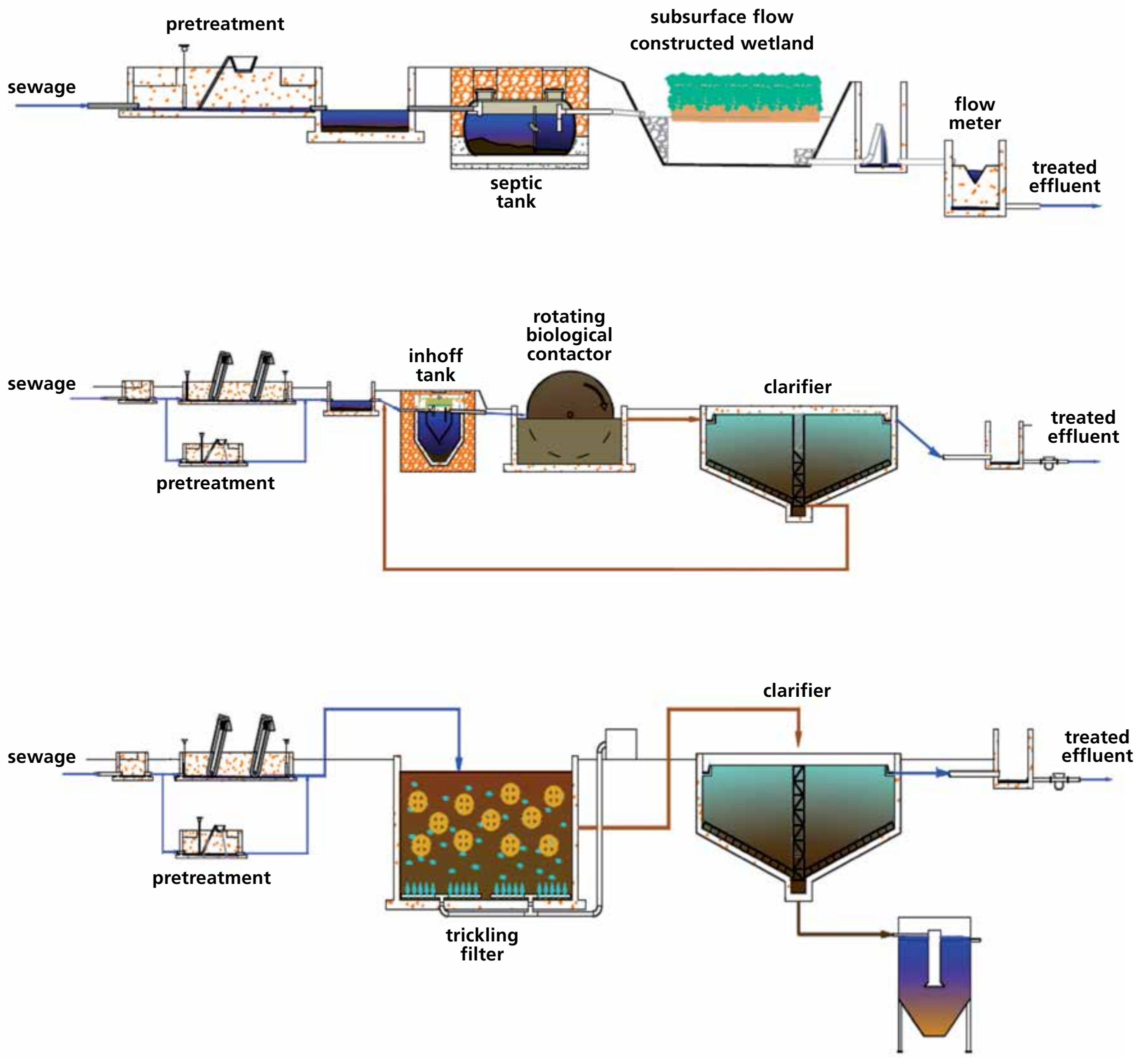
Environmental criteria include – production of foul odours, noise and landscape integration, carbon footprint, landscape integration, possibilities for resource recovery and reuse and environmental vulnerability of the receiving water body

Economic criteria include – costs of construction, operation and maintenance.

Primary treatments can achieve a removal efficiency of 50–60 percent for suspended solids (SS) and 20–30 percent for DBO_5 and DQO. Secondary (extensive and compact) technologies can achieve up to 95 percent removal of SS and 90 percent for DBO_5 and DQO, with the exception of maturation ponds that have lower removal efficiencies for these indicators. Removal of nitrogen and phosphorus is variable and range from almost zero with primary treatments to 80 percent N_T and 60 percent P_T for well-designed maturation ponds. An adequate combination of technologies can result in the effluent qualities required.

Figure 8.10 provides some examples of a combination of technologies. Other technologies and combinations can be found in: Metcalf and Eddy, 2000; CEDEX-CENTA, 2010; Ou, W., *et al.*, 2009; Li, J., *et al.*, 2009; Xu, Y., 2009; Wan, Y., *et al.*, 2010.

FIGURE 8.10
Different possible combinations of treatment technologies: (a) pre-treatment + septic tank + constructed wetland; (b) pre-treatments + inhoff tank + Rotating biological contactor + clarifier; (c) pre-treatment + trickling filter + clarifier



8.5 SOLID-WASTE TREATMENT

In rural areas domestic solid waste is divided into the following categories:

- organic waste for composting (kitchen waste, crop residues, etc.);
- recyclable waste, most (but not all) plastics, metals, wood, and other materials for recycling;
- hazardous waste (paint, chemicals, batteries, etc.) for special treatment;
- landfill site where other waste that cannot be recycled is sent, items include construction materials, cement, styrofoam packaging).

China requires the disposal and comprehensive utilization of rural domestic waste on the principle of 'harmless, reduction and recycling'.

Treatment methods

Currently, treatment of rural domestic solid waste is either centralized or decentralized. In the more developed areas of lakes Taihu and Chaohu and the Yangtze and Pearl river deltas and other developed areas, rural waste is generally collected, then treated centrally. In undeveloped rural areas in the southwest, northwest and central provinces, waste is managed using a decentralized treatment method.

In the centralized method, residents may sort the waste categories, or they are sorted at a central sorting facility. Different sized rural communities implement various methods of waste collection, ranging from simple collection into a truck or cart in villages, to waste compaction trucks in towns. In all cases the collected waste is taken to a central treatment facility where waste is treated according to national standards.

Households usually pay for the waste disposal service in central treatment systems. With decentralized systems, village waste is collected and composted or taken to a landfill in or near the village. While this is cheaper, it is less reliable, noxious odours may be emitted, and the waste is not inspected for health hazards or for the effectiveness of treatment.

Key technologies

Currently, in China rural solid waste treatment and resource recovery technologies include aerobic composting, sanitary landfill and incineration.

Aerobic composting – is a microbiological process in which organic domestic waste is biodegraded into an organic soil conditioner and fertilizer. The process uses specific conditions of temperature, humidity, carbon and nitrogen ratio and ventilation, together with the application of bacteria, fungi, actinomycete (bacteria) and/or other micro-organisms that are widely distributed in nature, to biodegrade organic domestic waste into stable humus (used as fertilizer). The compost product is dark brown and smells of soil; it is an excellent soil conditioner. Aerobic composting is widely promoted in China to treat and utilize rural domestic waste. This benefits both the environment and the farmer by using household organic waste as a 'free' soil conditioner and fertilizer.

Incineration – is widely used internationally to burn waste in high-temperature ovens. This method can be effective if carried out properly; if not it can produce a variety of toxic gases and by-products during the combustion process. This technology is rarely used in rural areas of China because of high-energy consumption, the high cost of operation, complex technical requirements and potential impacts of secondary pollution. Not included in high-temperature incineration is the burning of domestic waste by farmers, or at rural landfill sites. This is a low temperature process and produces much smoke that can contain hazardous chemicals, depending on what is being burned.

Sanitary landfill – is the burial of domestic waste. This requires specific conditions to prevent the penetration of rainwater, and the bottom of the landfill is sealed to prevent percolation of liquids from the waste into the groundwater and to prevent contamination of nearby water wells. In modern systems methane gas emissions from the landfill are captured and used as fuel. Currently, highly efficient, simple, low-cost domestic waste landfills are generally adopted in rural areas. Many, however, do not meet the technical requirements and are a hazard to surrounding farm families, especially through contamination of water wells.

In summary, domestic organic waste is easily converted into a natural, rich, organic humus that improves soil fertility and retains soil moisture, at no cost to the farmer. Therefore, for rural villages, organic solid waste should be composted and reused rather than incinerated or disposed in landfills.

8.6 RURAL BIOGAS TECHNOLOGY

Rural biogas technology is increasingly being utilized in Chinese farming communities. Human and livestock manure, domestic sewage, domestic waste and other organic substances can be easily converted to biogas (methane) and fertilizer through anaerobic digestion (fermentation). This is a clean technology that benefits the farmer by providing a free source of gas for cooking, heating and lighting. It is a rich soil conditioner that greatly improves soil fertility and moisture retention. This is a 'win-win' technology that provides benefits both to the farmer and to the environment.

By the end of 2008, there were 30.5 million households nationwide that were using rural biogas. It was estimated that by 2010 more than 40 million biogas digesters were additionally installed in China. There are many different ways to integrate biogas technology into farm living and operations. This depends on where the farmer lives and the particular climate. The more common methods are described below.

BOX 8.1

Biogas and climate change:

Methane – the gas produced by anaerobic digestion, is a major greenhouse gas that contributes to climate warming, and must **never** be released into the atmosphere without it first being burned. Methane is, however, an excellent fuel for farm cooking, light and heating and, after burning, releases carbon dioxide that, although also a greenhouse gas, is twenty times less potent than methane.

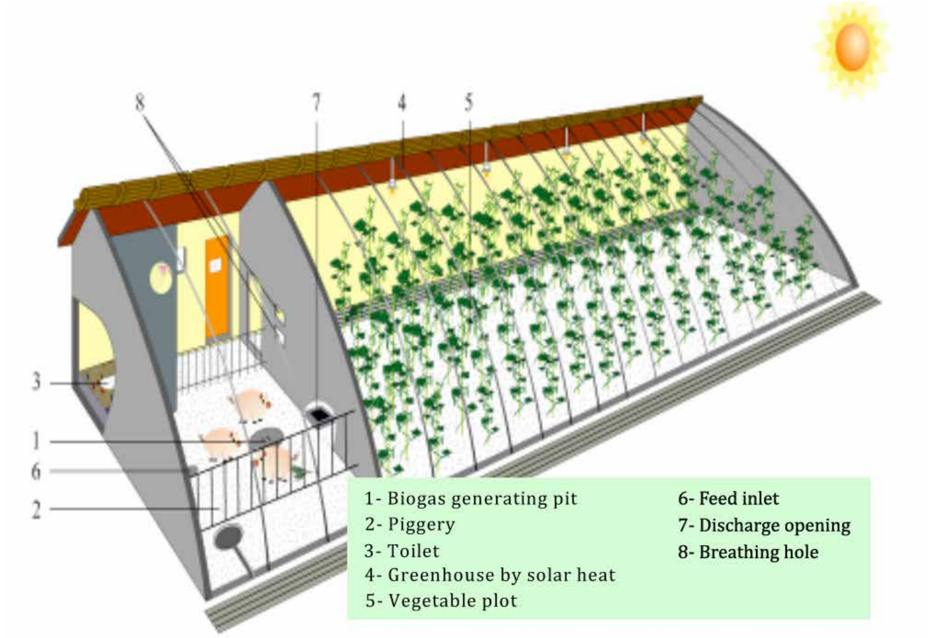
Household biogas system[4]

In China, research into biogas began in the 1920s, since then three main biogas systems have been developed for rural use. These are, based on agricultural production patterns and resources in the different regions:

In northern rural China the 'Four-in-one' ecological greenhouse system – is also known as the 'energy ecological mode'. This method uses spare land and is powered by solar energy. It combines planting in greenhouses, livestock and poultry breeding, with a biogas digester. This is a high-yield, high-quality, highly efficient agricultural production method that combines farm living and ecological agriculture. In this system, the collection of animal manure, planting and breeding, energy production and fertilizer production are integrated into a single harmonious system. The typical structure of the northern rural energy ecological system is shown in Figure 8.11. Typical investment is RMB50 000 with a payback period of 4 years. The government subsidy is RMB1 200. A government subsidy reduces the payback period.

4 References for this technology are found in: Qiu, J., 2008; Qiu, L., 2006; Li, J., *et al.*, 2009; Ye, X., *et al.*, 2007.

FIGURE 8.11
Diagram of northern rural energy ecological system



In northwest China the 'Five-match' ecological system– is a variation of the 'four-in-one' system described above. It is designed for use in northwest China where it is not possible to cultivate field crops because of the arid climate. It includes a 2 ha orchard, a 12 m^2 pigpen, a rain-harvesting system with 60 m^3 underground water storage and drip-irrigation for the orchard. The orchard creates organic waste that is fed into the digester together with pig manure and human waste. The sludge from the digester is used to fertilize the orchard, and the farm family uses the biogas for light, heating and cooking. The typical investment is RMB12 000 with a payback period of 1.7 years. The government subsidy is RMB1 200.

In south China the 'Three-in-one' energy ecological system – is located in the family farmyard or on nearby land. It combines the farmhouse, a small pigpen, a biogas reactor and agricultural activities such as crops or orchards. The elements for this system are one biogas reactor for each household, two pigs for each person in the household per year, 1 mu orchard or other crop per person.

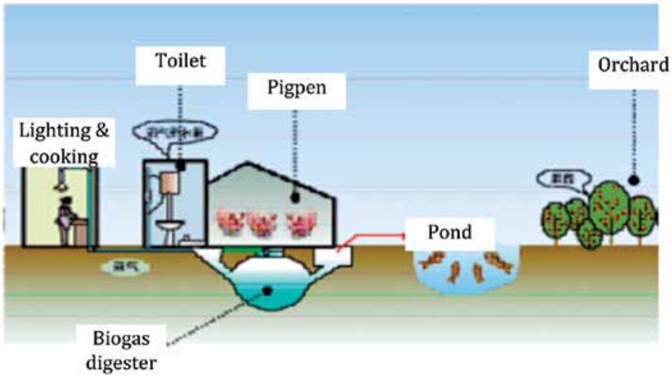
The basic operation method is as follows: household waste and toilet waste + pig manure go into the biogas reactor; the biogas is used for daily lighting and cooking, and liquid outflow + sludge from the bioreactor is used for fruit trees or other crops.

Other crops can be planted in the orchard for poultry or pig feed. In addition to pigs, the farm may also include cattle, sheep, chickens, or other livestock. Variations of the 'three-in-one' system include 'pig-biogas-orchard (Figure 8.12)', 'pig-biogas-vegetable', 'pig-biogas-fish' and 'pig-biogas-rice'. The typical investment is RMB7 000 with a payback period of 1.3 years. The government subsidy is RMB800.

Biogas management

Biogas management and service is controlled and guided by the Chinese government. Three main systems for biogas management have been introduced.

FIGURE 8.12
Diagram of the 'pig-biogas-orchard' ecological system



Professional cooperative method – local users of biogas establish a biogas cooperative and register it as a cooperative business operated by members. A registered cooperative develops its own regulations and rules, defines obligations to members to provide services, and establishes a fee system for provision of services. All biogas reactor construction, installation, repair and maintenance is carried out by qualified biogas technicians or professionals working for or contracted by the cooperative. The professional cooperative organization operates according to market principles and is self-financing.

Public service method – public authorities establish a service organization in association with other public services such as the local rural energy authority. This service organization provides a service network at different levels (e.g. county, town and village) to provide biogas digester maintenance and repair service to the users. This can be done 'for profit' or 'at cost', depending on how the local government has established this method.

Market-based service method – is implemented by a 'for profit' service company established by individuals or groups of investors. These service corporations carry out biogas reactor construction and maintenance, provide materials for installation and construction, supply and install spare parts for biogas systems, handle biogas reactor solid and liquid wastes and carry out fertilization with these wastes. Such companies provide a comprehensive service for biogas users on a 'fee-for-service' basis.

8.7 CONCLUSIONS

Agricultural villages and rural living cause significant pollution of the environment and watercourses. Much of this pollution represents wasted resources and a direct economic loss to farmers who could convert much of their waste into reclaimed water and nutrients for food production and energy for local lighting and cooking. Rural recycling and rural waste management reduces the impact of rural life on the environment. At the same time, farmers can benefit from the 'free' energy and fertilizer produced by recycling systems with low investment of money and time. In particular, fertilizer and soil conditioner produced by composting and biogas systems significantly contributes to improved soil fertility and reduced cost of fertilizers by increasing soil carbon (organic content of soil) soil nutrients, and moisture retention.

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9. Pollution from reclaimed wastewater use for agriculture

LIU Honglu[1], Sasha KOO-OSHIMA[2],
WU Wenyong[1], Javier MATEO-SAGASTA[3]

9.1 INTRODUCTION

As pressures on water intensifies, the conservation of freshwater through the use of non-conventional water, such as reclaimed water, becomes an increasingly relevant option. Although good irrigation and drainage practices may result in more efficient water use and ecosystem protection, irrigation schemes that are poorly planned and managed may result in increased impacts on ecosystems, and water reclamation and reuse schemes are no exception. While Chapter 5 deals with irrigation and drainage management in general, this chapter focuses on the health and environmental risks of the use of reclaimed wastewater for agriculture and shows how to make this practice safe and productive.

9.2 OVERVIEW OF CURRENT SITUATION

Water reclamation and reuse for agriculture is a strategy for alleviating water scarcity, which is gaining wider acceptance around the world. Countries such as the United States, Australia, Israel, Japan, Spain, France and many others have adopted reclaimed water irrigation (RWI) as a strategy for attaining the equilibrium between demand and supply of adequate quantities and quality of water. In 2010 use of RWI in Israel, Australia and Tunisia was 25 percent, 11 percent and 10 percent respectively of total agricultural water demand (Lazarova, 2001; EPA, 2004). Jordan plans to increase its reclaimed water use by four-times over its current use, while Spain increased its use 1.5 times in 2012, and Egypt is expected to have a ten-fold increase by 2025 (EPA, 2004).

In China there are water-scarcity problems in more than 50 percent of the 600 cities, especially in the northern region where more than 80 percent are water-scarce. It is estimated that, by 2030, reclaimed water use in China could be 20 percent of total water supply. The amount of reclaimed water use for irrigation was 0.51 billion m^3 in 2007 and

FIGURE 9.1
Water management plant and sewage water treatment station that filters underground and treated sewage water.

Photo: ©FAO/Rosetta Messori

1 Beijing Water Science and Technology Institute
2 US Environmental Protection Agency, Office of Water
3 FAO Land and Water Division

is estimated to grow to 5 billion m^3 by 2015, mainly for use in the rural areas of Beijing, Tianjin and other large to medium cities. Beijing is the largest city that uses reclaimed water, 264 million m^3 were reused in 2009 (Liu *et al.*, 2006; BWA, 2009), which was 25 percent of total agricultural water use.

