Water basin management for Nansi Lakes, Shandong

Wang Lin, Liu Yanping and Wang Baozhen

ABSTRACT

The water diversion project from south to north, which is under construction in the East Diversion Route, and that of the Middle and West Diversion Routes, which are to be started in the near future, will substantially alleviate the acute shortage of water resources in the northern area and will realize the optimal allocation of water resources in China. The Nansi (South Four) Lakes Basin in Shandong Province as the hydraulic hinge of the Eastern Route Project under construction during the period 2001–2010 will receive water downstream of the Yangtze River and divert it to the Tianjin area, Shandong and Hebei provinces. However, the water is heavily polluted at present, rendering it unsuitable as a drinking water source. An integrated water management strategy of around 4 billion Yuan RMB or about US$49 million for the construction of municipal wastewater treatment plants and sewerage systems to combat point source pollution has been drawn up for the Nansi Lakes Basin in China. The scheme pays attention to non-point source pollution control and water reclamation and reuse, to ensure that the project of diverting water from south to north performs adequately, as well as to pave a way for sustainable development.

Key words | Nansi Lakes catchments, sustainable development, water basin management, water quality grade, water quality parameter

Wang Lin (corresponding author)
Ocean University of China,
5 Yushan Road,
Qingdao 266003,
China
Tel.: +86 532 2031819
Fax: +86 532 2032799
E-mail: *lwang@mail.ouc.edu.cn*

Liu Yanping
Wang Baozhen
Harbin Institute of Technology (HIT),
66 West Dazhi Street,
Harbin 150006,
China

INTRODUCTION

Water resources are not well distributed in China; water is abundant in the south, while only 11.5% of the whole water resource is in the north. This results in water shortages in the northern area, a major agricultural area, accounting for approximately 40% of the national production of foodstuff and 34% of GDP. On the other hand, nearly 36.8% of the population lives in the north. Consequently, economic development and people's living conditions have suffered heavily from the water shortages in the northern area. The central government has decided to divert water from the Yangtze River, the largest river in China, to the northern arid areas, mainly the Beijing–Tianjin area, North China and Shandong Province, in order to substantially alleviate the water resource shortage and to maintain sustainable development in the northern area, on the basis of more than 50 years of investigations and studies.

The project of water diversion from south to north includes three routes: eastern, middle and western. Up to 38–48 billion $m^3\ yr^{-1}$ is to be diverted, which will realize the optimal allocation of the water resource after completion of this huge project (Figure 1).

The Eastern Water Diversion Route, which will be constructed in stages, has a total length of 1,150 km as the main diversion line and 13 stepwise pumping stations. The final annual water diversion capacity is 17 billion m^3. The Middle Route has a total length of 1,264 km as main canal and a designed annual water diversion capacity of 13–14 billion m^3. The Western Route is the most difficult to build, for the water has to be diverted from the Tibet–Qinghai Plateau through long tunnels to be excavated in the high mountains. Therefore, this route is not scheduled to start before 2010. Construction of the Eastern Water Diversion Route Project started in 2001 because of better