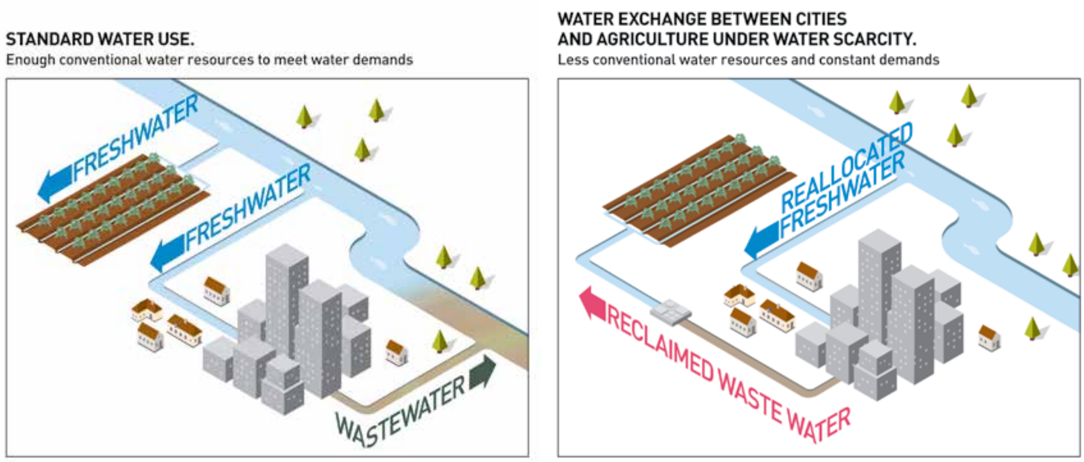
9.3 OPPORTUNITIES AND BENEFITS

Water reclamation and reuse may benefit all the parties involved: agriculture, cities and the environment.

Agriculture can benefit from reuse in different ways: Reclaimed wastewater is a year round supply of water and is one of the options at the farm level for improving long-term water security and minimizing exposure to seasonal water risk. Furthermore, nutrients and fertilizers in reclaimed wastewater can contribute to increased crop yields and productivity. Additionally, when reclaimed wastewater substitutes groundwater abstraction, farmers may benefit from reduced costs of water pumping.

Cities can also benefit from reuse: (i) water and nutrients contained in reclaimed wastewater may favour peri-urban agriculture and improve urban food security, (ii) agriculture can be a cost-effective wastewater treatment mechanism ('green' filter), particularly for nutrient removal, and (iii) reuse can increase water availability for cities when reclaimed water is used for municipal purposes or when it is exchanged for fresh water that was originally allocated for agriculture (Figure 9.2).

FIGURE 9.2
Simplified example of inter-sectoral water exchange under water scarcity



Source: FAO

The environment in general, and aquatic ecosystems in particular, could also benefit from the reclamation and reuse of wastewater, which can improve water quality in rivers, lakes and aquifers, and conserve freshwater for ecosystems. Additionally peri-urban agriculture and agro-forestry that rely upon recycled wastewater have significant potential for the reduction of carbon sequestration and for green house gas emissions as a result of shorter food chains between producer and consumer with greatly reduced need for transportation.

9.4 CROP, ENVIRONMENT AND HEALTH RISKS AND IMPACTS

While water reclamation and reuse may result in benefits for agriculture, cities and the environment, it can also pose risks to ecosystems and human health as reclaimed wastewater usually contain pollutants that could include salts, heavy metals, persistent organic pollutants, pathogenic micro-organisms, drug residues, ammonia, nitrate or phosphorus. Nitrogen and phosphorus in reclaimed water may be beneficial plant nutrients, but excessive nitrogen (N) leaching will cause groundwater pollution that, in turn, leads to public health problems when groundwater that is excessively enriched with nitrogen is used for drinking water.

A variety of risks are associated with RWI:

- pollution of soil from metals, organic components, and from salts and sodium that can give rise to salinity and sodicity (excess sodium);
- pollution of surface water and groundwater from runoff and leaching from RWI irrigated land. Runoff and leachate may contain nutrients (especially nitrogen), heavy metals and organic contaminants originating from urban and industrial sources, which are disposed of into municipal sewers;
- increased burden of disease from the use of reclaimed wastewater by farmers, and by consumers who eat produce that may be contaminated with chemicals and pathogens contained in wastewater.

All these risks can be reduced or eliminated by following the recommendations described in this chapter (section 9.5).

Impacts on crop yield and crop quality in Beijing

Studies in the Beijing area are indicative of crop yield and quality when irrigating using reclaimed wastewater that meets national standards (Tables 9.3. and 9.4). Note, however, that results may be different when using RWI from different types of wastewater treatment plants elsewhere in China. The studies in Beijing showed that:

For alfalfa – there was a significant average yield increase of more than 20 percent (Li *et al*., 2007).

For vegetables – there was no significant impact on vegetable total soluble sugar, vitamins, crude protein, amino acids, crude ash and fibre, or nitrate. RWI produced an increased level of nitrite in leafy vegetables, even though the level of nitrate and nitrite in this reclaimed water was far lower than the sanitary index limit for national and regional standards (Xu *et al*., 2008).

For contaminants in agricultural products – there was no increase in heavy metal content in agricultural products nor any negative effect on seed germination (Wang *et al*., 2008). Analysis of polycyclic aromatic hydrocarbons (PAHs)[4] in corn, peanuts, winter wheat, soybean, watermelon and other crops showed that only naphthalene and phenanthrene were detected but RWI did not lead to increases of PAHs in the fruit component of crops (Liu and Wu, 2009).

4 There are 16 polycyclic aromatic hydrocarbons (PAHs) that are considered to be human carcinogens. These are generated by industrial processes, combustion, etc. and may be found in municipal wastewater.

TABLE 9.1
Estimated daily intake (EDI) of metals in Beijing Nanhongmen RWI

	As	Cd	Cr	Cu	Hg	Pb	Zn
EDI ($mg \cdot d^{-1}$)	0.014	0.008	0.052	2.52	0.002	0.156	15.04

TABLE 9.2
Heavy metal content for soybean in different sources of irrigation water in Beijing RWI area.

Unit mg/kg

Irrigation condition	汞 Hg	砷 As	铅 Pb	镉 Cd	铬 Cr	铜 Cu	锌 Zn
RWI	<0.0006	<0.010	0.03	<0.002	0.53	14.80	44.10
Groundwater irrigation	<0.0006	<0.010	0.067	<0.002	0.30	15.70	44.60

Health risks in Beijing

The daily consumption of cereals should be 300 ~ 500 g per person. For this consumption, the estimated daily intake (EDI) of the heavy metals (As, Cd, Cr, Cu, Hg, Zn) in the Beijing Nanhongmen RWI area was lower than the acceptable daily intake (ADI) values shown in Table 9.1 (Yang *et al.*, 2005a and 2005b). As shown in Table 9.2, RWI did not cause an increase in heavy metal content in soybean as compared with groundwater. It was concluded that RWI of the type used in the Beijing area, resulted in low heavy metal pollution for irrigated crops and in low health risks.

In Beijing, studies show that a variety of intestinal bacteria including salmonella (typhoid, paratyphoid salmonella), diarrhoea-induced coli, legionella, shigella dysenteriae, plesimonas shigelloides, hydrophilic *Aerophilic aeromonas*, pathogenic vibrio (*Vibrio cholerae* and *Vibrio mimicus*) were not detected in reclaimed water of a typical sewage treatment plant, and faecal coliforms were within normal limits, indicating a low health risk from reclaimed water according to current Chinese standards (Liu *et al.*, 2009).

Impacts on soil and groundwater

RWI can improve soil nitrogen and fertility (Xu *et al.*, 2008) with no significant heavy metal increase (Fu *et al.*, 2008; Wu *et al.*, 2006; Yang *et al.*, 2005a and 2005b) and no substantial increases in soil toxicity from PAHs (Yu *et al.*, 2007a,b). However, research in which the long-term impacts of RWI on soil and groundwater were simulated for 69 and 139-year periods, suggest that RWI significantly increases soil salinity and the sodium adsorption rate (SAR). Soil salinity can be overcome by a number of measures that encourage leaching of salts by drainage, e.g. by increasing the irrigation frequency, irrigating before sowing and before rainfall. Sodium enriched soils negatively affect soil structure and agriculture production. This may be overcome by continued use of good irrigation water and methods, e.g. use of gypsum as a soil amendment, and good cropping practices (Davis *et al.*, 2010).

The impact of the long-term use of RWI on groundwater may increase calcium, magnesium and nitrogen, decrease sodium and potassium, and could increase groundwater salinity. Elevated levels of nitrogen in groundwater pose a health risk, especially to children. However, N in groundwater in China is mainly associated with excessive use of N-rich fertilizers and only locally with RWI.

TABLE 9.3

Basic control parameters for water and limits for typical crops in China, unit: mg/litre

No.	Basic control parameters	Crop type			
		Fibre crop	Dryland cereal and oil crop	Paddy field grains	Field Vegetables
1	BOD_5	100	80	60	40
2	COD_{cr}	200	180	150	100
3	SS	100	90	80	60
4	DO≥	-		0.5	
5	pH	5.5~8.5			
6	TDS	Non-saline-alkali area: 1 000 Saline-alkali area: 2 000			1 000
7	Chloride	350			
8	Sulphide	1.0			
9	Residual Chlorine	1.5		1.0	
10	Petroleum	10		5.0	1.0
11	Volatile phenol	1.0			
12	LAS	8.0		5.0	
13	Hg	0.001			
14	Cd	0.01			
15	As	0.1		0.05	
16	Hf	0.1			
17	Pb	0.2			
18	Faecal coliforms number /L	40 000			20 000
19	Helminth egg number /L	2[a]			

[a] WHO recommended limit is ≤1.0

Source: GB5084-2005

TABLE 9.4

Chemical control parameters and limits for irrigation water quality in China (mg/litre)

Chemical	Limit	Chemical	Limit	Chemical		Limit
Be	0.002	Zn	2.0	Chlorobenzene	≤	0.3
Co	1.0	B	1.0	1, 2- Dichlorobenzene	≤	1.0
Cu	1.0	V	0.1	1, 4- Dichlorobenzene	≤	0.4
Chloride	2.0	Prussiate	0.5	Nitrobenzene	≤	2.0
Fe	1.5	Chloral	0.5	Toluene	≤	0.7
Mn	0.3	Acrolein	0.5	Xylene	≤	0.5
Mo	0.5	Formaldehyde	1.0	Cumene	≤	0.25
Ni	0.1	Benzene	2.5			
Se	0.02					

Source: GB5084-2005

9.5 RECOMENDATIONS FOR THE SAFE, PRODUCTIVE USE OF RECLAIMED WATER

Consider the WHO-FAO-UNEP guidelines

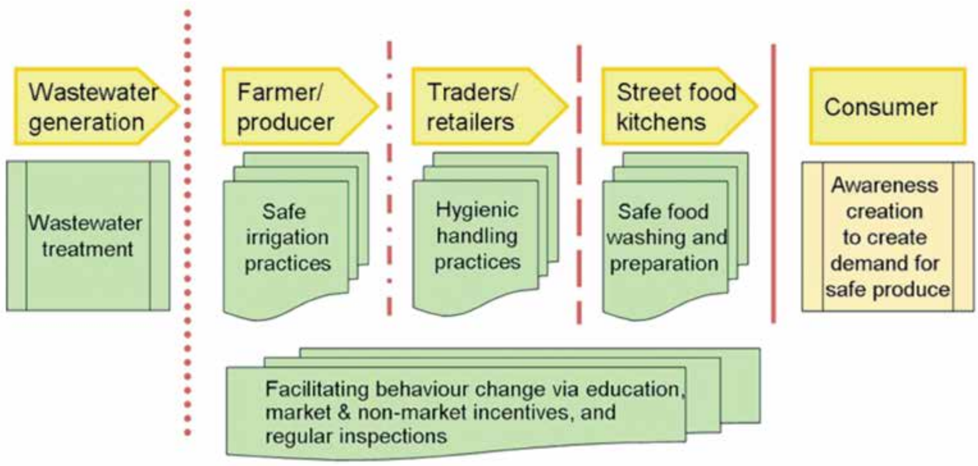
The 2006 WHO-FAO-UNEP *Guidelines for wastewater use in agriculture*[5] recommend that realistic health-based targets are defined and that risks are assessed and managed, from wastewater generation to consumption of produce ('farm to fork'). The health-based targets apply a reference level of tolerable disease burden of 10^{-6} 'Disability adjusted life years' (DALYs). The DALY is a quantitative indicator of 'burden of disease' that reflects by how much a healthy life would be reduced as a result of disability, or the life time lost because of premature death.

Some examples of health based targets are achieving ≤1 helmints egg per litre of reclaimed water for all types of crops, or a pathogen reduction of 6 log for unrestricted irrigation of lettuce (WHO, 2006). These health-based targets could be achieved along a chain of multiple risk reduction barriers. In the multiple barrier approach, conventional wastewater treatment is regarded as one of the barriers and not the only barrier. Treatment is combined with other health protection measures such as safe farm-based and post-harvest measures. These additional measures include: crop restriction, safe irrigation practices, hygienic food handling practices in transport, storage and markets to avoid recontamination, and safe food washing and preparation (Figure 9.3). Barriers are placed at critical control points along the food chain to reduce risks with an aim of total risk reduction from the combined use of barriers. In this way, wastewater treated to a lower standard may be satisfactory if combined with other risk reduction measures to achieve the threshold of $\leq 10^{-6}$ DALY loss per person and per year.

For example, a major risk is from helminths, a type of intestinal worm which pose health risk both to product consumers and farmers (especially to children). The WHO-FAO-UNEP (WHO, 2006) guidelines recommend a mean value of ≤1 helminth egg per litre for at least 90 percent of samples. The current value used in China (GB 20922) is two

FIGURE 9.3

The multiple-barrier approach, as applied in water reuse, reduces health risks to farmers and consumers.



Source: Amoah et al., 2011

5 Volume 2 of a four volume series: *Guidelines for the safe use of wastewater, excreta and grey water*. (WHO, 2006).

helminth eggs per litre. These levels of health protection can be achieved by advanced wastewater treatment; or by a combination of wastewater treatment and washing of produce to protect consumers of raw vegetables; or wastewater treatment and the use of personal protective equipment (shoes, gloves) to protect workers. When children less than 15-years old are exposed in the fields, either additional wastewater treatment or the addition of other health-protection measures (e.g. vaccination) is recommended.

Tailor projects to local geography

One way to ensure a safer use of reclaimed water is to adapt irrigation to the particular requirements of a geographical region. The main factors to consider are land slope, soil and geology and groundwater depth (Fuller and Warrick, 1985; Wu *et al*., 2009). The requirements are shown in Table 9.5.

Land slope – Sloping land increases water loss and soil erosion during the irrigation or rainy seasons and the movement of pollutants to water bodies can be accelerated outside the RWI district; and operating costs can be increased. Therefore, the slope of the irrigation district should be less than 15 percent (Crites, 1985), best management practices should be employed to minimize runoff. Improper use of RWI on sloping land is a significant non-point agricultural source of water pollution.

TABLE 9.5
Terrain indicators for RWI district

Type of irrigation areas	Control indicators for groundwater protection		
	Groundwater depth (D)	Permeation velocity in aeration zone (K)	Land slope (I)
Suitable	D ≥8 m	K <0.5 m/d	I < 2 %
Control	3 m ≤D < 8m	0.5m/d ≤K <0.8 m/d	2% ≤ I <6 %
Unsuitable	D <3 m	K ≥ 0.8 m/d	I ≥ 6 %

Note: '*Unsuitable*' indicates that this type of area is not appropriate for use of reclaimed water in order to avoid long-term impacts of RWI on groundwater. 'Control' indicates that this type of terrain may be used for RWI, providing that the irrigation area is far from groundwater/surface water sources, urban central waterworks. Also alluvial fans and riverbeds that are substantially permeable must be avoided. In these areas water-saving irrigating techniques should be used such as canal lining, pipe irrigation and drip irrigation and spate irrigation should be avoided. '*Suitable*' indicates that this terrain is appropriate for RWI, but best management practices should still be followed. RWI is prohibited near urban central waterworks and water sources.

Source: Liu&Wu, 2009

Soil and geology – Important indicators for determining the potential for groundwater pollution from RWI are the structure of the soil aeration zone, depth and permeability coefficient. For example, in the Beijing area the upper regions of the alluvial fan are highly permeable, therefore, leaching of RWI can accelerate groundwater contamination. Therefore, RWI is not recommended in the upper regions; in contrast, the soil is less permeable in the middle and lower regions, so RWI may be practiced with less impact on groundwater.

Groundwater depth – Depth of the water table is an important factor when analysing the risks of groundwater contamination from RWI.

Select the right crops

Crop selection and diversification may be needed to minimize health risks for consumers and to ensure crop productivity. This selection needs to account for crops market value and tolerance against salinity and specific toxic ions that may be present in wastewater or reclaimed water.

Health risks – The following crops are preferred for RWI schemes: (a) non-food crops (e.g. cotton, planted forests and 'biodiesel' crops such as jatropha, jojoba and rapeseed); (b) food crops that are processed before consumption (e.g. wheat); and (c) food crops that have to be cooked such as potatoes and rice. Consumers of these crops are protected because they are only eaten after extensive processing or cooking, which inactivates the pathogens. It is recommended that irrigated crops are cooked. (WHO, 2006).

Salinity – Reclaimed water may still have a high salt content. The most common indicator used to monitor water salinity is electric conductivity (EC). When the EC is higher than 2 dS/m salts can start to accumulate in the soils, preventing water uptake by plants, which can impact the productivity of many crops. Nevertheless some crop varieties have shown a high tolerance to salinity such as burley, cotton, jojoba, sugar beet, alkali grass, asparagus (FAO, 1992).

Specific ion toxiciy – There may be excess nutrients, heavy metals and other trace elements in reclaimed water, which can impact crop yields. For example it is common for Boron concentration to be over 0.7mg/litre in effluents from wastewater treatment plants. This concentration is already toxic for less tolerant crops. Some crops and crop varieties have shown moderate and high tolerance to specific ion toxicity, for example boron tolerant crops (4-15 mg/Bo/litre): cotton, asparagus, sorghum, alfalfa, tomato. Extensive crop classification based on their tolerance to different ions can be found in FAO, 1992).

Select the right infrastructure

An RWI project must take into account the infrastructure needed for water treatment, delivery, storage, use and drainage.

Water transmission and distribution infrastructure that pass through densely populated areas should use pipes or culverts. It is prohibited to connect pipes used for RWI to those used for drinking water. Pipes and equipment that are directly in contact with RWI pipes should be corrosion resistant. Recycled water pipes that are buried parallel to the water supply and drainage pipelines, should be more than 0.5 m distance. When these pipes cross underground the recycled water pipes should be located under the water supply pipes and/or drainage pipes by at least 0.4 m.