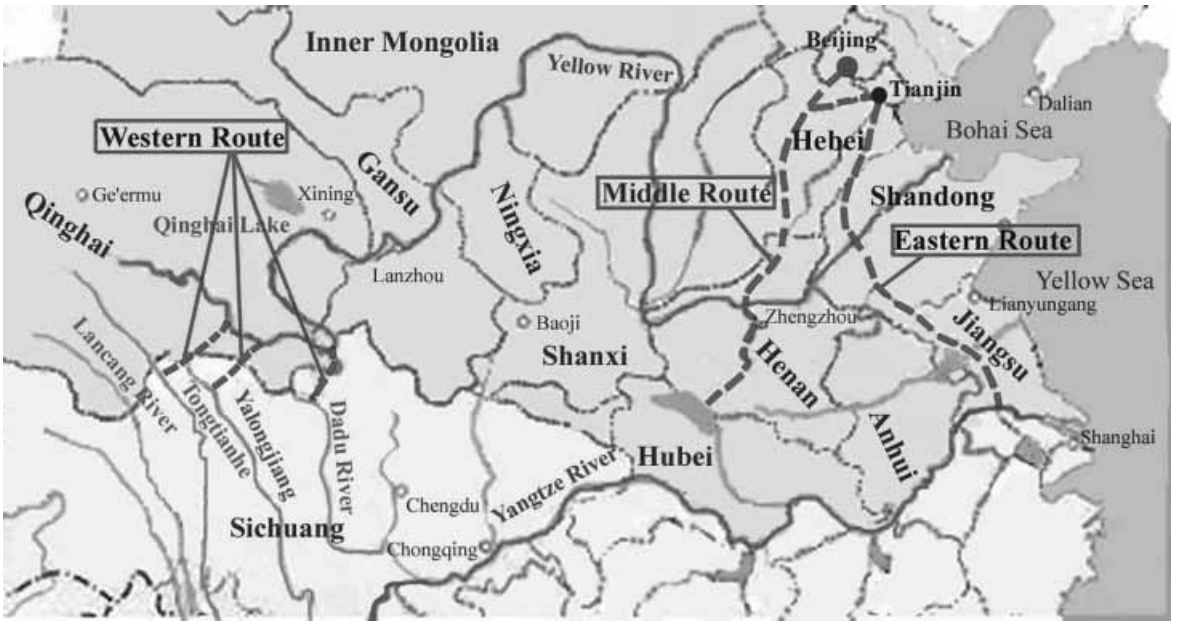

Figure 1 | Map of the water diversion project from south to north in China.

geological conditions, and will be completed in 2010. The Middle Water Diversion Route will be completed before 2010. The whole project of water diversion from south to north will take 50 years to complete with a total investment of 500 billion Yuan RMB or about US$62 billion, which is the biggest water diversion project planned to date in the world.

The Nansi Lakes basin as the hydraulic hinge of the Eastern Route Project will receive water from the south and divert it to Tianjin area, Hebei and Shandong Provinces after completion of the project. The Nansi Lakes catchment covers 26,255 km^2 in the south-west of Shandong Province. The catchment covers 7 cities, 16 towns and 4 independent districts. Among the water resources are local natural precipitation and pass-through watercourses, of which the largest is the Yellow River. The catchment includes 53 rivers, with a total convergence area of 31,700 km^2, of which 12 major rivers cover 24,042 km^2. The Nansi (Southern Four) Lakes, the largest freshwater lakes in the northern area, consist of four lakes connecting with each other by canals or rivers, with a total volume of 1,600 km^3 and a total surface area of 1,209 km^2. The Nansi lakes are multifunctional, providing flood adjustment and discharge, water reservation, navigation and aquaculture irrigation. The lakes will play major roles as important reservoirs in the Eastern Route Project.

Water quality in the Nansi Lakes catchments has deteriorated because of pollution and has reached or exceeded grade V of the Quality Standard of Surface Water Environment (GHZB1-1999, namely National Environmental Quality Standard No.1, 1999) according to monitoring statistics from the Provincial Environment Protection Bureau in 1999, as shown in Table 1. However, the water in the whole water diversion route must meet grade III of the above-mentioned standard in quality. The water quality evaluation of the monitored rivers in the catchments is shown in Table 1 and Figure 2.

The major water quality parameter is organic pollution. The main pollutants are organic substances measured as COD and BOD and ammonia, which result from both point and non-point pollution sources, of which domestic sewage is the major contributor. Moreover, eutrophication is of major severity. High turbidity and highly variable flow are other features. The main pollutant parameters are shown in Table 2, which shows that point source pollution contributes most of the COD discharge

Table 1 | Evaluation of water quality in the Nansi Lakes catchments

Rivers and lakes	Locations monitored	COD (mg l^{-1})	COD_{Mn} (mg l^{-1})	NH_3-N or TP (mg l^{-1})	Evaluated water quality grade
Peiyan River	Inlet of Weishan Lake	52.95	13.61	8.80	> V
Zhuzhaoxin River	Yulou	182.83	40.36	0.41	> V
Chenguo River	Qunlelou	405.44	66.1	40.86	> V
Hanzhuang Canal	Taierzhuang Bridge	46.43	5.9	0.03	> V
Liangji Canal	Southern Dock	56.93	19.99	6.95	> V
Dongyu River	Xiyao	37.83	11.76	0.67	V
Sihe River	Shuyuan	224.22	74.69	4.06	> V
Guangfu River	Huangzhuang	462.78	146.34	71.89	> V
Baima River	Malou	41.66	14.05	5.77	> V
Xizhi River	Beiwaihuan Bridge	36.68	11.38	1.36	V
Nansi Lakes	Dajuan	31.1	10.52	0.10 (TP)	V
	Second Dam	31.58	11.91	0.17 (TP)	V
	Nanyang	31.83	11.12	0.14 (TP)	V
	Qianbaikou	34.43	11.93	0.32 (TP)	> V
	Eastern Weishan Island	22.08	8.00	0.09 (TP)	IV