Open channel water distribution projects should establish buffer zones and, if these pass significantly permeable areas, or pass through a water source protection area, measures should be taken to prevent leakage. Secondary pollution of treated wastewater by other sources of pollution must be avoided.

For water application, irrigation methods that minimize the contact between water and edible parts of the crops are preferred. These methods could be microirrigation (e.g. drip irrigation) or furrow irrigation. Microirrigation is more efficient but more expensive and may require prior filtration to prevent clogging.

Select the right irrigation methods and systems

RWI may use surface irrigation or drip irrigation. Sprinkler irrigation may only be used if there is controlled access to this area by farm or other personnel. Micro-sprinkler irrigation devices should be equipped with gravel filters, with no less than 120-mesh screen filters or disk filters. A lable noting the water is reclaimed should be clearly displayed on the field irrigation pipes and equipment.

Accumulation of soil salinity can be reduced by increasing irrigation frequency; irrigating before sowing or before rainfall; alternating between freshwater and reclaimed irrigation water. When irrigating parks or greenbelts with reclaimed water, it should be done at night or at times when few people are present.

Include buffer zones

The RWI projects should establish buffer zones (or setback distances) to ensure the safety of surrounding activities. The size of these buffer zones depend on the type of activity to be protected. Thus, for a buffer zone to protect:

- drinking water wells or springs (for human or animal use): the buffer radius should be ≥ 150 m;
- residential areas or areas with heavy public traffic: the buffer width should be ≥ 50 m wide;
- well water used for irrigation: the radius of the buffer zone should be ≥ 20 m;

More generally, buffer zones around an RWI project as well as around open channels for transmission and distribution of reclaimed water should be ≥ 10 m. There are no requirements for a buffer zone in an urban greenbelt that is irrigated at night, when few people are present.

Monitor and evaluate the RWI district

Good RWI management requires a monitoring network in each RWI district for water, soil, crops, groundwater and drainage. Monitoring is carried out on a plot that is representative of soils and crops. Soil, crop and groundwater quality monitoring should be carried out together on the same plot. The density of monitoring points should meet the requirements listed in Table 9.6.

TABLE 9.6
Recommended density for RWI monitoring points

Irrigation area (S)	Point density
S≥ 5 000 ha	1 point /every 500~2 000 ha
500 ha≤ S<5 000 ha	1 point /every 250~1 000 ha
100 ha≤ S<500 ha	1 point /every 100~250 ha

Source: DB11/T-2010

Monitoring points for reclaimed water quality should be established at the head of the main channel/pipe and each branch channel/pipe and on the drainage channel. Soil, including soil salinity, should be monitored at a depth of 30 cm according to the parameters in *Environmental quality standard for soils* (GB/T15618) (Li, 2001). Agricultural products should be monitored according to *Hygienic standards for grains* (GB2715), and by *Safety requirements for non-environmental pollution vegetable* (GB18406.2).

Producers of export crops should also observe FAO–WHO Codex Alimentarius (Codex, 2009) *Code of hygienic practice for fresh fruits and vegetables*. The Codex assesses risks from 'farm to fork' and provides a list of fresh produce commodities of concern and their relative priority. Groundwater monitoring should be based on the quality standard for groundwater (GB/T14848). The frequency of monitoring is at least once a year.

Inform the public

RWI projects should set up warning signs so as to prevent RWI impacting public health. The warning signs include 'RWI District', 'No Swimming', 'No Drinking', 'No Playing', etc. Figure 9.4 illustrates these signs. The background colour of warning signs should be brown and the letters/lines/phrases should be white. The RWI sign (top-left) should be set up on each side of the main road to the irrigation district so they are easily seen. Other signs are located at suitable points within the irrigation area. The colour of pipes used to transport reclaimed water should be different from those for freshwater supply and should be well marked so there is no confusion between treated wastewater and freshwater pipes.

Manage projects professionally

A professional management company or organization should be in charge of any RWI project. The duties include daily operation, project maintenance, water-metering, environmental monitoring and security management.

FIGURE 9.4
Examples of warning signs used around RWI districts

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10. Water quality monitoring

YANG Linzhang[1], MA Li, QIN Boqiang[2],
FENG Yanfang[3], Edwin D. ONGLEY[4]

10.1 INTRODUCTION

Monitoring of water quality has been carried out across China for more than 25 years. Until recently, surface water monitoring mainly focused on urban and industrial wastewaters and their impact on rivers and lakes. The data show that continuing deterioration of water quality is not only caused by industrial and municipal wastewater, but is greatly influenced by the impact of agriculture on surface and groundwater. This chapter explores the types and methodologies of water quality monitoring and how the data are used to identify sources of pollution. Because agricultural non-point sources of pollution are difficult to measure directly, methods are described that allow estimation of the amount of agricultural water pollution from paddy and field crops, from animal raising, and from rural living.

10.2 WATER QUALITY MONITORING IN CHINA

China began physico-chemical monitoring of surface water in the mid-1950s and the Chinese index for water pollution monitoring classes was introduced in the 1970s. Currently, China uses a National Water Monitoring Network that comprises river basin agencies, as well as provincial and municipal monitoring bureaus. Monitoring is carried out both by the Ministry of Water Resources and the Ministry of Environmental Protection according to their respective legislative mandates. These agencies regularly monitor and evaluate surface and groundwater quality in order to protect and manage water resources.

Monitoring in each agency is designed according to national monitoring standards and, for some sites, on the basis of investigations into the unique conditions requiring specialized monitoring. National standards determine the frequency of sampling, the parameters to be monitored, sampling methodology, methods of laboratory analysis and quality control of data. Water quality monitoring includes both environmental monitoring as for example water, sea, air and groundwater, and monitoring of pollution sources such as industries, hospitals and municipalities. In addition to regular monitoring many agencies carry out water quality studies for many different purposes. State agencies publish annual yearbooks of data on water and river flow. Some data are published on-line (available at: http://www.zhb.gov.cn/).

10.3 MONITORING OF AGRICULTURAL POLLUTION

According to monitoring data, most water bodies in China, are threatened by severe

1 Jiangsu Academy of Agricultural Sciences
2 Chinese Academy of Sciences, Institute of Soil Sciences
3 Chinese Academy of Sciences, Institute of Geography and Luminology
4 Formerly, National Water Research Institute Environment Canada (retired; currently international consultant)

eutrophication and reduced quality of drinking water (Jin, 2002). Groundwater levels are declining and its quality is deteriorating (refer to Chapter 1; Wang *et al*., 2009). For example, ammonia, nitrate and nitrite content in water all show an increasing trend; this is mainly the result of discharge of industrial effluent, municipal wastewater and agricultural NPS pollution. Therefore, China suffers dual pressure of water resource shortage both in quality and quantity, especially in northern China.

Monitoring of nutrients, other agricultural chemicals (such as pesticides), and suspended matter is important not only to reveal the physico-chemical composition of water, but to assist decision-makers identify the causes and to implement appropriate remedial action.

Monitoring and assessment of agricultural NPS pollution has been difficult in China because there has been no long-term NPS measurement at the field and watershed level. There have also been difficulties in using Western models to assess NPS because of the very different farming systems and geography of Chinese farms: very small; labour-intensive cultivation; and field architecture where fields are often surrounded by shallow berms containing irrigation water that prevent runoff from rainfall (Ongley, 2010).

Indicators used to assess water pollution

In China the basic established indicators for the regular monitoring of surface water are: water temperature; pH; dissolved oxygen; permanganate index; COD; BOD_5; NH_3-N; TP; TN; Cu; Zn; Fluoride; selenium; arsenic; Hg; Cd; Cr; Pb; Cyanide; volatile phenol; petroleum; ionic surface active agent; sulfide; paracolon). Supplementary measurements used for drinking water include nitrate, sulfate, chloride, Fe and Mn.

Turbidity is an important indicator of water quality. Water transparency is affected by organic particles (algae, etc.) and inorganic particles (soil and sediment). Poor quality water in lakes and rivers is almost always insufficiently clear. In rivers, opacity is usually the result of suspended solids (sediment); an example is the Yellow river, which carries large loads of suspended sediment. In lakes, low transparency is almost always related to organic particles such as algae.

Monitoring methods for water quality in aquatic environments

The following provides general guidance for monitoring of water that has possibly been polluted by agricultural runoff.

Collect basic data – This needs to be assembled before monitoring. This includes land use (what types, areas of each land use); topographic and hydrological information from the area of interest; physical and chemical properties of the soil in planting areas; cropping systems; plant species in the area; the quantity and types of chemical fertilizers and pesticides used in the monitoring area; types and number of livestock and whether these are in large, medium or family-farm sized livestock units.

Identification of problems – In some cases, there are specific reasons for carrying out monitoring. This might include intense algal blooms, fish kills resulting from lack of oxygen, physical pollution from solid waste. In some cases, such as for solid waste, the cause and effect is obvious. In other cases where, for example, there have been fish kills, the cause is not readily apparent, so there needs to be a more sophisticated approach to identifying the problem. In other cases, as is often the situation in China, an effective programme of pollution control requires improved knowledge of the loading of N, P and other agrochemicals into the water environment so that this can be evaluated against other types of loads coming from municipalities and industry. Each issue requires a different approach to monitoring.

Establishing a sampling programme – Based on the comprehensive analysis of the surveyed results and related information the type of cross-sections and the number of sampling points can be determined. When surface water is collected from farmland, dead zones, backwater areas, the outfall of sewage should be avoided and an attempt made to select a straight, wide section with a smooth flow. In rivers a sample is usually taken from the centre or in the zone of maximum flow; water near river banks is avoided, as this is often contaminated by nearby shore activities (e.g. animals drinking from the river; clothes washing upstream).

Water quality monitoring at the farm and field level

Monitoring at the farm level is different than monitoring rivers and lakes. At the farm level the focus is on specific farming activities such as paddy rice, field crops, animal husbandry, and rural living.

Monitoring of irrigation supply water – is much like monitoring small rivers. A sample is taken, often at weekly intervals, from the mid-point of the canal. If the canal has a flow gauge, then the volume of flow should also be recorded.

Monitoring of water quality on farmland (paddy and dry fields) – involves monitoring the quality of water going onto the field (or paddy), the water that runs off the field or paddy, and groundwater; sampled in bores (wells). In much of Chinese agriculture, especially in northern China, there is very little runoff. In part this is because the climate is semi-arid, and also because the field architecture is generally comprised of relatively small plots surrounded by bunds that not only delineate ownership, but also contain irrigation water that might otherwise run off. In paddies, a large amount of rainfall will cause the water in the paddy dyke (berm) to flow over the top and the water will run off.

Paddies, however, are also drained at specific points in the rice growing cycle, and it is at this time that water quality can be assessed as it is drained from the paddy.

Where there are field crops, farmers will often cut holes in the bund because many plants cannot survive in waterlogged fields. An example is shown in Figure 10.1; during heavy rains the fields are naturally drained when water flows through cuts in the bund and can be sampled at that time.

FIGURE 10.1
Break in cotton field bund (berm) used for drainage can also be used to sample runoff water.

Photo: © E. Ongley

Sampling at the field level for scientific studies requires extensive instrumentation, measurement of soil porosity and soil water, seepage rates. To do this a lysimeter[5] is used. Because use of this instrument is quite detailed, specifics are not included in this publication.

Background values – are useful to know, which are the 'natural' background levels of pollution such as from the air and natural erosion processes. This is established by monitoring an area that is not directly contaminated by fertilizers or other agrochemicals. This tells us what the 'normal' runoff of nutrients will be when there is no direct use of agrochemicals. Generally, the background must be monitored at least once per year at several locations. The average value will indicate the background values for runoff characteristics.

Determination of sampling time and frequency – is determined by several factors, including variability in rainfall and runoff; fertilizer application; and manure management as part of feedlot operations.

In areas where sewage water is used to irrigate, the sampling frequency should reflect the major periods of irrigation. Monitoring of drainage channels should not be less than three times per year so that the main period of irrigation runoff is contained in the collected data. Monitoring of pesticides should be carried out soon after, within one week of pesticide application. Modern pesticides tend to degrade after use, therefore monitoring for these long after they have been applied usually results in non-detectable amounts. Groundwater sampling should be carried out during wet and dry seasons or twice per year. Water sources used for irrigation should be monitored at least twice per year.

Sampling methods

Paddy fields and dry land crops are the two main forms of agricultural land use. There are three methods for monitoring runoff water quality in dry fields, especially in southern China where there is frequent runoff.

Dry fields

- A drainage ditch around the field is used to collect runoff. A flow meter can be used to calculate the volume of runoff. Water samples are collected twice during the period of runoff and the results are averaged.
- The second method is to place clean, wide-mouth, sample bottles directly into the soil so that the top of the bottle (the mouth of the bottle) is level with the field surface. The soil around the mouth of the bottle must be tamped down so that no loose soil will fall into the bottle. The space between every two water-sampling bottles is no more than 5 m, and the bottles should be located in furrows rather than on mounds so that water will naturally flow into the bottle. The number of sampling bottles depends on the size of the field; generally one should use at least four bottles per hectare. During runoff the water will flow into the bottles. Collect the runoff water at the end of the runoff period and record time and date of sampling. This method will not be used to estimate the amount of runoff, but will provide a reasonable estimate of water chemistry. A method to determine the volume of runoff is noted below.
- The third method can be used when there is subsoil drainage. The water that passes through the soil and into the drainage pipes can be collected where

5 Apparatus for measuring soil water, runoff, etc.. Mainly used for scientific research.

the pipes discharge into a drainage canal. This method cannot be used to determine runoff volume because the area that the pipe is draining may be unknown.

FIGURE 10.2
Runoff from a paddy in Ninghe County, Tianjin Municipality. Arrows indicate the overflow.

Photo: © E. Ongley

Paddies

- To monitor the water quality in runoff from paddy fields, a collection device can be installed on the paddy dyke at points where water is drained or where excess rainfall is allowed to run over the dyke. For research purposes, the collector is usually made of plastic pipe or PVC pipe and installed every 5 m along the berm. Continuous recording of flow from the paddy will provide a value for total volume of runoff. For more practical monitoring, the water can be sampled inside the paddy when there is runoff over the dyke. The volume of runoff can be estimated using the guidance provided in the following paragraphs. The chemistry of water in the paddy will be the same as that running over the dyke. An example of runoff over a paddy dyke is shown in Figure 10.2.

Estimating runoff

Dryland crops – can be measured directly under experimental conditions, however this is more difficult for local agricultural officials. An estimate can be made using rainfall data, which is often measured at nearby locations such as county agriculture bureaus or water resources bureaus. The methodology can be used on relatively flat land but not on sloping land of more than 3–4 degrees:

- Determine or estimate the saturation infiltration capacity of the local soil. This can be done quite easily, using simple experimental apparatus or charts showing infiltration capacity according to local soil type. Once the soil is saturated, the infiltration capacity will be relatively constant. Before saturation the infiltration will be more rapid.
- Using the 24-hour rainfall data from nearby (within 3–5 km), calculate the average rainfall intensity by dividing the amount by 24; this gives the intensity per hour. (mm/hr).
- Calculate the number of hours in which the rainfall intensity exceeds the saturation infiltration capacity. Any rainfall that is less than the saturation infiltration capacity will not runoff, as all of it will move into the soil. Rainfall that exceeds the saturation infiltration will runoff. For each hour the rainfall intensity exceeds the field saturation infiltration capacity, calculate the amount of rainfall (in mm) that is more than the infiltration capacity. For example, if the calculated rainfall intensity is 4 mm/hr and the field saturation infiltration capacity is 3 mm/hr, then the excess is 1 mm/hr – this is the amount that will runoff. If the area of the field is known, the total amount of runoff can be estimated. In our example, 1 mm of excess rainfall/hr over an area of 1 ha (100 x 100 m), produces 10 m^3 of runoff/hr/ha. Of course, this is only an approximation, but it provides an estimate

that can be used to calculate total runoff and, therefore, the amount of fertilizer runoff according to the chemical concentration obtained from bottles or from sampling of runoff from fields as shown in Figure 10.1.

Runoff from rainfall (paddies) – Experienced field staff at country agricultural bureaus usually have a good knowledge of how much rainfall is required to produce runoff from paddies in their area. This is because farmers tend to keep water at roughly the same level so that local officials usually have a good idea of how much rainfall will produce overflow of the paddy dykes. Using local rainfall records on a 24-hour basis, calculate the depth of rainfall that will produce overflow of the paddy dykes.

For example, if local officials believe that 40 mm of rain in a 24-hour period will cause overflow, then in each 24-hour period one looks for rainfall in excess of 40 mm in the 24-hour period. Any rainfall that is more than 40 mm is assumed to produce runoff. Knowing the area of the paddy and the amount of rainfall that is in excess of 40 mm (in this example) allows a rough estimate to be made of total volume of runoff from paddies.

This method must be adjusted regionally to account for local differences in paddy construction and operation; however, it has been found that local agricultural technical officers are quite knowledgeable about rainfall and runoff from paddies within their control area. Where agricultural officials are directly involved in the estimation and management of agricultural pollution, they will pay more attention to measuring rainfall that produces runoff.

Runoff from paddy drainage – is a second type of equally important paddy runoff. This is the water drained from paddies when they are emptied of water prior to harvesting. The volume can be determined by knowing the depth of water to be drained, and the area of the paddy. The chemistry of the water should be sampled at the time the paddy is drained.

Monitoring groundwater

Groundwater travels laterally through the soil and bedrock; therefore it is often difficult to establish a background (control) sampling location. Generally, a control well should be sampled some distance from agricultural fields, which may not be possible. One or more wells that are used to supply water to fields and household drinking water should be selected for routine groundwater monitoring. However, sampling groundwater requires some knowledge of the local hydrogeological conditions to ensure sampled groundwater is relevant to the land-use activity.

For example, in many places there is more than one level of groundwater. If the top layer (aquifer) is contaminated (e.g. for drinking water), water pumped for drinking will be pumped from a lower level aquifer. This water is unsuitable for determining agricultural pollution as it will be the upper aquifer that will be the most contaminated. It is useful to sample groundwater at least twice per year, especially in areas where there is a wet and dry season.

10.4 ESTIMATING AGRICULTURAL POLLUTION AT THE COUNTY LEVEL

Often, direct measurement of pollution is neither feasible nor possible. Therefore, estimation becomes an important part of a monitoring and assessment programme for agricultural pollution. Direct measurement of pollution at the field level requires a high level of scientific investigation. Assessment of agricultural pollution is best done at the county level. This provides 'average' information; however it should not be forgotten that detailed scientific data at the field level is highly variable. When the attempt is made to scale the results up to larger areas. The following approach has proven useful. The methodology is provided in detail in Yang *et al.*, (2012) and should be consulted so that the nature of assumptions and generalizations are clearly understood. The specific data in Table 10.1 refer to Ninghe county (Tianjin municipality) and should be used with care, elsewhere. It is the methodology that is important, not the specific values for Ninghe.

TABLE 10.1

Estimation methodology for N, P and COD at the county level (from Yang *et al.*, 2012). Specific values in the table are those developed for Ninghe county and are provided here as examples.

Pollution source	Excreted load	Potential load	Delivered load
Pollution load from fertilizer application to field crops (rice + other field crops)		TN = total of N application (elemental) × (1-utilization rate - volatilization rate) Remarks: ➢ N application is 309 kg/ha: from investigation and Ninghe Year Book ➢ Utilization rate=40 % ➢ Volatilization rate=45 %	TN = Total N application as fertilizer (elemental) × delivery coefficient Remarks: ➢ Delivery coefficient = 0.75 %
		TP = Total of P application (elemental) × (1-utilization rate) Remarks: ➢ P application is 81 kg/ha: investigation and Ninghe year book ➢ Utilization rate = 15 %	TP = Total of P application (elemental) ×delivery coefficient Remarks: ➢ delivery coefficient = 0.34 %
Pollution Load from Livestock (excretion in centralized feedlots)	Contaminant (COD, TN, TP) = ∑ amount of livestocki × excretion coefficienti × contaminant coefficienti Remarks: ➢ i – type of animal ➢ Amount of livestock (from investigation and Ninghe Year Book) ➢ Excretion coefficient and contaminant coefficient (see tables 2 and 3)	Excreted Load x untreated rate ➢ (assumes treated manure does not runoff – currently not a valid assumption)	Contaminant (COD, TN, TP) = ∑ number of livestocki × excretion coefficienti × contaminant coefficient x delivery coefficient Remarks: ➢ i – species of livestock ➢ Amount of livestock comes from investigation and Ninghe Year Book ➢ Excretion coefficient and contaminant coefficient (see tables 2 and 3) ➢ delivery coefficient = 5%, 10% & 30%
Pollution load from rural living (Wastewater)	Contaminant (COD, TN, TP) = Rural population × contaminant coefficient Remarks: ➢ Rural population: Ninghe year book ➢ Contamination coefficients (kg•head-1•a-1): COD-3.33, TN-0.35, TP-0.04	Excreted Load x untreated rate (90%)	Contaminant (COD, TN, TP) = Rural population × contaminant coefficient × delivery coefficient Remarks: ➢ Rural population comes from Ninghe year book ➢ Contamination coefficient ($kg \bullet head^{-1} \bullet a^{-1}$): COD-3.33, TN-0.35, TP-0.04 ➢ Delivery coefficient = 5%, 10% & 30 %
Atmospheric N deposition		TN=cropland area × deposition coefficient Remarks: ➢ Cropland area (from Ninghe Year Book) ➢ Deposition coefficient = 50 $kgN \cdot ha^{-1} \cdot a^{-1}$	TN=cropland area × deposition coefficient × delivery coefficient Remarks: ➢ Cropland area (from Ninghe Year Book) ➢ Deposition coefficient = 50 $kgN \cdot ha^{-1} \cdot a^{-1}$ ➢ Delivery coefficient = 0.75 %

Agricultural pollution estimation usually involves three types of pollution sources: paddy and field crops (either together or separately), livestock raising (feedlots) and rural living. It has been found that conventional estimation techniques do not work well in China because the methodologies were developed in Western countries having very different agricultural systems (Ongley *et al.*, 2010). In Western countries the 'export coefficient' approach is often used, but this depends on knowing the amount of pollutant transported to watercourses from each type of land use; this is given as kg/ha/yr for each chemical constituent.

Relatively little research has been done on export coefficients in China so there is insufficiently reliable data for wide-scale use. This deficiency is being addressed by researchers in China but will take many years to produce the type of reliable coefficients that have been researched in the United States and Europe for more than 40 years.

Notes on application of Table 10.1

- This is a mass balance approach used to calculate pollution loads from agriculture at the county level. The pollution load at the source (on the field or in the feedlot = potential load) is the amount of chemical applied (or excreted, in the case of animals) minus losses that occur at the source. For fertilizer, losses include the amount taken up by crops and the amount lost to the atmosphere as a result of volatilization.
- Potential load is created at the source, such as in the feedlot or on the field. For fertilizer, the potential load is the amount of fertilizer applied, minus the amount taken up by the crop, minus the amount lost to the air through volatilization from urea, green manure. Volatile loss on the North China Plain is estimated at approximately 50 kg/ha/yr for Ninghe county (refer to Yang *et al.*, 2012).
- Delivered load is the part that is transported to the nearest watercourse. Some of the potential load is retained at the source as, for example, N and P that are retained in the soil. The delivered load is generally calculated as a 'delivery coefficient' and expresses the percent of the potential load transported to the nearest watercourse. Delivery coefficients can be estimated in the field, or taken from the literature from similar situations. 'Export coefficients' (which are the load of each pollutant in kg/ha/yr from specific land uses) are not used as these are poorly known in China as noted above.
- When the delivery coefficient is unknown, a range of possible delivery coefficients is used to provide scenarios for the load that may be delivered to nearby watercourses. This is especially true for livestock, as little is known about how much of the pollutant load generated in the feedlot is actually transported into a watercourse. This depends greatly on how manure is managed in the feedlot, how it is applied to the field as green fertilizer, and the location of the feedlot relative to watercourses. In Ninghe, many feedlots were examined so as to better understand how load might be delivered to watercourses.
- Fertilizer loss is assumed by many researchers to be very large because of the excessive amount of fertilizer used by farmers in China. However, this is highly variable and is closely related to climatic factors. In the dry North China Plain, for example, the observed delivery coefficient is only 0.75 percent of the applied fertilizer (Chen *et al.*, 2011). The reason for such a low runoff amount is because, on much of the North China Plain, there has been very little runoff over many years. Without runoff, there can be no transfer of fertilizer to nearby watercourses except indirectly through volatilization into the air, followed by subsequent deposition by rainfall. Where irrigation causes runoff, then it is expected that fertilizer would be seen running off the fields. In southern China much larger

amounts of fertilizer runoff can be expected because of the more frequent rainfall and intense rainstorms.

- Livestock raising in Ninghe is the single largest source of agricultural pollution. This has also been found in many other parts of China. Potential load of animal pollution is calculated using the number of animals and the known quantity of pollutant in animal manure. This requires two tables (Tables 10.2 and 10.3). Table 10.2 allows estimation of the weight (kg) of waste from each type of animal. Table 10.3 is the known concentration of pollutants in urine and animal faeces. Therefore, the potential pollutant load from each animal is calculated as: Potential load = Number of animals in the breeding cycle x kg of manure and urine x concentration of each pollutant per tonne of animal waste. The actual load is calculated using three different scenarios of delivery coefficient insofar as the actual delivery coefficient is highly variable from one feedlot to the next.
- Rural living is the pollution load that comes from human settlement in agricultural villages. In the past, it was assumed that, as 75 percent of China's population is rural, then 75 percent of human pollution must also be from rural living. It is known now that this is not true, at least in dry northern China because of the lack of rainfall that produces runoff. In southern China this will be different insofar as most agricultural villages are located on the banks of rivers and canals and much of the human waste is put directly into these channels. The actual pollution impact of southern agricultural villages has not yet been sufficiently studied.

Atmospheric contribution to agricultural pollution – In China, because of severe air

TABLE 10.2
Excretion coefficient

Type		Unit	Cattle	Pig	Chicken	Duck
Faeces		kg/day	20	2	0.1	0.1
Urine		kg/day	10	3.3	—	—
Breeding cycle		Day	365	150	60	60
Total	Faeces	kg/yr	7 300	300	6	6
	Urine	kg/yr	3 650	495	—	—

Source: NEP, 2002

TABLE 10.3
Chemical loading coefficients, unit kg/tonne [a]

Type		COD	TN	TP
Pig	Faeces	4.4	31	1.2
	Urine	8	6	0.4
Cattle	Faeces	5.9	52	3.4
	Urine	3.3	9	0.5
Chicken	Faeces	9.8	45	5.4
Duck	Faeces	11	46.3	6.2

[a] kg of chemical per tonne of faeces or urine

Source: NEP, 2002

pollution in many areas, the atmosphere contributes significant amounts of nitrogen to agricultural fields. This is rarely accounted for in nitrogen balances in agriculture but can be significant. Further information is found in Yang *et al*., (2012).

Using this approach in Ninghe county, it was found that most agricultural pollution was from animal raising, and the amount from rural living was almost undetectable.

10.5 METHODS USED TO MONITOR AGRICULTURAL WATER QUALITY

A comprehensive and practical guide to field sampling and data analysis for water quality monitoring is that of Bartram and Balance (1996) which is still relevant today. Analytical methods for analysis of pollution in water and sediments can be found in a variety of manuals including those from APHA-AWWA-WEF (2006) and the Government of China (1992, 2006). Design of field sampling programmes and quality control including correct preservation of samples collected in the field are essential elements of a successful water quality monitoring program.

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11. Regulatory framework

WANG Yi[1], LI Yingming[1],
HUANG Ren[2], Edwin D. ONGLEY[3]

11.1 INTRODUCTION

Water pollution in agriculture is recognized worldwide. However, unlike point sources, the experience worldwide is that non-point source (NPS) pollution is difficult to regulate effectively because of its inherently diffuse nature. This chapter reviews the regulations and legislation for NPS pollution in the European Union (EU), Japanese regulations for control of water pollution for agriculture, and guidance and the total mean daily load (TMDL) approach used in the United States as a means to include agricultural pollution within the larger framework of total pollution in a river basin.

11.2 INTERNATIONAL EXAMPLES

European Union (EU) Water Framework Directive

The EU Water Framework Directive (WFD) was adopted in 2000 (European Council, 2000) as a means of protecting inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. The WFD uses the integrated water resource management (IWRM) approach in which the river basin is the management unit for water. The Directive requires Member States to create management plans for each river basin on a six-year cycle. Point and NPS pollution are to be managed using an integrated approach.

Nitrogen pollution, especially from agriculture, is a particular problem in Europe. An earlier EU Nitrates Directive (European Council, 1991) requires that Member States submit a report to the European Commission every four years including information pertaining to codes of good farming practice, designated nitrate vulnerable zones (NVZs), results of water monitoring and a summary of relevant aspects of action programmes for vulnerable zones.

FIGURE 11.1
Rice fields treated with the Azolla biofertilizer give the same yields as those treated with chemical nitrogen fertilizers.

Photo: ©FAO/Sergio Pierbattista

1 Chinese Academy of Sciences, Institute of Policy and Management
2 Chinese Academy of Sciences, Institute of Agricultural Economics and Development
3 Formerly, National Water Research Institute Environment Canada (retired; currently international consultant)

To fulfill the task of these directives, farmers are obliged to take into account the following aspects for control of pollution from nitrogen:

- Crop rotations, soil winter cover, catch crops, in order to limit leaching during the wet seasons.
- Use of inorganic fertilizers and manure, with a balance between crop needs, N inputs and soil supply, frequent manure and soil analysis, mandatory fertilization plans and general limitations per crop for both mineral and organic N fertilization.
- Appropriate N spreading calendars and sufficient manure storage, for use only when the crop needs nutrients and good spreading practices.
- 'Buffers' – non-fertilized grass strips and hedges along watercourses and ditches.
- Good management and/or restriction of cultivation on steeply sloping soils, and of irrigation.

The implementation of the WFD is, admittedly, uneven and some countries are behind schedule. Nevertheless, the WFD is a landmark legislation that provides a standardized watershed approach to water management across Europe.

United States guidance for the control of agricultural pollution and TMDL

The United States, mainly through the US-Environmental Protection Agency (US-EPA) and the US Department of Agriculture, has the largest NPS management programme in the world covering agriculture, forestry and urban NPS (US-EPA 2003; 2005a,b). Under the federal Clean Water Act (CWA), the US-EPA has the overall federal responsibility for developing policies for environmental management, implementing programmes, and regulating water quality. This responsibility is shared with the 50 States, with other federal agencies, and with Native American tribes that manage their own land. In the 1987 amendment of the CWA the American Congress added Section 319, which deals specifically with NPS pollution.

Undoubtedly, one of the most comprehensive guidance publications on agricultural NPS is, *National management measures to control non-point pollution from agriculture, which* is too long to be summarized comprehensively here. This document covers erosion control; the management of fertilizer, land-use, pesticides, grazingland; animal feeding operations; as well as auxiliary topics such as the monitoring of NPS, planning of fertilizer management and best management practices.

While not all of the US-EPA guidance is similar to the situation in China, there are many useful lessons. It is useful to note that in the United States, guidance is used instead of regulation. This is because regulation of agricultural NPS has proven to be extremely difficult and ineffective, with the exception of feedlot operations (see below) as point sources are subject to regulation.

The approach in Canada and the United States to managing rural NPS pollution has been (i) farmer education; (ii) demonstrating the economic benefits to farmers of practicing GMPs; (iii) incentives to remove erosion-prone land from production and to convert land to wetland; and (iv) extensive provision of (free) advisory services to farmers from government agricultural field officers.

In some jurisdictions there are limited regulations such as a requirement to fence streams so cattle cannot enter a stream channel; minimum distances between cattle operations, small feedlots and surface watercourses. Notably, in China and the United States, livestock raising operations are a particularly substantial source of agricultural pollution. The intensive rearing of animals is strictly regulated in the United States as noted below.

TMDL – is a continuous process in the Clean Water Act, no other country has a similar legislated TMDL process. It is a compulsory requirement when a water body has been identified as not meeting (i.e. 'non-conforming') the required water quality objectives (nutrients, contaminants, microbiological parameters, sediment, etc.). The problem in the United States was that, within a river basin, all dischargers could be within their regulated effluent standard, but the cumulative waste load was still too high to meet the in-stream water quality objective or standard.

This situation is similar to that found in many Chinese rivers. TMDL was introduced as a process through which wastewater discharges (initially) and now including NPS pollution, can be reduced so that the in-stream concentration objective can be achieved. The pollution load from all sources (point and NPS) in a river basin is calculated; load reductions are allocated to various sources so that the in-stream water quality objective can be achieved. Today, where agricultural NPS can be more cost-effectively reduced than for industrial sources, farmers are paid to achieve the required level of pollution reduction.

Formulation of TMDL: TMDL = SWLA + SLA + MOS

Where TMDL: Total maximum daily load
SWLA: Sum of all wasteload allocations to point source discharges
SLA: Sum of all load allocations to non-point source discharges
MOS: Margin of safety

In China, **total load control** is different than TMDL insofar as total load control refers to total load reduction of COD and ammonia as a basis for assigning load reduction targets in the Five-Year Plan for individual provinces. It is not linked to achieving in-stream water quality standards and is not related to NPS pollution.

Caution in using TMDL in China:

- TMDL has taken 30 years to become fully functional in the United States;
- it is a full watershed approach;
- TMDL is data intensive, involving knowledge of land use, biogeochemical cycling during transport in rivers and lakes (integrated science);
- requires integration of water quality and quantity;
- requires active involvement of the agriculture ministry;
- requires statement of likely uncertainty of TMDL outcome;
- requires full knowledge of actual loads – problems in China include major discrepancies between MEP and MWR data; poor NPS knowledge; lack of data sharing; etc.
- TMDL includes NPS, but is limited because it is difficult to determine and manage NPS, which is still a major problem in the United States).

Japanese regulations for control of water pollution in agriculture

Agriculture is also a major source of water pollutants in Japan, causing eutrophication of lakes and reservoirs and loadings of nutrients in coastal waters. Water resources management is regulated by legislation such as the Water Pollution Control Law (updated 1996), the River Law (updated 1997), the Land Improvement Law (updated 2001), the Water Resources Development Law (updated 1983). In 1992, the Ministry of Agriculture, Forest and Fisheries (MAFF) introduced the concept of 'environmental safe agriculture'. In relation to agriculture, there are three basic laws: (i) the Law for Food, Agriculture and Rural Areas (1999) emphasizes that agriculture should play an important role in land conservation, fostering water resources; (ii) the Law for Promoting the Introduction of Sustainable Agricultural Production Practices (1999), followed by a bill partially amending the Fertilizer Control Law; and (iii) a bill for promoting proper treatment and utilization of animal manure.

There are three characteristics to Japan's laws for agriculture: **(i) the cooperation of the different laws**. The three environmental agriculture laws strengthen coordination between crop farming and raising livestock, so animal manure is effectively composted and crop soils are revitalized with organic fertilizer; **(ii) the requirement of the government and farmers according to the laws** – local governments are required to draw up their own plans to introduce sustainable agricultural production methods suited to the unique characteristics of their communities. Farmers who comply with the three laws can be certified as 'Eco-Farmers'; and **(iii) financial support and taxation measures** – these provide incentives and penalties that support compliance to these laws.

11.3 CHINESE LEGISLATION TO CONTROL WATER POLLUTION FROM AGRICULTURE

In early 2010, after several years of study, the Ministries of Agriculture (MOA) and the Ministry of Environmental Protection (MEP) jointly announced that agriculture is a major contributor to total water pollution in China, with livestock rearing being among the worst offenders. This is similar to the situation in many countries, including the United States. Existing laws such as the *Law on Soil and Water Conservation, the Water Law, the Water Pollution Prevention and Control Law, the Solid Waste Pollution Prevention and Control Law* and other environmental laws are not designed to control NPS pollution from agriculture. The Law on Agriculture is designed mainly to promote food production and is not specific about environmental protection.

Chinese laws tend to be fairly general and lack the high degree of detail contained, for example, in laws in the United States. It is only in the detailed regulations that the necessary specifics are found. For example, to combat environmental pollution caused by the livestock-breeding industry China has introduced a number of management regulations, such as *Regulations for the prevention and control of pollution from livestock breeding, Pollutants discharge standards for the livestock and poultry breeding industry, Technical specifications on pollution prevention for the livestock and poultry-breeding industry,* etc. in which a number of requirements on site selection and associated facilities for livestock and poultry farms are identified.

Livestock rearing

There is consensus in the literature, and in recent government reports, that the greatest agricultural impact on water quality in China is from intensive livestock rearing: cattle, dairy cows, swine, egg and meat chickens. The definition of 'intensive' livestock operations is based on the criterion of the number of animals that exceed the number

TABLE 11.1

Classification of 'intensive' feedlots in China and US subject to regulation

	Pigs (>25 kg)	Chickens		Cattle	
		Laying chickens	Meat chickens	Adult dairy cow	Other cattle
China Class I (Large)	≥3000	≥ 100 000	≥ 200 000	≥ 200	≥ 400
China Class II (Small)	500 –3 000	15 000 –100 000	30 000– 200 000	100–200	200–400
US (Large CAFO)	≥ 2 500	≥ 30 000[a] ≥ 125 000[b]	≥ 30 000[a] ≥ 125 000[b]	>700	>1 000
US (Medium CAFO)	750– 2 499	9 000 – 29 999[a] 25 000 - 81 999[b]	9 000 – 30 000[a] 37 500 –124 999[b]	200– 700	300–1 000

[a] with liquid manure handling
[b] with other types of manure handling
Note: there are also criteria for ducks, turkeys, sheep, etc.