load, accounting for 84.95%. However, the contribution of non-point source pollution to the water environment accounts for only slightly less than point sources in terms of total nitrogen (TN) and total phosphorus (TP) loads, mainly from runoff from farmland due to over-application of synthetic fertilizers.

The main causes of pollution of the watercourses are described as follows:

- The construction and operation of wastewater treatment plants (WWTPs) has lagged behind the development speed of urbanization and industrialization in the catchments.
- Industrial wastewater is an important contributor to this pollution. The pollution load abated by the existing WWTPs is much less than the increased pollution load from expanding urbanization and industrialization.
- Non-point source pollution has contributed significantly to the additional pollution load to the water environment and water quality has gone from bad to worse.
- The increasing shortage in the water resource due to the abnormal climate in recent years has aggravated the deterioration of the water quality in the catchments.

It is imperative that effective measures are taken to improve the water environment of the Nansi Lakes catchments as quickly as possible, so that the Eastern Route

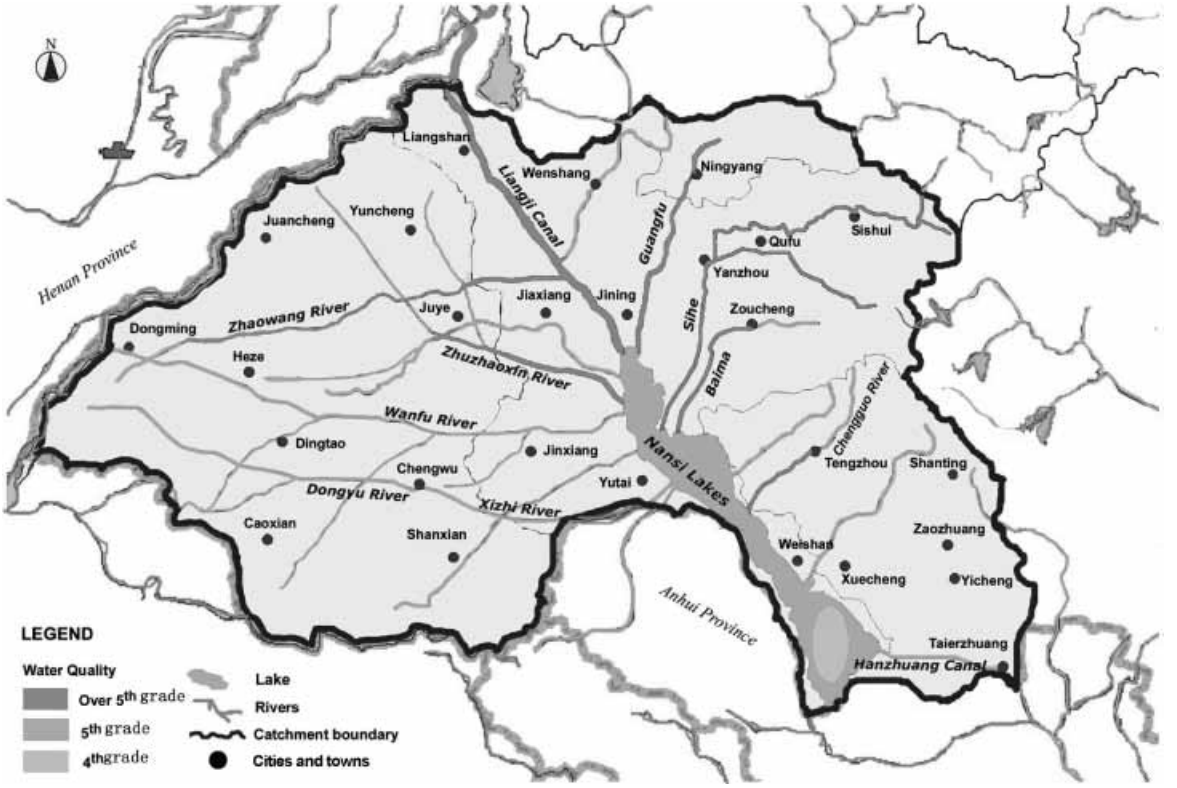

Figure 2 | Map of water quality in Nansi Lakes Basin.