TABLE 11.2

Regulations for feedlot, poultry and animal husbandry in China

Regulation	Issue/Implementation date	Description
SEPA Decree No. 9: Management methods for pollution from livestock and poultry breeding	Issue date: 8 May 2001 Implementation: 8 May 2001	Focuses on principles of recycling, reuse and reduction of animal wastes, requirements for EIA, etc.. Establishes basis for EIA, permitting, pollution fees and fines, and prohibits intensive livestock production in specified areas.
Official code: HJ/T81-2001: Technical standard for preventing pollution from livestock and poultry breeding	Issue date: 19 Dec. 2001 Implementation: 1 April 2002	Prescribes basic technical standards including: location, interior layout, waste cleaning techniques, waste storage and treatment, manure reuse, feeds and feeding management, disposal of dead animals, and monitoring.
Official code: GB18596-2001 Discharge standard for pollutants from livestock and poultry breeding	Issue date: 28 Dec. 2001 Implementation date: 1 Jan. 2003 for Class I & II feedlots in prescribed areas. For other areas, local EPBs can set the implementation date but no later than 1 July 2004.	Sets: daily maximum allowable concentration of water and odour pollutants; maximum allowable discharge volume of wastewater, and water quality standards.
Official code: HJ 497-2009: Technical specifications for pollution treatment projects at livestock and poultry farms	Issue date: 30 Sept. 2009 Implementation: 1 Dec. 2009	This standard stipulates the technical specifications concerning the design, construction, check and acceptance upon completion, and operation and maintenance of pollution treatment projects of livestock and poultry farms, based on the ongoing emission standards and pollution control technologies.
Official code: HJ 555-2010: Technical guideline on environmental safety application of chemical fertilizer	Issue date: 8 March 2010 Implementation: 1 May 2010	The standard specifies such contents as the principle for safe use of fertilizers, technical measures for pollution control and management measures. It is applicable to the supervision and management of safe use of fertilizers in planting industry. Further, it can serve as the basis for the agricultural technical department to guide scientific application of fertilizers.
Official code: HJ 556-2010: Technical guideline for environmental safety application of pesticides	Issue date: 9 July 2010 Implementation: 1 Jan. 2011	The standard specifies such contents as the principle for safe use of pesticides, technical measures for pollution control and management measures. It is applicable to the supervision and management of safe use of pesticides in the planting industry. It also can be served as the basis for the agricultural technical department to guide scientific application of pesticides.
Official code: HJ 574–2010: Technical specifications for domestic pollution control in town and village	Issue date: 9 July 2010 Implementation: 1 Jan. 2011	The standard specifies the technical requirements of town and village domestic pollution. This standard guides the supervision of domestic sewage, rubbish, and air pollution, to improve environmental quality in rural areas and promote new rural construction.

for which the waste can be effectively utilized on-farm or in surrounding areas, and is similar to that used by the US-EPA for concentrated livestock-feeding operations (CAFO). MEP, like the US-EPA, classified large- and medium-scale livestock-rearing as point sources in 2001 and these are subject to detailed regulations (Table 11.1).

The Chinese regulations are roughly similar to those of the US-EPA, which were promulgated the same year. However, in China, direct (ADB, 2004) and anecdotal evidence suggests that enforcement of these regulations is not very effective and that intensive livestock rearing continues to be a serious problem for water quality. The law on Animal Husbandry (2005) is mainly focused on the production of animals; the article (46) on control of water pollution contains no detail on how this is to be done.

11.4 OBSERVATIONS AND RECOMMENDATIONS FOR CONTROL OF WATER POLLUTION FROM AGRICULTURE

Guidance on agricultural NPS – Unlike the United States, where there is extensive technical guidance for NPS pollution control, there is very little similar guidance in China that is easily available to farmers. This publication is the first major attempt to provide guidance. However this must be supplemented by the more detailed specifications in all areas of farm production and management, and be implemented broadly by agricultural and environmental officials.

There are different requirements for guidance for small- and large-scale farms. For large-scale farms, scale and cost-efficiencies go together. Conservation tillage, rational fertilizer management and integrated pest management (IPM) should be required and enforced. For small-scale farms, without economies of scale, guidance should focus on specific issues such as efficient use of fertilizer and pesticides, good soil management practices, efficient and non-polluting use of straw and manure.

Laws and regulations – In Western countries, regulations that control water pollution are generally not very effective and are difficult to enforce. The exception is regulations that focus on animal/poultry-rearing. While China has such regulations for medium- and large-scale livestock-rearing, none specifically apply to the hundreds of thousands of small-scale animal raising activities on the family farm. As the large-scale activities are controlled, authorities will have to develop regulations that can be applied to family farms. These regulations will focus mainly on manure management and actions required to protect local watercourses.

Integrated approach to agriculture and environmental protection – The Ministry of Agriculture has primarily been concerned with food production, whereas control of pollution is vested in the Ministry of Environmental Protection. Lack of an effective approach to integrating production and environmental protection has led to a regulatory gap in dealing comprehensively with agricultural NPD pollution. The two ministries need to develop a consolidated approach to this issue, as has been done in other countries such as the United States, where the US-EPA and the United States Department of Agriculture have worked together for many years to achieve a common objective.

Education – Farmers in Western countries are well educated, with many having university degrees in agricultural science. In China, this is not the case. Policies need to be developed that will lead to the next generation of farmers being more knowledgeable of farm production, agronomy, farm management and marketing. In the meantime, small-scale farmers need hands-on training by local agricultural bureaus on topics such as fertilizer and pesticide management. This may also require upgrading the skills of county-level agricultural bureaus.

Farm size – Small or family farms are unable to adopt conservation technologies in agriculture that, generally, require larger scales to be effective. Use of fertilizer is an example where small-scale farms generally use far too much fertilizer because of the absence of a scientific approach to fertilizer management. In contrast, large-scale farms have economies of scale in which scientific farming becomes effective and fertilizing equipment is adjusted according to the need for fertilizer application to the soil.

Recently farmers have been moving away from agriculture, which can lead to the amalgamation of small tracts of land into larger, more economic farm sizes that are more suitable for scientific farming.

Incentives and subsidies – should be reconsidered for fertilizer, insofar as these result in overuse of fertilizer by farmers. On average, Chinese farmers use 25–40 percent more fertilizer than required. Elimination of fertilizer subsidies will have the effect of reducing fertilizer use to a level that is more consistent with crop requirements. In contrast, financial incentives to remove marginal land from crop production and convert it to forest or grassland is already having a beneficial impact in some parts of China and is leading to reduced erosion and soil loss.

Compliance and enforcement – Although China has a well-developed system of laws and regulations, the lack of compliance and failure of enforcement is a significant problem. In the future, as farms are amalgamated into larger units, farm owners/managers need to be made aware that they are responsible for preventing the pollution of agricultural production systems.

Land tenure – of property for long-term use means long-term interest. Under the new rural land property rights, which provide a legal basis for transfer of land for farming, long-term and stable property tenure is one of the key factors required to avoid NPS pollution from agriculture. This, however, must be backed by effective regulations.

11.5 SUGGESTIONS FOR A REGULATORY FRAMEWORK

The basis for a regulatory framework should be the concept of the circular economy as applied to agriculture. Environmental protection and economic growth in farming areas are parts of a single framework. The framework should be comprised of four main parts:

Legal definition

Article 18 of the *Water Pollution Prevention and Control Law of the Peoples Republic of China (2008)* gives the Ministry of Environmental Protection (MEP) the power to control total pollution loads. Using an accepted non-point source assessment methodology, the MEP could bring all of point and non-point source pollution loads into the framework of total load control. It would likely require considerable joint effort with the Ministry of Agriculture to develop an agricultural non-point source methodology that would be mutually acceptable. Nevertheless, the principle that total load control should contain all forms of pollution would be a forward looking step and bring agricultural non-point source pollution into the current legal framework.

Administrative actions

- **Develop an integrated national NPS pollution control strategy for agriculture:** The object of the strategy includes environment protecting objectives and economic improvement objectives. The strategy would be mainly the responsibility of the key ministries involved – MOA, MEP and MWR.
- **New policy and regulatory measures:** (i) new fertilizer and pesticide laws and regulations in which the government encourages NPS pollution reduction methods such as by setting higher quality standards for agro-chemicals and organic manures, and by establishing BMPs for dosage, timing and method of application of fertilizers, pesticides and livestock manures to crops, and (ii) stronger controls and incentives for waste discharges and recycling.
- **Improve policies for land transfer:** Under new rules, farmers or non-resident farmers and corporations can manage larger areas with long-term tenure rights. With increasing scale, responsibility for applying BMPs should also come increasing.
- **Strengthen the assessment of NPS pollution from agriculture:** A monitoring system should be established. Agricultural EIA performance indicators should be introduced into local government reporting requirements.
- **Increase public awareness of agricultural NPS pollution:** The effectiveness of regulatory control depends very much on the ability or readiness of the farming community to understand and act upon educational programmes. A certification system should be established to improve the skills of public and private extension workers and to raise the environmental awareness of all extension workers.

Economic polices

The success of NPS pollution control will depend upon a combination of regulations and economic polices.

- **Compensation for pollution mitigation programmes:** In cases where pollution control measures require change in agricultural use or land management practice, or may take land entirely out of production, appropriate compensation for farmers should be considered as part of pollution mitigation programmes.
- **Price and tax reforms for environmental protection:** Internalizing the externalities of agriculture is the key factor. It is neglected to a certain degree in the current environmental protection polices in China. For example, input taxes on the price of nitrogen fertilizer may reduce nitrogen applications. On the other hand, some supporting policies, such as tax reduction or falling land prices, can increase the profit related to the production of methane and lead to reduction of NPS pollution from the rearing of livestock.
- **Agricultural subsidies:** The entire issue of subsidies needs to be reformulated, to eliminate subsidies that encourage overuse (of fertilizers, for example), new subsidies for farmers that incur expenses in applying new BMPs, and expand subsidies for conversion of marginal farmland to non-farm uses.

Technical innovation

Western countries possess a wealth of experience in conservation farming. China needs a similar programme of innovation to determine techniques that will benefit both the farmer and the environment and that are suitable in the Chinese context. This should be a step-by-step process insofar as Western farming is quite different from Chinese farming because of its large scale, high level of technology and investment, and the high education of Western farmers. Nevertheless the principles of conservation farming are in the application. A programme is required to identify how these principles can be applied to Chinese agriculture and how these should be adapted for small versus large farmers.

A parallel programme of farmer education needs to be developed. Through education, farmers will understand how the technologies are to be used, why these make economic sense for the individual farmer, and when there is a net cost to the farmer, how subsidies can be obtained to offset the costs.

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12. Economic instruments

WANG Xiahui[1], WANG Jinnan[1], LI Zhitao[1],
HUANG Ren[2], ZHANG Huiyuan[1]

12.1 INTRODUCTION

In economic terms, water pollution caused by agriculture is an external cost to society; usually there is no direct cost to the farmer who causes the problem. This provides no incentive for farmers to mitigate pollution. Therefore, to solve this dilemma and to move the cost to the person who has caused the pollution (in this case the farmer), economic measures are required. In other words, the cost of pollution that has been generated by farmers should be part of their production costs (i.e. the external costs are internalized). This is the the principle of the 'polluter pays', which is currently applied to industrial pollution in China, where industries pay a pollution charge, and are regulated according to the amount of pollution they emit. On the other hand, those farmers that implement practices that improve the environmental services provided by their farming systems should be rewarded, and the costs of these practices may need to be compensated.

This chapter reviews the economic measures (or economic instruments) usually employed in a number of countries to regulate and control agricultural water pollution and discusses the conditions to render these measures effective. Prospects for the application of such measures in China are also provided.

12.2 TYPES OF ECONOMIC INSTRUMENTS

Subsidies, taxes, charges, prices, rewards, penalties, payment for environmental services or credits are all common measures that encourage the limitation of pollution, and influence and/or regulate production, processing, distribution and use of agricultural inputs (e.g fertilizers and pesticides). The result is that pollution is controlled and the water environment is protected (Wang, 2003). In contrast to command and control measures, in which farmers are forced to take specific steps dictated by the government, these measures are intended to be flexible so that farmers can choose the measures that best meet both their needs and the needs for water pollution control. The following are the principal economic instruments used in many countries:

Subsidies – refer to financial support to agricultural producers as an incentive to control water pollution and improve water

BOX 12.1

SUBSIDIES: In 1992, the European Union (EU) revised the 'Common Agriculture Policy', to provide a subsidy to farmers who reduced the breeding density of livestock, the amount of fertilizers and insecticides and who adopted conservation tillage methods.

To protect the environment, in 1998, the EU required that at least 20 percent of agricultural land should be left fallow; subsidies are offered to farmers for restoration of natural vegetation. It is the responsibility of farmers to convert a certain proportion of low-yielding land to ecological use. In 2000, the EU offered subsidies to farmers who adopted environmentally-friendly production methods.

1 Chinese Academy for Environmental Planning
2 Chinese Academy of Sciences, Institute of Agricultural Economics and Development

quality. Subsidies normally take the form of loans, tax deductions or exemption, or financial contribution from the government. These are used to encourage changes in production methods, or the switch to improved farm management methods.

China has always been under pressure to ensure self-sufficiency in food production. In recent years, the Chinese Government has provided many forms of subsidies for agricultural development including comprehensive agricultural development, farmland capital construction, agricultural tax deduction and exemption and industrial support. (Qiu, 2008).

To encourage food production, the government provides subsidies for the production and distribution of fertilizers, which lowers the cost to farmers. With no change in other conditions, farmers will use more fertilizers in the belief that this will lead to a higher yield. In fact, the average use of fertilizer by farmers on, for example, the North China Plain is up to 50 percent more N and P than is required to maximize yield (Vitousek *et al*., 2009), and from 30–60 percent more N than is necessary in the Taihu area with large amounts lost to the environment (Ju *et al*., 2009).

There are subsidies for agricultural production materials, in addition to fertilizer, including subsidies for chemical pesticides, power supply, water, plastic film and other agricultural materials. Subsidies for water and power can artificially lower their utilization cost, causing farmers to use an excess of these resources, which, in turn, may lead to increased water pollution. In all these cases, subsidies have a negative impact on the environment and, as for fertilizer subsidies, a negative impact on farm incomes by encouraging excessive purchase of fertilizer.

Subsidies can also have very beneficial effects when used correctly. For example, subsidizing farmer producers, either through direct subsidies, or through payment for environmental services (PES) (see below), to return marginal land to forest or grassland is beneficial. Similarly, subsidies to encourage construction of artificial wetlands and oxidation ponds, implementing eco-engineering practices, comprehensive utilization of poultry and manure excrement, all have beneficial impacts on the environment and can increase farmers' profit when used effectively.

Subsidies are a normal practice in Western countries, but are not always implemented so that negative impacts on other areas of the economy are avoided. Subsidies can lead to large price distortions that should be avoided (OCED, 1994). For example, subsidies for ethanol production from corn (maize) have led to major price rises in corn, which has negatively impacted consumers and importers of corn-based food products.

Taxes – are punitive, and are used to deter farmers and agricultural processors from using products that are polluting. In principle, the amount of tax is related to the amount of harm that the polluting activity will cause.

For example, many members of the Organisation for Economic Cooperation and Development (OECD) levy a tax on agricultural fertilizer and insecticides. A tax may be imposed on raw materials or energy use that result in water pollution; this type of tax encourages a reduction in the use of these raw materials.

Tax imposed on products can lead to producers using alternative products that are more environmentally friendly. For example, if the tax rate of normal chemical fertilizer and pesticide is higher than that of less polluting biological and micro-organic fertilizers, producers have an incentive to use these less polluting products.

Taxes normally have a dual function: they encourage people to change their behaviour and raise funds through the taxation authority. Use of taxes to control agricultural behaviour has a long history in many Western countries; China can learn from this practical experience.

BOX 12.2

TAXES: In the middle and late twentieth century agricultural development in the EU depended on large consumption of natural resources and the application of fertilizers and pesticides that resulted in groundwater and drinking water pollution and eutrophication of surface waters. Taxes were adopted as a method of discouraging poor farming practices. In many EU countries taxes were imposed on fertilizers and pesticides, which have resulted in a substantial decline in the use of these products.

In the Murray-Darling river basin in Australia salt is a major problem in irrigation water. The cost of controlling salt content is allocated to irrigators in the form of water charges.

In the Colorado river basin in the United States, reducing salinity in irrigation water costs about US\$0.15/m^3 whereas the tax on general irrigation water is only around US\$0.4/m^3 (Wang, 2003). These measures improve agricultural water-use efficiency and reduce water discharges carrying nutrients from the fields.

Examples of taxation to modify farm behaviour

- Tax based on excess nitrogen content in soil at the end of the growing period. Since the management cost is high for this type of charge it would only be applied to areas designated for protection such as for drinking water supply.
- Tax on nitrogen and phosphorus content in fertilizers sold for farm production will discourage excessive use. This includes removing fertilizer subsidies and may be combined with subsidies to encourage farmers to leave land fallow using nitrogen-fixing crops as part of a crop rotation system, or subsidies to encourage comprehensive use of manure.
- Tax on excess animals, above the carrying capacity for manure spreading on land.
- Tax on pesticides according to the environmental impacts of the active ingredients (OCED, 1994).

Charges – 'Charge to the user' or 'cost allocation' refers to the amount charged to the polluter to remove the pollution. The charge is based on the pollutant treatment quantity and the unit treatment cost. Charges are more easily applied to point source pollution, where the polluting source can be easily identified. For farm-based pollution, charges can be imposed based on estimates of pollution generated according to the farming activity, including use (or lack of use) of best management practices (BMPs), amount of fertilizer applied.

Price and credit – the market price of products and services influences agricultural production and can limit poor or stimulate good practices. Pricing strategies can be employed to encourage farmers to use 'environmentally-friendly' green agricultural products with low toxicity and high efficiency, often in conjunction with subsidies, to encourage use of such materials.

BOX 12.3

PRICING: In many large Chinese cities, vegetables are tested for nitrate and pesticide residue before marketing. Vegetables having low nitrate and pesticide residues fetch a higher price and are preferred by many urban consumers. Vegetables below the minimum acceptable standard cannot be sold, which serves as a deterrent to farmers. Pricing also serves to educate consumers about the close correlation between agricultural production activities and market prices.

Low or no-interest loans may be provided to those producers who introduce improved technologies and equipment or production methods. Pricing is also used at the consumer level to influence production methods. As shown in Box 12.3, higher prices for 'green', or 'organic' vegetables are an incentive for farmers to move to green production methods.

BOX 12.4

REWARD: In Ping Hu city, Zhejiang province, RMB20 000 is awarded to the unit or individual rated as a pollution-free production base in that year; RMB50 000 is awarded to the unit or individual issued with a 'Green Food' certificate. Both rewards, and the 'Leader' mechanism, encourage farmers to produce safe products, promote clean agricultural practices and reduce pollution of the aquatic environment from agricultural production (Qu, 2007).

Rewards and incentives – Rewards are given to farmers who excel in some aspect of farm production, or in demonstrating exceptional results from good management practices, are economic incentives.

Pollution compensation and penalties – or fines are covered within the scope of civil liabilities and refer to economic compensation to victims of pollution. Pollution fines are a kind of economic sanction imposed on unlawful acts.

Payment for environmental services (PES) – is a form of economic instrument based on the principle of 'ecological compensation'. China is a leader in the use and promotion of PES systems (Bennett, 2009). PES is based on the principle that the environment provides services to society that can be valued. These may include water pollution control, through assimilative capacity of waterbodies and natural forests or grasslands that prevent erosion. The value is based on what it would cost for a person to provide the same service or benefit.

This can work in two ways – the first is disincentive: farmers may be required to pay for the ecological damage (loss of service) caused by farm-based pollution. The second is a positive approach, where farmers are paid to change farming practices that result in improved ecological services as a result of reduced water pollution.

One of the largest such programmes in China is the Conversion of Cropland to Forests and Grassland (CCFG – *tuigeng huanlin huancao*) programme (Bennett, 2009). Compared to other incomes, ecological compensation may be limited; however it provides a stable income for the farm family (Ren, 2008).

Experience in other countries indicates that ecological payment systems are effective in modifying farmers' behaviour (Pagiola *et al*., 2006). For example, a survey of farmers in the Catskill mountains of New York State indicated that 44.3 percent were willing to implement production methods favourable to the environment because of income from watershed compensation. Another example is the Sukhomajri community in India, which compensates land owners and nearby communities for the protection of an important water source. Consequently, farmers in the areas upstream of the water source actively use ecological production methods to generate extra income from ecological compensation.

12.3 ENABLING CONDITIONS FOR USE OF ECONOMIC INSTRUMENTS

The use of economic measures is affected by the following factors:

Government and public-awareness – of food supply problems, ecological damage and environmental pollution, and the high cost to society caused by this damage, makes it much easier to promote environmental economic measures.

Acceptability of policies – Certain economic means may affect the interests of some departments, districts or groups after implementation. These interests must be recognized and constructively managed. The alternative is resistance to the measure, which may result in the measure being altered or abandoned.

Comprehensive approach – Different government agencies have their own sectoral agendas. Therefore, for economic measures to work, coordination is essential among the various interested agencies. For example, a measure taken solely to increase food production may be very negative for the environment. Economic measures should be used that optimize the benefits to all parties. In China, local government protectionism is a particular challenge to the development of optimal solutions that benefit society as a whole.

Ease of implementation – Complex measures are difficult to introduce and manage.

Fairness - Because the implementation of economic measures can result in an unfair advantage to some groups, the consideration of social fairness is an important factor. For example, if the price of agricultural water increases considerably, it will have different consequences for producers with varying scales of production. The economic measure may marginalize poor farmers, who cannot afford the increased charge and are unable to pass on this cost to consumers.

BOX 12.5

Conditions for tax application in developing countries

Although taxation of farm practices and products will have a beneficial effect on water pollution from agriculture, the application of tax policy requires careful scrutiny to ensure it does not further marginalize an already poor sector of the national population. Unlike China, the agricultural market is small in some developing countries and the commercial economy is not well developed. As in China, production is mostly by individual small-scale farmers who cannot take advantage of economies of scale.

Furthermore, many agricultural products have low commodity prices, with little elasticity of supply. Production methods, therefore, cannot be altered by use of taxation policies in the short term, especially so if they are implemented in the absence of a larger and more complete system of taxes and subsidies. Small producers should not be disadvantaged when they shift to less polluting production methods. However, for products with high commodity rates, such as vegetables and flowers, where excesses of fertilizers and pesticides are used for maximum profit, taxation is an effective means of influencing farmers to change their production to more environmentally-friendly methods.

12.4 APPLICATION OF PAYMENT FOR ENVIRONMENTAL SERVICES

In a PES system a market for environmental services is created when money is collected or re-allocated from the beneficiaries who use environmental services (e.g. water consumers) and payments (compensations) are made directly to those who provide these services (e.g. farmers or watershed land managers). Many of these goods and services are provided indirectly – that is, there is no direct link between the service provider and the consumer of the service.

Ecological compensation and PES can be applied through government and market mechanisms.

Government mechanisms

In China, the traditional approach to the provision of environmental services has been through ecological compensation payments made directly from the government to providers of environmental services.

Governments at different levels (national, regional and local) may need to adopt a transfer payment system that refers to the movement of funds between governments at all levels. The objective is to achieve a balance among the financial capacities of governments and the public and environmental services they provide. Transfer payments provide the capital base for ecological compensation. Ecological compensation or PES projects that are supported by the central government include returning cultivated land to forestland (or grassland), desertification treatment, natural forest protection and construction of shelter forest in the 'Three Norths'. At the local level, local governments are attempting to adopt flexible transfer payment policies to encourage the protection of the ecological environment. For example, the 'Environmental Protection Programme for Guangdong province' uses ecological compensation as the primary means of promoting coordinated ecological development (China Ecological Compensation System and Policy Research Group, 2007).

Special funds are also used to support ecological objectives, including water quality improvement. In recent years special funds have been established by the Ministry of Land and Resources, Ministry of Forestry, Ministry of Water Resources, Ministry of Agriculture, and Ministry of Environmental Protection to support activities that facilitate improvement of the rural environment, such as construction of rural clean energy, balancing fertilizer subsidies, improving lavatories and drinking water in rural areas, comprehensive improvement of village environments and setting up ecological demonstration models in rural areas.

Market mechanisms

The desire of local governments to have a clean source of water is a powerful incentive for investment in the protection of water sources. Increasingly common in China is a market arrangement between, for example, a polluted downstream jurisdiction and an upstream jurisdiction that has cleaner water.

In such an arrangement, referred to as water rights trading, the downstream jurisdiction purchases water rights from the upstream one. Water rights trading can also occur between different industries, where there is limited water supply and one industry is willing to sell part of its water rights because it has found a way to decrease the amount of water it requires.

This market mechanism is a powerful tool for increasing the efficiency of water use. An example in French agriculture is that of the famous French producer of Perrier natural mineral water, which invested approximately US$9 million to buy 1 500 ha agricultural land around the water source area. The company then gave this land without charge to those farmers who were willing to improve their production measures to ensure the quality of the water source. The company also provided the farmers free technical support, and compensated them for any losses related to water source protection measures (Ren *et al.*, 2008).

An example from China is that of DongYang city, in the JinHua river area in ZheJiang province. DongYang city sold the permanent water rights of HengJin reservoir in DongYang city, equivalent to about 49 999 000 m^3 each year, to YiWu city. DongYang city guarantees that the water quality will meet the current national I-grade standard for drinking water. DongYang continues to own the water, even though they have transferred the water rights. This water rights trading is beneficial to both parties, which not only optimizes the water resources allocation, but also encourages DongYang city to adopt production methods that are favourable to the protection of water quality.

Methods for determining amount of compensation

Two methods are used to determine the amount of ecological compensation. One is a method for accounting and the other for negotiation. The accounting method is based on the computed real cost for environmental service provided (environmental benefit) and/or the environment loss (value of the environmental service that is lost). During negotiation the parties concerned negotiate and agree on the level of compensation. This is related to the willingness and capacity of the parties to pay. In general both these methods are used to determine the amount of compensation.

Some specific considerations when determining amounts of compensation include:

- the value of ecological reduction of pollution is usually calculated according to the cost of providing the same level of pollution reduction through pollution treatment technology;
- the cost of preserving or constructing wetlands can be associated with the economic benefits of the wetlands (fishery, non-forest wetland products, value of wetland for flood control);
- the value of land that is converted from marginal agriculture to forests or grassland in semi-arid areas can be equated to the value of lost agricultural production over an agreed number of years from that land. More complicated calculations would include the cost of off-site erosion control measures, cost of damage from wind-blown sand, etc.;
- the value of agricultural land, in the peri-urban environment, taken for parks, windbreaks, etc. is easily calculated from recent land transaction costs between the government and land developers.

12.5 FUTURE TRENDS IN THE APPLICATION OF ECONOMIC MEASURES

Experiences in China and abroad have been gained concerning the use of economic measures to improve control of water pollution from agriculture. These are some key lessons and prospects for the future learnt from these experiences:

- The relationship between market and government compensation measures must be sufficiently integrated to ensure these two mechanisms re-enforce, rather than oppose, each other.
- The support of the government will be dominant in the protection of large rivers or important ecological areas, with a lesser role for market mechanisms for specific purposes.
- The market mechanism is becoming increasingly important for upstream – downstream situations involving specific users on medium or small rivers.
- The government will be responsible for the development of macro policies involving economic levers such as prices, taxes and subsidies to encourage farmers to adopt production methods that are favourable to the environment. The role of the market mechanism will continue to increase within this macro-environment.
- In many countries, including China, the willingness to reduce carbon emissions has increased along with concern about global warming. Further growth in the carbon trading market, therefore, can be expected. This will directly affect agriculture, and be beneficial for reducing water pollution from agriculture. To offset carbon emissions from greenhouse gases, an increasing capacity is required to permanently store carbon in trees, wetlands and in the soil. All are linked to improved agricultural production and reduced impact of agriculture on water

quality. Therefore, China needs to carefully examine the potential of carbon trading as a means of (i) improving the agricultural environment; and (ii) providing funds to farmers for improving carbon sinks. (China Ecological Compensation System and Policy Research Group, 2007; Wan, 2008; Ren *et al.*, 2008).

- In market systems, there is need for the government to improve the system through market development. This can be achieved by developing market-based regulations to govern market transactions, and by providing a legal basis on which market decisions can be supported by law.

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13. Application of guidelines in South and Southeast Asia

Edwin D. ONGLEY[1]

13.1 INTRODUCTION

This publication focuses on China, because of the Chinese Government's interest in addressing agricultural non-point source (NPS) pollution. This final chapter examines how these guidelines can apply to other South and Southeast Asian countries.

Many publications identify the status of surface and groundwater quality in the countries of South and Southeast Asia. For the most part, the quality of water reported tends to be far below the standards set out by national legislation or national plans. Most countries have legislated point source control, however, the water quality situation remains dire and is widely acknowledged as approaching calamitous proportions, as in China. Severe water pollution eliminates many beneficial uses and thereby aggravates water scarcity in countries such as Bangladesh, north and northeast China, India, Pakistan and parts of Thailand.

As the Chinese have recently established, agriculture is responsible for a large part of surface water pollution and almost exclusively is responsible for the pollution of groundwater with nitrogen. This suggests that, without an agricultural NPS assessment and control strategy, South and Southeast Asian nations will be unable to bring water quality back to standard, no matter how much money is spent on urban and industrial wastewater control.

Whereas China has carried out a national assessment of the role of agricultural contribution to total water pollution, which was completed in January 2010, similar data for other countries are less easy to obtain. Except for China, no other South and Southeast Asian country has carried out a national and comprehensive inventory on the role of agriculture in water pollution. There is, however, a growing awareness of this issue across South and Southeast Asia. A regional conference on this subject was held in 2000 in Yat Hai, Thailand, and was included within a theme area dedicated to water quality at the 2011 Rio+20 conference (UNEP, 2010).

There is a growing literature, especially in regards to water use and water pollution from rice production and, less, from rearing of livestock. There are, however, no comprehensive studies on agriculture and water pollution in any country other than China[2]. Table 13.1 contains data from many sources and may be considered indicative though not comprehensive. Notably, data on the contribution of agriculture to water pollution at national or regional levels is difficult to find and seems to be inaccessible in many countries.

1 Formerly, National Water Research Institute Environment Canada (retired; currently international consultant).

2 Web searches have not revealed national pollution surveys that contain specific information about the role of agriculture in water pollution.

TABLE 13.1

Role of agriculture in water pollution in Southern and Eastern Asian countries; no data available for countries not listed

	N in groundwater wells > drinking water standard[1] (% of samples)	BOD loads to water (%)	COD loads to water (%)	Nitrogen loads to water (%)	Phosphorus loads to water (%)	Potassium loads to water (%)	Agricultural[2] contribution to total pollution load to water (%)
China[3]	30–60	37[4]	43[5]	57[5]	67[5]		
Malaysia		20[6]					
India	20–50						
Thailand		53.3[7]		41.0[7]	49.1[7]		
Japan	86[8]						
Vietnam				60–65[9]	60[9]	60	
Philippines	30[10]						37 [11]

[1] *Relative to national groundwater standard. Not all countries use the same standard.*
[2] *Includes crops and livestock.*
[3] *A larger set of estimates for N, P, COD and BOD for China is found in Ongley et al., 2010.*
[4] *(World Bank, 2006).*
[5] *(MEPC, 2010).*
[6] *For pig farms only. (MNRE, 2010).*
[7] *Paddy field contribution to all agricultural NPS. (Charin, 2007).*
[8] *This is for the most impacted municipality of Ibaraki Prefecture. (Nishio, No date).*
[9] *Estimates of amount of nutrients not taken up by crops (MARD, 2011). Not all will runoff (Editors note).*
[10] *(Tirado et al., 2007).*
[11] *For all agricultural production, including fertilizers, pesticides and animal waste; (Tirado et al., 2008: citing the National Economic & Development Authority for the Philippines).*

13.2 SEDIMENT AND EROSION

Erosion of agricultural land, and sedimentation in rivers and lakes, is an issue that affects all South and Southeast Asian countries. Chapter 2 discusses the many ways erosion is managed (in China and elsewhere). There are, however, some unique differences in erosion management among South and Southeast Asian countries. Indonesia in particular, but also mountainous areas in for example; the Philippines, suffer from land-slipping (landslides) as a result of a combination of steep slopes, geology, high rainfall and land use.

While unstable mountain slopes may be natural, the problem is greatly exacerbated by degraded forests and forest clearing for agriculture. A key response is strong land use legislation. In countries like the Lao People's Democratic Republic (PDR) and Vietnam, swidden (shifting) agriculture by landless farmers and mountain-dwelling minority people is a major concern, especially as the rotation period for swidden clearing is reduced as the population grows. The reduction in rotation period has two major consequences – the first is permanent loss of soil fertility; the second is the inability of natural vegetation to regenerate and stabilize the cleared area on mountain slopes. Accelerated swidden agriculture is generally associated with erosion; although in Lao PDR, at least, there is relatively little direct evidence of erosion insofar as swidden-clearing leaves roots in the soil that binds soil to the mountain slope. It is this writer's observation that erosion attributed to swidden clearing, at least in Lao PDR, is in fact, caused by poorly constructed access roads in mountainous terrain. In Lao, as in other countries such as mountainous areas of Vietnam, clearing is now done by hand which leaves most of the roots in the ground; this retains slope stability and inhibits erosion. However, with the movement towards clearing of larger areas for plantations, the use of mechanized clearing by commercial enterprises not only eliminates local employment but also greatly increases erosion potential on sloping land. Governments may need to consider regulations that control use of mechanical clearing on steep lands both for erosion control and to ensure local employment.

The solution to most erosion problems is better land use through the application of best management practices. In China and Japan, and to a lesser extent in Thailand, reforestation of erodible mountain slopes has transformed erosion and sediment transport. Construction of thousands of small check-dams, together with strict land use controls in the arid valleys of the Loess Plateau of China, has measurably reduced sediment in the Yellow river and has produced new agricultural land in the sediment deposited behind the dams.

The State Forestry Administration was transformed several years ago from a forest products organization to one that focuses on forest conservation, with the responsibility for replanting and protecting an entire new generation of forests across much of the country. In Japan one can see the dramatic result of reforestation of the entire country after the Second World War. The lessons of reforestation are slowly being implemented in countries such as Cambodia, Lao PDR and Vietnam, where the environmental and social cost of erosion and sedimentation is seen by governments to be too high to allow uncontrolled deforestation.

13.3 FERTILIZER POLLUTION

Groundwater

According to the China Geological Survey, nitrate pollution of the shallow groundwater in China is widespread, almost 100 percent of water samples contain some level of nitrate and 30–60 percent of samples contain N at levels above the national standard of 20 mg/litre nitrate as N (Chapter 3). Similar observations are made in the Philippines and Thailand where 30 percent of artesian wells sampled are reported by Tirado (2007) as having NO_3^- levels that are above the World Health Organization (WHO) safe drinking water limit of 10 mg/litre of NO_3^--N, with some levels exceeding the safe limit by three times (Tirado, 2007). FAO (1996) reported that, according to various surveys, 20–50 percent of groundwater wells in India (and Africa) were contaminated with nitrate at levels greater than the WHO safe drinking water limit.

As in China, the Thai and Philippine examples of nitrogen contamination of groundwater tends to be associated with crops on which farmers apply excessively large amounts of N-fertilizer, such as vegetables, and for which the nitrogen uptake is relatively low, implying that the excess is lost to the atmosphere, to groundwater and in surface runoff. Indeed, Tirado illustrates that there is almost a 1:1 correlation to application rate of N-fertilizer and groundwater N contamination on asparagus farms in Thailand. Similar observations are published for Japan. The correlation between intensive agriculture (especially vegetables) and groundwater contamination with nitrogen is a common observation across South and Southeast Asia.

The excess use of nitrogen fertilizer is a common problem in many South and Southeast Asian countries. Least developed countries such as Lao PDR and Cambodia have no data on agricultural NPS pollution, however these countries are unlikely to have serious agricultural NPS pollution from fertilizer as they are reported to use less than the minimum amount of fertilizer required for optimal crop growth (USDA, 2010). Farmers in the Lao People's Democratic Republic, for example, used only 9.1 kg of fertilizer (N+P+K) per hectare of arable land in 2000 (WRI, No date); this compares with 256 kg/ha in China (WRI). Nevertheless, local officials describe local pockets of pollution from plantation agriculture (rubber, cassava, oil palm).

Implications for South and Southeast Asia

Because the geochemical dynamics of nitrogen in soil and water are similar in south China and in the rest of South and Southeast Asia, the guidelines for managing nitrogen-fertilizer, especially for rice, are generally applicable to South and Southeast Asia. There will be specific differences, as there are within China, of N-fertilizer application that depends on the crop and on the cultivar being grown.

More important for off-field impacts than fertilizer management for rice is the way in which paddy farmers manage water, however this is just as true in China as in the rest of South and Southeast Asia. It has been shown that the 'System of rice intensification' (SRI) as practiced in China and in many other South and Southeast Asian countries can increase rice yield by 50–100 percent, while at the same time reducing the amount of water used by 50 percent or more, and reducing the amount of fertilizer and pesticides applied. The result is economic gain for the farmer and environmental benefits from reduced leaching and runoff of N, P and K.