Project can be constructed without difficulty and operated safely for a long time, which will in turn boost sustainable development in the northern area of China.

A catchments-wide integrated management approach

The Government of Shandong Province has commissioned an integrated water management strategy to eliminate pollution and eutrophication and to create favourable conditions under which the water will be safely diverted to the northern area without deterioration.

The integrated feature of the strategy is a number of water management studies and a comprehensive analysis at catchment-wide level, which will not only provide an understanding of the characteristics of water supply, water consumption, wastewater discharge, pollution load and water environment through numerous surveys and investigations, but will also simultaneously conduct an evaluation of water, sewerage and storm water management strategies. The potential for development is evaluated. An integrated water management approach is being used at a basin level to develop solutions to problems, based on the above-mentioned work.

The integrated strategy includes a combination of measures employing total pollution load control and the required water quality control with the emphasis on the need to improve water environmental conditions and relieve the constraints hindering development, supported by technico-economic evaluation and environmental impact assessment.

The principles of the master plan are described as follows:

- adopting environmentally friendly measures and protecting existing environmental assets;

Table 2 | Main pollution loads in the Nansi Lakes catchments

	Point pollution					
Pollution load (t yr^{-1})	**Industrial wastewater**	**Domestic sewage**	**Sub-total**	**Non-point pollution**	**Total**	**Point pollution load (%)**
COD	48,839	79,406	128,245	22,727	150,972	84.95
TN	5,504	12,704	18,208	16,387	34,595	52.63
TP	259	2,262	2,521	2,261	4,782	52.72

- taking practical and realistic measures according to specific local conditions;
- making the best use of water resources and realizing wastewater reclamation, reuse and water recycling;
- keeping sustainability both in environmental protection and ecological systems;
- highlighting priorities, integrated planning and construction by stages.

Total amount control measures

COD is chosen as the major pollution control index because the main characteristic of water pollution in Nansi Lakes basin is organic pollution. Since COD load from point source pollution accounts for 84.95%, with only 15.05% from non-point sources, the emphasis is laid on point source pollution control to abate organic load.

Maximum pollutant load tolerance in each river is calculated by means of mathematical models using main control parameters and hydrological and water quality monitoring data from the past 10 years. Total COD discharge allowed has been calculated as up to 81,400 tons yr^{-1}, as shown in Table 3.

The total amount control measure must be carried out on the basis of an urban water environment forecast. Urban water environment forecasting is a highly scientific and technical task, because it relates not only to the forecast of social, industrial, economic and population development, but also to scientific and technological development, including forecast of economy, population, water consumption and discharge, water body pollution, and environmental protection technologies and investment.

Construction of WWTPs

The integrated management strategy adopts the method of combining centralized and decentralized control to combat point source pollution, which contributes most to water pollution in the Nansi catchments. The emphasis is laid on the construction of WWTPs in order to reduce the pollutant discharge load. At present, there is only one WWTP in operation using the oxidation ditch process, with a capacity of 70,000 m^3 day^{-1}, which was put into operation in 1991. Eight WWTPs were commissioned by the end of 2001.

In the integrated management strategy, 27 WWTPs are planned to be built and expanded in cities and towns in the catchments by 2010, including the existing one and those under-construction and in design, with a total capacity of 159×10^4 m^3 day^{-1}, according to the present and forecast development trend in terms of economy, population, water supply, water consumption, wastewater production and sewerage development. The construction of the WWTPs is divided into two stages, 2001~2005 and 2006~2010, according to how much pollution load the respective site is allowed to contribute to the project. The WWTPs' allocation, capacity and schedule are shown in Figure 3.