Common problems of fertilizer use in China and South and Southeast Asia

These guidelines address a variety of common problems shared by all South and East Asian countries, except Japan:

- widespread and false belief among farmers that if some fertilizer is good, then a lot more fertilizer is better;
- farmers lack education on suitable application of fertilizer (amount and scheduling);
- poor understanding of the benefits of combining organic (manure) and inorganic fertilizers as part of a complete fertilizer and soil management strategy;
- limited understanding of alternative water management techniques that reduce total water used and reduces runoff and environmental impacts;
- farmers' poor understanding of the magnitude of loss of fertilizer and the cost in terms of lost income;
- farmers' lack of understanding of the environmental and public health consequences of overuse of fertilizers;
- governments' increasing understanding of the role of excessive fertilizer use in surface and groundwater quality problems including drinking water, eutrophication of surface waters (rivers and lakes), marine red tides, and negative impacts on aquatic biodiversity.

13.4 PESTICIDES

Improper handling, dosage, and disposal of pesticides are major problems in many South and Southeast Asian countries. For paddy rice and major crops, the situation in China (Chapter 4) is mirrored in other South and Southeast Asian countries and best management practices will reduce the probability of off-site environmental impacts. There are, however, some exceptions. In many of South and Southeast Asian countries dryland rice is grown either under permanent upland farmland or as swidden agriculture. In swidden agriculture, natural vegetation is eliminated by heavy use of herbicides such as paraquat, which is highly toxic and is highly persistent in sediments and soils.

FIGURE 13.1
Recently cleared land for swidden agriculture, the Lao People's Democratic Republic.

Photo: © E. Ongley

Where rainfall in swidden areas causes soil erosion, paraquat is moved downhill, into surrounding paddies, and then into adjacent watercourses.

Paddy farmers in Lao PDR, for example, complain of impaired paddy rice and fish kills in paddies from, it is assumed, the transfer of herbicides from upland areas.

13.5 ANIMAL WASTE MANAGEMENT

Management of animal waste is a major problem across South and Southeast Asia. As Asian populations increasingly eat more meat and dairy products, animal husbandry has grown considerably across South and Southeast Asia. In parts of China, it is estimated that animal waste has become a larger contributor to water pollution than that of fertilizers (Yang *et al*., 2012). For example, one pig excretes as much pollution as 7–9 adult people yet little of this is controlled and much enters into nearby watercourses. In part, the growth of animal-related water pollution arises from the growth of livestock production across all of Asia, as shown in Table 13.2

TABLE 13.2
Percent growth in livestock in selected South and Southeast Asian Countries, 1981–2000

Country	Pork	Beef	Chickens
Cambodia	15.0	8.3	8.2
China	6.2	14.3	10.1
India	3.8	2.7	8.2
Indonesia	7.2	2.8	7.2
The Lao People's Democratic Republic	3.5	9.0	4.8
Rep. of Korea	5.9	8.0	7.5
Philippines	4.0	No date	7.0
Thailand	No date	3.2	6.8

Source: FAO, 2002

Combined organic and mineral fertilizer schemes offer a useful way of recycling animal manure back into the soil, where it adds carbon, slow-release nutrients (N, P, K) and many micronutrients required for healthy crops. This reduces the cost to farmers of mineral fertilizer.

Most important, is the siting of manure storage facilities. In China, small- to medium-size feedlots tend to be inappropriately located near watercourses to facilitate cleaning. Manure storage requires specific design criteria so that the manure is contained and cannot runoff when there is rainfall.

In China, as in many other countries, the problem of animal waste is increasingly linked to family and village/community animal production. These tend to be unregulated and, where regulated, difficult to enforce. As livestock rearing becomes increasingly commercial and large scale, the Chinese example suggests that industrial scale animal raising is less of a water pollution problem insofar as animal waste is a resource from which commercial livestock companies generate biogas and organic fertilizer, and create additional profit for their enterprise.

Chapter 6 provides an extensive analysis of this issue and which has useful application across South and Southeast Asia.

13.6 AQUACULTURE

Throughout South and Southeast Asia aquaculture is a major source of protein and of income from commercial species. However, as seen in China (Chapter 7 provides more details), caged fed-aquaculture in lakes and reservoirs has resulted in serious pollution issues. Caged production is increasingly being reduced or banned in many Chinese lakes and reservoirs. However, banning of caged fish production is only one component of aquatic pollution; good decision-making on nutrient control requires a balanced approach in which the mass balance of N and P from different sources is known. These sources may include (municipal and industrial wastewaters, nutrient runoff from land-based agriculture, fed-aquaculture, and nutrients contained within lake bottom sediments 'internal load'). With knowledge of mass balance from these various sources, the different options for pollution control can be evaluated for effectiveness relative to cost.

Intensive caged crab culture, found in wetlands in many areas in China and in other countries, may pose a direct threat to aquatic habitat and an indirect threat of water pollution. Crabs feed on submerged plants and, when excessive stocking occurs which is typical of most caged crab compounds, can lead to total destruction of the submerged vegetation. In turn, this contributes to the degradation of water quality because aquatic vegetation can no longer assimilate N and P. This can lead to an excessive amount of these nutrients in the water that can induce algal growth that can turn a lake from a macrophyte-dominated system to an algae-dominated system. Natural lakes and wetlands should have an abundance of macrophytes which keep algal dominance from occurring. Once algal dominance has occurred it is almost impossible to re-establish macrophyte dominance as demonstrated in many Chinese lakes that now suffer annual algal blooms resulting in economic loss and danger to public health. In China, many wetlands have been totally destroyed by unsustainable crab culture. The challenge is to convince crab raisers that a sustainable crab culture is in their long-term economic interests. This means controlling crab populations so that a balance is maintained between predation and growth of aquatic vegetation.

Pond aquaculture becomes an environmental problem when ponds are cleaned with no care and the contaminated bottom sediments are flushed into adjacent watercourses. This releases nutrients (from excess feed + fish excreta + N&P in pond sediment) and drugs used in pond aquaculture. Because ponds require cleaning from time to time, it is preferable to put the pond water onto fields (green filters) so that the nutrients are used in crop production. Pond sediments are rich in organic matter and add fertility to the soil.

Good management practices ensure both development of the fishery and protection of the surrounding aquatic environment. These practices include:

- Sustainable biomass of fishery products (fish, crabs, etc.). This must be established for each water body, according to its carrying capacity.
- Rational planning of caged aquaculture to prevent eutrophication of local waters.
- Standardized feed inputs by: (i) selecting of the correct type of feed; (ii) carrying out feeding using best practices, including avoidance of excessive amounts of feed.
- Correct use of drugs for prevention and control of fish diseases.
- Creation of non-infected aquaculture areas by using modern breeding techniques and control of fish diseases so that use of drugs is minimized.
- Use of water recycling for industrial-scale aquaculture so that contaminated water from fish pens is treated and reused.
- Avoid flushing pond water and sediments directly into nearby watercourse.
- Promote integrated farming (e.g. integrated aquaculture-agriculture), which ensures that waste from one sector becomes inputs to another and, thus, the use of resources is optimized and pollution reduced

13.7 RURAL LIVING

Control of water pollution from rural living (Chapter 8) depends upon the particular environment of the village and the activities that occur in each village. Water pollution from rural villages includes human waste and rural sewage (including solid and liquid excreta), farm animals that are kept in villages, solid waste from domestic life, and chemical wastes associated with fertilizers and pesticides that are kept in villages. Rural sanitation is often overlooked by central governments, leading to public health problems in rural areas from contaminated drinking water, exposure to agricultural chemicals and to toxic compounds found in solid waste (such as mercury that is released from broken compact fluorescent lights [CFL] that are now used in all villages (Matson, 2009).

The hydrological environment is an important factor in the role of rural living in water pollution. For example, in northern China, villages are often located far from watercourses because of the semi-arid nature of this part of China. In southern and coastal areas where there are many water courses, villages tend to be located on, or near river channels. In China, Lao PDR, Vietnam and other south Asian countries, in small villages, much of the human waste goes directly into the ground via latrines, pit toilets or septic systems that leach wastewater back into the soil. In larger villages and, in particular, those villages located near watercourses, human waste is often ejected directly into the watercourse via street drains or small canals.

When national governments begin to focus beyond large urban areas and industry for pollution control, as in China, rural living comes under scrutiny. There is no single solution for controlling water pollution from rural agricultural villages. In China as well as in other south Asian countries, the solutions include:

- Centralizing cottage industries that are often found in rural villages, into one central location so that their wastes can be managed cost-effectively in a communal treatment system;

- Collection of domestic wastewater into decentralised or communal systems;

- Implementation of cost-effective wastewater treatment systems, easy to operate and maintain and with a clear cost recovery strategy for operation and maintenance. This may include:

    - o installation of household biogas reactors that transform domestic solid and liquid waste into biogas for cooking, and a residual sludge that makes an excellent fertilizer,

    - o in areas with wetlands, the use of a controlled or constructed wetland for assimilating domestic wastewater. These wetlands can be used for productive purposes such as for fish, flower growing, etc..when wastewater is pretreated,

- Composting of organic wastes into fertilizer,

- Organized and controlled land-fill for solid wastes, including control of used pesticide containers and disposal (not burning) of styrofoam,

- Collection and disposal of out-of-date or unused agricultural chemicals, and of common appliances such as batteries, light bulbs, etc., that contain toxic chemicals,

- Recycling of scrap metal, wood, etc., where these can be reused.

Rural sanitation is effective when it is well organized, and when village residents have been informed of the importance of this issue. Organized rural sanitation can be cost-effective when it involves resource recovery and reuse, such as generation of biogas, composted biosolids, or nutrient reach waters, as these all provide benefits for the community through cheap energy, soil conditioners, organic-rich fertilizer, and reduced health costs due to a cleaner and safer rural environment.

13.8 CHALLENGES FOR SOUTH AND SOUTHEAST ASIA

As South and Southeast Asian countries increasingly address point source pollution, the balance will shift towards non-point sources, especially from agriculture. This is the recent experience in China. Other South and Southeast Asian countries have the advantage of learning from the Chinese experience and taking preventative action through policy, regulation, education and research. The creation of these guidelines leads directly to the following issues that need attention in South and Southeast Asia.

BOX 13.1

Export coefficient – describes the pollutant load delivered to edge of stream (EoS) as mass per unit area (usually kg/ha/yr) from a particular land use and is based on empirical studies of transit losses or from measurements of nutrient loads at EoS (Johnes, 1996; AERC, No date; as cited in Ongley *et al.*, 2010).

The export coefficients, especially in North America, are based on more than 40 years of research at different scales of land use and crops, and chemical/sediment runoff. These observations are summarized in the 'MANAGE' database. This method is generally used at the basin scale.

NPS assessment

There are formidable challenges to applying a variety of 'Western' NPS assessment methodologies. First, these methods were developed under Western agricultural and land use situations that are very different to agronomic practices in South and Southeast Asia. In particular, the 'export coefficient' model (Johnes *et al.*, 1996) is gaining favour because of ease of use and robustness (good results under a variety of conditions). Export coefficients for the United States are available from the 'MANAGE' database (Harmel *et al.*, 2008). This model has useful applications in Europe, the United States and Canada, and has been used extensively in China.

Problems exist, however, in applying this approach in China and elsewhere in South and Southeast Asia in that the export coefficients in the literature reflect Western, not South and Southeast Asian, agronomic conditions. For South and Southeast Asia, there are commonalities in areas such as paddy rice, cotton, maize, etc. for which a South and Southeast Asian database of export coefficients would allow all governments to better assess NPS pollution from agriculture and to take cost-effective policy and regulator measures. The coupling of such a regional database with global information system (GIS) tools would create a very effective South and Southeast Asian NPS assessment tool.

Many other models are used for NPS assessment (see Ongley *et al.*, 2010 for a list of models), however, most of these are data-intensive models require real-time data for the simulation of the processes of rainfall, runoff, and chemical runoff.

Information

- Comprehensive analysis of the role of different agricultural activities and their role in national water pollution is essential if national governments are to develop meaningful and cost-effective policies and technical interventions that target the right problem at the level of intervention that is effective. The realization in China that livestock, not rural living, is the major agricultural contributor to water pollution, was accepted only a few years ago.

- Regional differences in the role of agriculture in water pollution need to be assessed, especially in large countries with regional differences in climate. Policy responses in such instances need to be flexible to deal with geographical differences in type and intensity of agricultural pollution.

Policy and legislation

- Agricultural NPS pollution is highly variable, depending both on climate, land

and agronomic factors. Much has been written on the role of fertilizer in water pollution in many South and Southeast Asian countries, but little is known if this is, in fact, the most serious agricultural pollution problem. In China, until recently, this was the case. Yet, recent studies show that animal husbandry has much more impact than fertilizer pollution in those large areas in China where runoff is low. The policy importance is that policies should adopt a flexible approach so that policy options are focused on the most important agricultural NPS issues.

- South and Southeast Asian countries need comprehensive agricultural strategy that includes pollution control. These should include coherent and cost-effective policy choices and regulations that target those parts of agriculture that can be realistically controlled by legislation. Other areas of agriculture are not amenable to control by regulatory measures. For example, regulating the amount of fertilizer a farmer can apply is unlikely to be effective. Regulating the livestock industry can be effective, as are regulations that control how wastewater can be used in agriculture. In most countries, the problem is enforcement, not legislation.

- In China, the Water Pollution Prevention and Control law (as amended in 2008) gives the environment agency the power to establish total pollution load control at the administrative level (i.e. by provinces and lower administrative areas). While this provision was enacted with a view to controlling point source waste loadings, it could also be used to include the estimated NPS load from agriculture as part of the total load control strategy. Those South and Southeast Asian countries that have similar provisions could, with the use of a regional NPS assessment tool (discussed above), make administrative managers responsible for managing the entire range of point and non-point source pollution. In those countries in which administrators are assessed annually on their environmental performance (as in China), this would be a powerful way to include agricultural pollution control in the total pollution management scheme.

- Policies that encourage the use of organic fertilizer together with mineral fertilizer have both economic and agronomic benefits.

- Legislation that controls medium- and large-scale livestock operations (feedlots) is effective, if enforced.

- Countries that have not adopted wastewater reuse legislation in agriculture should do so, both as a water-saving technology and to protect the health of farmers and consumers.

Institutional arrangement

In most South and Southeast Asian countries and in China, ministries of agriculture are responsible for food production, whereas ministries of environment (water and environment; natural resources and environment) are responsible for pollution legislation and control. Generally, there is a lack of shared responsibility for pollution from agriculture – partly because this is a relatively new issue, and partly because vertically managed institutional responsibilities have been cemented into the legislative and institutional framework for a very long time.

In smaller countries such and Cambodia and the Lao PDR, governments are small enough that officials tend to know each other; therefore, crossing institutional boundaries can be relatively easy. In large countries, traditionally vertical management of government agencies makes it more difficult to implement cross-ministry cooperation, especially when the main laws are written to provide the power essential for each ministry to carry out its core functions (as in China).

The transition from vertical cooperation to horizontal cooperation generally comes from an empowered public that holds government accountable for social and environmental progress, a court system that allows stakeholders to challenge government departments for not doing their job, and easy access to information by stakeholders (and the public).

In countries with strong ministerial mandates, and low levels of inter-ministerial cooperation, the policy framework should be oriented towards '*divided responsibilities*'. This is in contrast to '*shared responsibilities*'[3]. The former reflects a policy framework wherein the responsibilities for NPS pollution control are allocated both in law and in policy, to the institution that is chiefly responsible. The latter occurs in, for example, many western governments and in small countries where cross-ministry cooperation is easy and effective.

For example, ministries of environmental protection would generally be responsible for setting national pollution control strategies, norms, methodologies, for monitoring water pollution, for oversight of the national pollution control agenda, and for publishing environmental information; agriculture departments would have specific responsibility for all aspects of on-farm management so that off-farm environmental impacts are within national targets; 'local' governments would have the responsibility for ensuring that total pollution (point and NPS) in their territory does not exceed a total load that is established under a national planning system[4].

Education and awareness

- Countries that have relatively successful control over agricultural water pollution generally have strong farm outreach programmes operated by agricultural departments. In South and Southeast Asia, farm extension programmes tend to focus on production, not on conservation and pollution control. In part this reflects that agricultural extension workers are not well informed about agriculture and water pollution and are more focused on production rather than conservation.

- Farmers in many countries are concerned about their surrounding environment, especially when it directly impacts on their health and/or income. Education in fertilizer use is a high priority given the economic loss to farmers and the impact on the environment. Programmes such as integrated pest management (IPM) in China have demonstrated that farmers recognize the benefits.

- In South and Southeast Asian countries, where there is seasonal or permanent aridity, education in agricultural best management practices produce benefits in soil tilth, increase soil fertility, reduce water loss, and reduce erosion and sediment + fertilizer runoff.

- Farmers need to know the impact on their incomes of irrational fertilizer use. Focusing on economic benefits is likely to be more appealing to farmers than off-farm.

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3 This concept was originally articulated by Si Zhizhong, of NREM International. (personal communication).

4 This would apply to those South and Southeast Asian countries where provincial/state governments have specific responsibilities for implementing the national pollution control agenda.

- The general public have little idea of the role agricultural plays in water pollution. This aspect should be part of government campaigns to educate the public about the sources of pollution.

Knowledge and research needs

- Development or adaptation of non-point source assessment models that reflect agronomic realities of each country are urgently needed. It is likely that there will be considerable similarity between many South and Southeast Asian countries, however, it is clear that use of 'Western' models without extensive research into calibration issues will produce false numbers. As noted above, a regional NPS assessment 'tool' would be useful across most South and Southeast Asian countries.

- Export coefficients need to be researched at various scales (from field level to medium-sized catchment) so that a national (or regional) database of reliable export coefficients can be developed.

- Combining GIS with NPS assessment tools can generate maps that identify hotspots of agricultural water pollution. This reduces reliance on interpreting water quality monitoring data in order to identify problem areas, and focuses government attention on those areas that produce the highest levels of surface and groundwater pollution.

- Investigations are needed into standard hydrological models so that they include the unique rainfall-runoff interactions in South and Southeast Asia, especially in the context of bunded[5] fields that are found in many countries. New concepts, such as 'threshold' runoff need to be defined that allow modellers to link rainfall with runoff from bunded fields and from paddy overflows resulting from rainfall.

- The role of animal waste in water pollution is known to be serious in many South and Southeast Asia countries. What is less well known is how to accurately assess the contribution of animal waste to water pollution. In contrast with North America and Europe where the rearing of livestock is highly regulated, in South and Southeast Asia animals tend to be raised at the level of the family farm where there are few, if any, pollution control requirements. Without the ability to assess individual and community (village) feedlots for their role in water pollution, governments are unable to develop focused and cost-effective policies or control measures.