Table 3 | Allocation of environmental capacity in Nansi Lakes Basin

Serial number	River or lake	Control point	Limit of COD load (t yr^{-1})
1	Liangji Canal	Southern wharf	13,022
2	Zhuzhaoxin River	Liangshan brake	6,256
3	Dongyu River	Yucheng	770
4	Guangfu River	Huangzhuang	12,424
5	Maima River	Malou	5,882
6	Xizhi River	Yutai	1,069
7	Sihe River	Shuyuan	5,956
8	Shahe River	Yicheng	4,694
9	Chenghe River	Tengzhou	6,338
10	Nansi Lake		25,000
Total			81,411

The secondary effluents from the WWTPs must meet class 1A (in warm seasons) or 1B (in cold seasons) of the China National Municipal WWTP Comprehensive Discharge Standards (GB81918-2002): COD 50 or 60 $mg.l^{-1}$; BOD_5 10 or 20 $mg.l^{-1}$; SS 10 or 20 $mg.l^{-1}$; TN 15–20 $mg.l^{-1}$; NH_3-N 5 or 8 $mg.l^{-1}$; TP 1–1.5 $mg.l^{-1}$; Fecal coliforms 103 or 104 $cfu.l^{-1}$.

The industrial wastewater must be pre-treated on-site to meet the Standard of Industrial Wastewater Discharge into Urban Sewerage System, before entering the WWTPs. Use of clean production technologies is recommended in industries. Moreover, the enterprises that will heavily pollute the water environment such as chemical plants, pulp and paper mills, breweries and metal processing factories, will be forbidden to build and expand in second-class protection areas from now on.

The existing sewerage systems in cities and towns in the catchments are incomplete, with combined systems in most places. In the integrated strategy, separate sewerage systems will be constructed in coordination with the construction of WWTPs, thus improving the municipal sewerage and wastewater treatment system step by step.

Suitable treatment processes

Most of the cities and towns located in the Nansi Lakes Basin are of medium or small scale in terms of population and economic level. The effluent contains household and industrial wastewater, of which more than 70% is domestic sewage. The wastewater production in a city or town usually varies between 10,000 and 50,000 m^3 day^{-1}. Highly variable flow and water quality are the main features of wastewater in a city or town. In addition, suspended solids concentration is higher, but organic substance concentration is quite low, which is mainly due to the incomplete sewerage system that leads to infiltration of groundwater into the system.

In most medium and small cities and towns, the capital and Operation and management (O/M) costs of

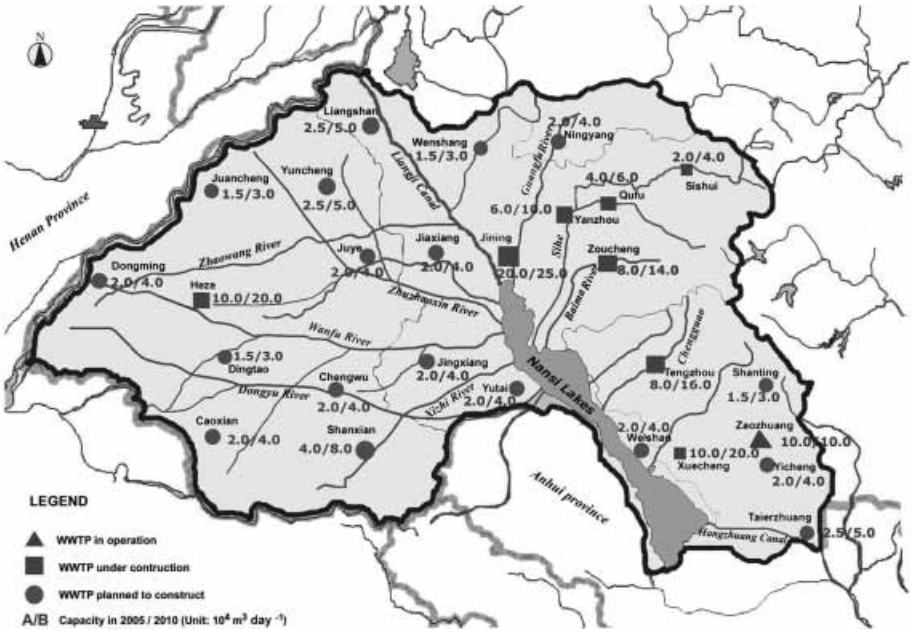

Figure 3 | Map of WWTPs construction planning in 2001–2010.

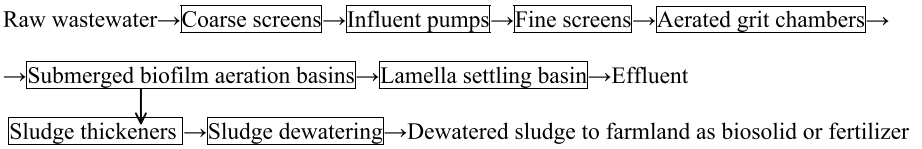

Figure 4 | Flow chart of the submerged biofilm process.

wastewater treatment plant are limited and the technical knowledge of the work force is insufficient. As a result, the use of appropriate wastewater treatment technologies with such characteristics as high performance, easy operation, energy saving and low costs, is becoming imperative. Suitable processes include the submerged biofilm process (Wang *et al.* 2000), pond systems (Oswald 1991, 1995; Pearson 1996; Wang *et al.* 1996; Zhao *et al.* 1996), land treatment systems (Pettygrove & Asano 1985; Von Sperling 1996) and integrated or combined systems of the above (Lettinga 1996; Wang *et al.* 1999). At the same time, these technologies will be integrated with local agriculture; the effluent is reclaimed and reused in farmland irrigation and aquaculture, thus forming an ecological wastewater treatment and utilization system (EWTUS). The typical flowcharts recommended are shown in Figures 4 and 5.

In Shandong Province there are 43 WWTPs in operation at present, with various processes including the activated sludge process, oxidation ditch process, pond system, reed wetland system and the integrated ecological process. A comparison of various processes can provide a reference for the choice of a suitable process, as shown in Table 4.

In summary, the COD load will be abated by 261,700 tons yr^{-1} by municipal wastewater treatment plants and the industrial wastewater treatment facilities, and the total COD discharge amount will be decreased to 72,100 tons yr^{-1} by 2010. Thus, the required abatement of point source pollution load for water environmental protection will be met.

Non-point source pollution control

Non-point source pollution contributes about 47.37% TN and 47.28% TP to the total water pollution load.

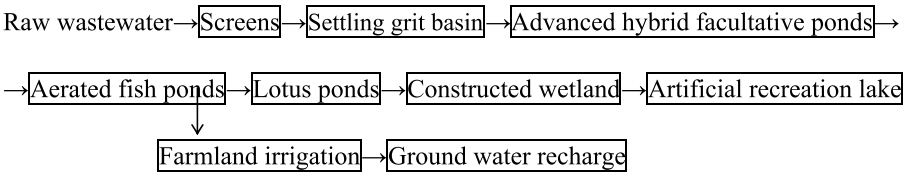

Figure 5 | Integrated wastewater treatment and utilization process recommended for small cities and towns.

Table 4 | Comparison of various treatment processes

Process	Construction capital (Yuan m^{-3} day^{-1})*	Operation cost (Yuan m^{-3})**	Effluent quality (mg l^{-1})***				
			SS	BOD	COD	NH_3-N	TP
Activated sludge process	1,200–1,500	0.4–0.5	20–30	20–30	80–120	3–10	1–3
Oxidation ditch process	800–1,200	0.4–0.5	20–30	20–30	70–120	3–10	1–3
Submerged biofilm process	800–1,000	0.2–0.3	10–20	10–20	60–80	1–5	1–3
Wetland system	600–800	0.1–0.15	20–40	20–50	60–120	2–10	0.2–1
Pond system	500–600	0.1–0.15	20–30	20–50	60–100	2–10	1–3

*Yuan (RMB)/US$=1/8.3; **amortization is not included; ***the performance of pond and wetland systems is good in warm seasons, but poor in winter.

Table 5 | Comparison of non-point source pollution contributors

Pollution load	The proportion of total non-point source pollution load (%)			
	Farmland runoff	Dispersed household	Stockbreeding	Others
COD	10.7	44.5	44.2	0.6
TN	45.0	4.3	24.3	26.4
TP	32.6	43.2	16.5	7.7

The non-point pollution is mainly caused by farmland runoff and stockbreeding sites. A comparison of their contributions to non-point source pollution is shown in Table 5.