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5 Fields that are surrounded by low berms to hold irrigation water or, in dry areas, to retain rainwater.

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Annex. Agricultural water management in Asia[1]: challenges and options

CHEN Zhijun[2]

1. TRENDS AND CHALLENGES

The trends of continuous population growth, economic development, urbanization, globalization, and climate change, bring multiple challenges to irrigation and agricultural water management in Asia, including:

Water competition: Asia is the home to the largest portion of the world's undernourished population. In 2006, a total of 559.1 million people in Asia were undernourished, accounting for 13.7 percent of the regional total population and 66 percent of the world total undernourished population (FAO 2010). Food security is a regional concern. FAO projects that by 2050, rising population and incomes will result in a

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1 Asia in this paper refers to the following sub-regions and countries:

Middle East–Western Asia

Arabian Peninsula:	Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen
Caucasus:	Armenia, Azerbaijan, Georgia
Iran:	Islamic Republic of Iran
Near East:	Iraq, Israel, Jordan, Lebanon, Occupied Palestinian Territory, Syrian Arab Republic, Turkey
Central Asia:	Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan

Southern and Eastern Asia

South Asia:	Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
East Asia:	China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea
Mainland Southeast Asia:	Cambodia, Lao People's Democratic Republic, Myanmar, Thailand, Viet Nam
Maritime Southeast Asia:	Brunei Darussalam, Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore, Timor-Leste

2 Irrigation and Rural Infrastructure Engineer, FAO Investment Centre Division, Viale delle Terme di Caracalla 00153, Rome, Italy, zhijun.chen@fao.org

70 percent increase in global demand for agriculture production; from a 2009 baseline this will need to be a 100 percent increase in low- and middle-income countries; and most future growth in crop production in developing countries is likely to come from intensification, with irrigation playing an increasingly strategic role through improved water services, water-use efficiency improvements, yield growth and higher cropping intensities (FAO 2011). As water scarcity and water competition is spreading in this region, room for increasing agriculture water allocation will be limited and will be a source of conflict amongst productive sectors (e.g. industry and urban water use). One of the most commonly used measures of water scarcity is the 'Falkenmark indicator' or 'water stress index'. If the amount of renewable water resources in a country is below 1 700 m^3 per person per year, that country is said to be experiencing water stress; below 1 000 m^3 it is said to be experiencing water scarcity; and below 500 m^3, absolute water scarcity (Falkenmark 1989). Currently, most Middle East countries plus some Central Asia countries are already under water stress, and some South Asia and East Asia countries, including China are already very close to water stress. Experience in recent years shows that with rapid economic development and urbanization, the priority of water allocation in rapidly developing countries increasingly shifts to domestic and industrial use; and the percentage of water allocated for agriculture declines (Table 1). This trend is expected to continue in the coming decades. Therefore, FAO projects that by 2050, the harvested irrigated area will need to increase by 17 percent while agricultural water withdrawals can only increase by 10 percent (FAO 2011). Agriculture will have to produce more food with less water.

ANNEX TABLE 1
Percentage of Agricultural Water Withdrawal in Selected Countries (%)

	1978-1982	1983-1987	1988-1992	1993-1997	1998-2002	2003-2007	2008-2012
India	93.93	94.09	92		91.48		90.41
Sri Lanka			96.01		92.24	87.34	
China	88.17	86.3	83	77.6		64.61	
Myanmar		98.58			88.99		
Indonesia			93.14		81.87		
Malaysia			82.02		45.16		

Source: FAO AQUASTAT online database, 2011

Agriculture diversification. Agriculture systems in Asia are shifting from traditional sustenance model to more diversified food security, incoming generation and rural livelihoods improvements. This is especially obvious in Southern and Eastern Asia where farmers are shifting from mono rice cultivation to more diversified and market-oriented cropping activities. A good example can be found in China, where the rice cropping area declined by 3.88 million ha (-11.7 percent) from 1984 to 2006 while vegetable cropping area increased by 15.39 million ha (+312.4 percent) during the same period, and orchard area increased by 7.9 million ha (+356.2 percent) (Liang 2006). In some areas, diversification goes beyond cropping to fishery, livestock, forestry and even more composite models. These require irrigation and agriculture water management systems operated for multiple purpose and provide more reliable and flexible water services. This brings new challenges to most of the existing water supply systems that were originally designed mainly for food production under rigid irrigation scheduling.

Demographic transition. Sustained economic growth and urbanization in Asia has been accompanied by significant demographic transition. Large numbers of farmers have emigrated from rural areas to urban areas. Populations in rural areas of some countries, such as Malaysia, Indonesia and the Philippines, have decreased in the recent 10 years. Around 100 million farmers in China move to city areas seasonally for short term jobs. Farm households are also diversifying their income sources outside of agriculture. This has triggered a series of changes in farming pattern and style, and brought new challenges to irrigation and agriculture water management systems. As a result of migration from rural to city areas, farm households are becoming older and more likely to be headed by women. This causes difficulty in rural labour markets and the increase of labour price in rural areas, and has a significant impact on irrigation design, construction and management. Innovations for labour-saving and cost-effective irrigation practices are expected. The decline in numbers of active farmers may require, or facilitate, land consolidation and bring in larger scale and more efficient farming including industrial scale farming. In turn, this will require changes not only in farming practices, but also physical changes and institutional adjustments for management of irrigation systems.

Climate change. Future trends of climate change in Asia have been projected in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), including: acceleration of warming; rising sea levels and melting of glaciers; increase in annual precipitation in most areas during this century with decreased summer precipitation in West and Central Asia, and decreased precipitation in South Asia from December to February; increase in occurrence of extreme weather events including heat waves and intense precipitation events in South, East and Southeast Asia. Accelerated glacier melting is likely to increase the number and severity of glacial melting-related floods, and decrease river flows as glaciers recede. Freshwater availability in Central, South, East and Southeast Asia, particularly in large river basins such as Changjiang, is likely to decrease. Projected sea-level rise is very likely to result in significant losses of coastal ecosystems, and a million or so people along the coasts of South and Southeast Asia will likely be at risk from flooding. Saltwater intrusion in estuaries due to decreasing river runoff can be pushed 10 to 20 km further inland by the rising sea level (IPCC, 2007). Vulnerability to climate change varies across geographic areas and social groups. The Hindu Kush Himalayas, the mega deltas in the Asian coastal zones and the small Island Countries are the most vulnerable. Overall, agriculture water management will face increasing water demand, reducing water availability and intensifying water disasters. The resent rush to bio-energy production may add more pressure on land and water resources, and bring additional challenges.

Decentralization and participation. The trend of decentralization of operation and management responsibilities of public irrigation systems and participatory decision-making started from the second half of 21st century has resulted in irrigation management transfer (IMT), participatory irrigation management (PIM), and water users associations (WUAs) in transitional economies like China, Viet Nam and Mongolia, and in other developing countries such as Cambodia, the Philippines and Indonesia. While relevant operation and management responsibilities of large number of irrigation systems have been transferred to lower level government units, WUAs, contractors and individual farmers, over a short period of time, the trend is expected to continue in the coming decade. Challenges to government departments include how to combine institutional reform with physical improvement and technical innovation, identification of proper transfer policies and procedures, strengthening of relevant capacity building, and providing continuous assistance to WUAs and irrigation farmers to ensure smooth transfer and full functioning of WUAs. Challenges have also been brought to those new operators and managers on how to adopt proper operation and management strategies and improve their capacities to ensure sustainable operation and good performance of the systems.

Water pollution. Water pollution from agriculture is directly related to water management in agriculture. Comprehensive estimation of the magnitude of water pollution from agriculture in Asia remains limited so far. The Chinese Government in February, 2011, announced after a three year study, that agriculture was responsible for about half of the COD and ammonia pollution in Chinese surface waters. Traditionally, water managers have tended to focus on fertilizer runoff from fields, however in China the evidence suggests that animal raising can be the most polluting agricultural activity.

In Thailand, Charin (2007), citing a government study, has reported that, among all the agricultural non-point source water pollution, water discharged from paddy fields is a major source and is responsible for 53.3 percent of BOD, 41.0 percent of total nitrogen, 49.1 percent of total phosphorus, and 7.6 percent of total pesticides. In the Philippines, Tirado *et al.* (2008), citing the Philippine National Economic Development Authority (NEDA, 2004) reports that 37 percent of total water pollution originates from agricultural practices and includes animal waste, and fertilizer and pesticide runoff.

Green economy. Competitive water use and segmented water resources management resulted in rapid water degradation in Asian's river basins in terms of both quantity and quality, and brought negative impacts to local environment and ecosystems. In Indonesia, the number of degraded river catchments increased from 22 in 1984 to 59 in 1998. In China, Republic of Korea, India, Malaysia and Philippines, water quality is a growing concern. In Viet Nam and Thailand, mangroves and coastal reefs were destroyed by shrimp farm contamination. Agriculture water management is mainly responsible for irrigation induced salinization, waterlogging and methane emission from paddy fields; and is partly responsible for groundwater depletion, drying up of river courses, agriculture non-point source pollution and transmission of water born diseases. The new global trend of green economy aims to the establishment of a system of economic activities related to the production, distribution and consumption of goods and services that result in improved human wellbeing over the long term, while not exposing future generations to significant environmental risks and ecological scarcities. This will require agriculture irrigation to improve water and energy use efficiency, and watch its water footprints, ecosystem footprints and carbon footprints, and water pollution impacts. It will not be achieved unless integrated water resource management is adopted at the river basin level and agriculture water management is fully integrated into river basin water resources management.

2. OPTIONS AND INITIATIVES FOR IMPROVED WATER MANAGEMENT IN AGRICULTURE

Various options for improving agriculture water management in Asia have been proposed and initiated by different stakeholders in recent years, which can be categorized as:

Improvement of irrigation systems and performance Two options have been advocated and practiced for addressing water scarcity and poor system performance, i.e. water saving irrigation and irrigation modernization. Water saving irrigation is mainly advocated and implemented in water scarce countries such as China, Pakistan, India and the Middle East. China adopted comprehensive strategies in promoting water saving irrigation since the 1980s, including establishment of various demonstration projects, improvement of large and medium scale irrigation systems, formulation and implementation of relevant policies, plans and technical guidelines, and has achieved good progress. In the past three decades, total effective irrigation area in China increased by 11.5 million ha, while agriculture water withdrawal maintained zero increase, which was mainly achieved by through increasing national irrigation efficiency from 30 percent to 51 percent (Chen, 2012a). This trend will continue in the coming decade. According to the government plan, by 2020, nation irrigation efficiency will be further increased to 55 percent; irrigation area will be increased by 6 million ha; while total agriculture water withdrawal will remain unchanged (Chen, 2012b). Traditional concepts of irrigation efficiency counts all water amounts not directly consumed by crops, such as seepage, percolation and runoff as pure 'losses'. These 'losses', however, move back into the hydrological system through percolation to groundwater and by runoff to watercourses and become available for other uses; therefore, since 2000, the World Bank proposed and practiced 'real water savings' in China to estimate the irrigation water amount which can be actually saved and reallocated for other purposes.

FAO has been promoting improved irrigation system performance in this region through on-farm water management, institutional reform, and irrigation rehabilitation, and has developed practical tools for benchmarking (RAP[3]) and modernization planning (MASSCOTE[4]); formulation and dissemination of relevant training materials; and implementation of regional capacity building programme. The objective of irrigation modernization is to capture the synergies amongst irrigation reliability, flexibility, equity, productivity and sustainability, which requires systematic strategies to address institutional, physical and technical issues.

Utilization of rainwater, flood water and non-conventional water resources: Where water conditions limit normal irrigation development, opportunities may be explored in rainwater harvesting, flood water utilization and non-conventional water resources. Water harvesting can be applied in areas where annual precipitation is above 250 mm; and has a long history in Asia. Combined with low-cost deficit irrigation technologies, it can benefit rain-fed agriculture production in arid, semi-arid and seasonal drought areas. China experienced large scale water harvesting and deficit irrigation development at the end of last century. By 2006, a total of 30.4 billion square meters of water harvesting area were developed, with 10.3 million various water storage facilities, and an annual water harvesting capacity of 4.5 billion cubic meters, providing deficit irrigation to 2.89 million ha of farmland (Tang, 2009). Non-conventional water resources, such as treated waste water, sea water desalinization and low-quality groundwater also contribute to irrigation development however their financial and environmental implications need to be further studied.

Integration of water and agronomic options: A good combination of water and agronomic options can improve both water and agriculture productivity while conserving local environment and ecosystems. Examples include water saving irrigation for paddy fields, integrated water and nutrition management, Conservation Agriculture (CA) and the System of Rice Intensification (SRI).

- CA is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment (FAO 2010). It is characterized by three linked principles, namely continuous minimum mechanical soil disturbance, permanent organic soil cover, and diversification of crop species grown in sequences and/or associations; and can improve soil water conservation and water quality, reduce soil erosion and water pollution, and reduce the maintenance costs

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of water facilities. By 2000, CA practice area reached 1.33 million ha in China and 1.3 million ha in Kazakhstan (FAO AQUASTAT 2011).

- SRI is a methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients. It involves careful planting of young seedlings (8-12 days old) singly and with a wide spacing (25 cm or more), keeping the soil moist but well-drained and well-aerated, and adding compost or other organic material to the soil as much as possible. Practices in 42 countries in the world from 1999 to 2000 shows that it has the potential to increase rice yield by 50 to 100 percent, reduce seed requirement up to 90 percent, save irrigation water amount by 50 percent or more, and reduce the application of chemical fertilizers and pesticides. During the past 10 years, SRI was practiced in 21 countries in Asia (SRI-Rice, 2010), including China, Indonesia, Bangladesh, Laos, Cambodia, Indonesia, Nepal, Myanmar, the Philippines, Sri Lanka, Thailand, Pakistan, Vietnam, Bhutan, Iran, Iraq, Afghanistan, Japan, Timor-Lest and DPRK. In 2008, SRI expanded to 204 000 ha rice area in Sichuan Province of China, which reported an average yield of 9.4 tonne per ha (22 percent higher than with present practices). With the regional and global trends on green economy and sustainable development, it is obvious that these options will be further expanded in the coming decades.

Water pollution control: Most water pollution from agriculture is related to water management practices (irrigation, flushing animal wastes with water, etc.); water is the vector by which nutrients and contaminants are moved into watercourses and to the groundwater table. With the exception of industrial or large, animal-raising facilities, few countries have legislated broadly based controls on water pollution from agriculture. This is because, as a non-point source, water pollution from agriculture is extremely difficult both to measure and to control, and laws that attempt to control this are not enforceable. It is necessary to summarize and disseminate good water management practices to reduce agricultural runoff and agriculture chemical inputs, and strengthen water resources protection. Certain types of legislation are effective, including prohibition of animal raising directly on the banks of watercourses, prohibition of spreading of manure on frozen ground (which runs off during snowmelt periods), and enforcement of manure management regulations to prevent excessive leaching of, especially, nitrogen, into the groundwater.

Climate change adaptation and mitigation: In the context of changed climate, the planning, design, construction and management of agriculture water management systems needs to be reviewed and adjusted to fit with changed hydrological-meteorological conditions arising from climate change. Many good practices derived from previous sustainable development activities are ready available at farm, system and river basin levels, and can serve the purpose of climate change adaptation. This includes integrated disaster risk management (IDRM), especially for integrated flood and draught management.

Agricultural water management also contributes to green house gas (GHG) emissions, mainly through methane emission from irrigated paddy fields, and from carbon emission from energy consumption. New irrigation investment is thus suggested to innovate rice irrigation methods, improve energy and water use efficiency, and encourage clean energy use. A good agricultural strategy will capture the synergies and manage the trade-offs between climate change adaptation/mitigation, food security and sustainable development.

Innovations in water governance: Options proposed, advocated and/or practiced in recent years can be grouped into four categories: strategic guidance; legislative enforcement; policy innovation; and institutional strengthening.

- Strategic guidance sets the overall objectives and principles for agriculture water management at river basin and watershed levels.
- Legislative enforcement helps in the establishment and improvement of water rights system, property rights system, legal status of WUAs, and protection systems for water quality and groundwater aquifers.
- Policy innovation is normally aimed at improvement of water pricing, government subsidies, incentives to environmental services, and system operation and management.
- Institutional strengthening is normally focused on the establishment of proper planning and implementation mechanisms for incorporating agriculture water management into integrated water resources management at river basin and watershed levels; this may include proper mechanisms for public consultation, multi-sector coordination, and participatory-decision making; sector capacity-building; and establishment and strengthening of WUAs.

3. CONCLUSIONS

Asia is by far the region with the largest irrigation area and highest rate of irrigated cultivated land in the world. As many of the irrigation systems were developed 40 years ago, under a top-down approach and in supply-driven model, they are often constrained by poor system design, incomplete or degraded infrastructure, and improper institutional arrangements. Despite their great contribution to agriculture and economic development, they are often criticized for inefficient water use, poor system performance, and negative environment impacts including serious water pollution. Entering the new era, continuous population growth and economic development, urbanization and globalization, and climate change, poses new challenges in social-economic development, and brings multiple challenges to irrigation and agriculture water management, including intensifying water competition among different sectors and users; agriculture diversification; demographic transition; climate change; decentralization and participation; and green economy development. Various options for improving agriculture water management in Asia have been proposed and initiated by different stakeholders in recent years, which can be categorized as: improvement of irrigation systems and performance; utilization of rainwater, flood water and non-conventional water resources; integration of water and agronomic options; climate change adaptation and mitigation; and innovations in water governance. Agricultural water management in some countries such as China, has an important role to pay in controlling non-point source pollution.

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FAO WATER REPORTS

Guidelines to control water pollution from agriculture in China

Decoupling water pollution from agricultural production

Deterioration of water quality is considered a key constraint to future economic development and social progress in China, and agriculture is known to be a major source of pollution.

Agricultural systems in China have expanded and intensified to meet increasing food demand related to population growth and changes in diet. This has led to greatly increased pressure on water quality. Huge amounts of agrochemicals, organic matter, drug residues, sediments and saline drainage are being discharged every year into water bodies. Water pollution from rural sewage has also increased with the rapid development of the economy and improving living standards in rural areas. Rural sewage is estimated to be about 9 billion tonnes a year; most is discharged into the environment untreated. The resulting increased concentrations of pollutants in water bodies pose demonstrated risks to aquatic ecosystems, human health and productive uses.

These guidelines produced by the Food and Agriculture Organization of the United Nations (FAO) and the Institute of Environment and Sustainable Development in Agriculture (IEDA) of the Chinese Academy of Agricultural Sciences (CAAS) review the key pressures and impacts from the main agricultural and rural activities (i.e. cultivation, animal raising, aquaculture, and rural living) and propose a set of good agricultural practices and economic and regulatory actions to minimize pollution and to move towards a more sustainable agriculture intensification in a greener economy.

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