The long-term excessive and irrational application of fertilizers and a wide spectrum of pesticides for increasing crop production has caused pollution from agriculture, which has degraded the agricultural ecosystem by reducing the soil organic matter content and hardening soil structure, aggravating eutrophication of water bodies, thus deteriorating both surface and groundwater quality (Li & Zhang 1999). Moreover, the application of fertilizers is increasing every year; however, only 35% of this exerts its effect in the Nansi Lakes catchments. Farmland drainage

and runoff are the major mechanisms for transporting fertilizers and pesticides from farmland and orchards into water bodies. According to specific conditions, corresponding measures must be taken to abate agricultural diffuse pollution in the context of moving towards sustainable agriculture which has already emerged in the US and Europe (Novotny 1999).

In terms of wastewater produced by dispersed households and stockbreeding sites, it is difficult to centralize treatment owing to the remote and scattered distribution and small and uneven quantity of sewage. It is preferable to combine natural purification processes with enhanced artificial treatment processes to receive and treat the wastes on site. Practical measures include multi-pond systems, eco-ponds and constructed wetlands, of which a wetland system in combination with ponds is the first choice. This has the advantages of low capital and O/M costs, easy construction and operation, energy saving and high performance, as well as benefit to agricultural production by enlarging the irrigation area and aquaculture production (Yin *et al.* 2001), according to the specific conditions in the catchments.

Comprehensive schemes to abate non-point source pollution are worked out through research and systematic analyses, and are summarized as follows:

- Improving fertilization technologies, making better use of both synthetic fertilizers and organic fertilizers from the WWTPs in form of bio-solids, and reforming cultivation and irrigation patterns in order to improve the utilization rate of fertilizers, to minimize nutrient pollution.
- Utilizing pesticides scientifically and rationally, abandoning the production and use of highly toxic and persistent pesticides like DDT and HCCH, while popularizing comprehensive technologies for preventing and killing pests in order to abate pesticide pollution.
- Setting up demonstration projects of comprehensive waste treatment and utilization in large and medium scale stockbreeding sites.
- Treating wastewater from dispersed households and stockbreeding sites by combining natural purification processes with enhanced artificial treatment processes; the pond and wetland system are proposed as preferable processes.
- Building greenbelts around the banks of lakes, as well as lakeside wetlands and ecosystem restoration projects on the banks, which will stabilize the lakeshores and enhance the removal of nutrients to reduce non-point source pollution.
- Dredging up the sediments from the bottom of rivers to prevent them entering lakes.
- Strictly managing navigation, aquaculture and fish farming along the water diversion line.

Wastewater reclamation and reuse

The integrated water management strategy promotes the reclamation and reuse of secondary effluent as an effective alternative to the regenerated and reusable water resources, in order to alleviate the severe and escalating water shortage caused by water pollution and dry climate. The amount and method of water reuse is determined according to the specific conditions of the cities and towns concerned in the catchments, with a total amount of approximately 490,000 m^3 day^{-1} by 2005 and 990,000 m^3 day^{-1} by 2010. Suitable uses are as follows:

- Agricultural irrigation in accordance with Chinese guidelines. The amount to be used is estimated at up to 200,000 m^3 day^{-1} by 2005 and 405,000 m^3 day^{-1} by 2010, which accounts for most of the water reuse as agriculture plays a major role in economic development in the catchments.
- Multipurpose domestic uses except potable use, such as toilet flushing, garden watering, and municipal uses, such as impounding of recreational lakes, watering of parks and greenbelts, and recharge of groundwater.
- Industrial uses, such as cooling water, process water and wash-down, which is mainly planned for bigger cities with developed industry, such as Jining, Heze and Tengzhou cities.

Finance

The estimated cost of the master plan is around 4 billion Yuan RMB or about US$48.4 million. The capital cost will

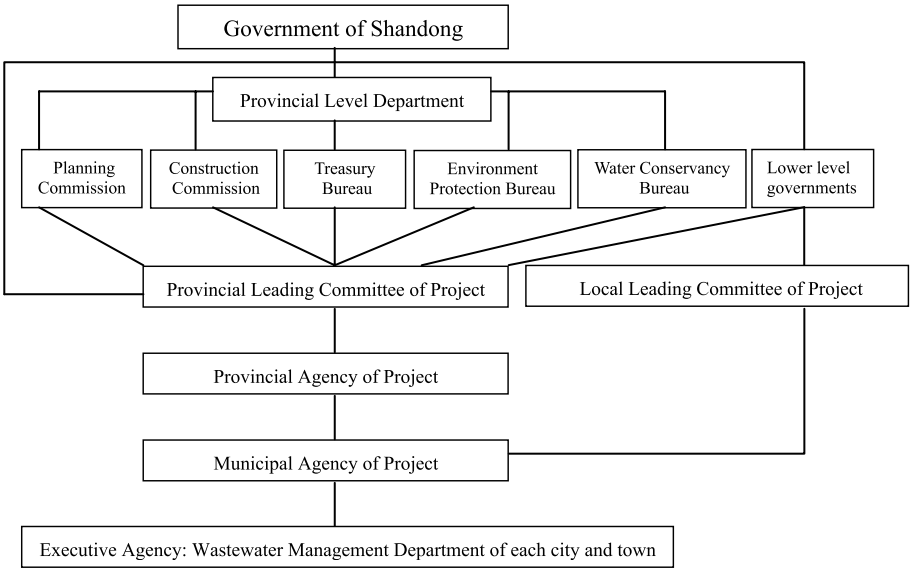

Figure 6 | Proposed management and implementation organization.

be collected from various sources: national, provincial and local governments; industries and enterprises will offer investment.

The specific financing systems include:

- Emission-offset systems: the project is huge and could not be completed in time without external support. Therefore, the central government will allocate funds for the regional subordinate project from special sources for the project to divert water from south to north.
- Polluter-payment systems: the polluters are liable to share the costs of wastewater treatment and protection in proportion to their contribution to the pollution load.
- Benefit-payment systems: the region benefiting from the eastern route project should offer part of the investment.
- Local self-finance systems: The local authorities concerned can raise various funds, such as governmental flexible funds, municipal infrastructure construction funds, construction fees for the municipal sewage treatment plant and sewerage system, auxiliary fees for public utility, environmental discharge fees, funds for environmental protection, the dues for municipal sewage disposal and the dues for using water discharge facilities, and so forth.
- Various loans or foreign investment systems: the market mechanism will be introduced into the management of sewerage systems and wastewater treatment plants, so that the various loans or foreign investment will be taken into account.

Management and implementation organization

Policies, legislation and management measures, as the means of support for this project, are the key for taking the integrated strategy into effect. The Government of Shandong Province has established a Project Leading Committee, which is responsible for working out policies, management and supervisory systems to ensure effective implementation so that the Eastern Route Project will be built and operated without any doubt. The proposed organization system is shown in Figure 6.

Each department of various levels of government involved in the project organization has a specific role, performing respective functions and responsibilities. At the same time, they should cooperate with each other. The

specific duties of various departments are described as follows:

- The Department of Construction is in charge of coordination between various departments during the construction period.
- The Project Plan Committee is in charge of the establishment, evaluation and investment plan of each construction item.
- The duty of the Treasury Department is to plan for the treasury, to provide financial support for each project and to insure the project will be conducted with enough money.
- The Environment Protection Bureau is in charge of monitoring and management of water quality.
- The Water Conservancy Bureau is in charge of providing records of flood discharge and permitting treated effluent discharge into lower watercourses.
- The Executive Agency is in charge of the implementation of construction projects on schedule, as well as supervising, checking and accepting construction items.

CONCLUSIONS

Under the umbrella of the water diversion project from south to north, an integrated water management strategy for Nansi Lakes basin of more than 4 billion Yuan RMB or about US$48.4 billion is being put into effect at catchment level to combat serious water pollution and to improve environmental and ecological conditions, which will guarantee delivery of good quality water from south to north.

The construction of wastewater treatment plants and sewerage systems is the major part in the master plan to control point source pollution, while paying attention to non-point source pollution control and water reuse. The integrated management measures aim at reducing pollution loads to the water environment to obtain comprehensive environmental, economic and social benefits, and to maintain sustainable economic and social development.

The Project Leading Committee should make great efforts to carry out its duty in enforcing management and implementing policies, in order to ensure that the integrated strategy is carried out favourably. Central, provincial and local government will draft legislation to adopt effective and comprehensive measures to deal with relationships between pollution control, water conservation and water diversion; to strengthen water management programmes in the cities and towns in order to improve community acceptance and implementation of water conservation policies and regulations; to promote and improve water saving appliances in the industrial and commercial sectors; and to encourage the use of recycled water in order to reduce the demand on existing and new water sources. The specific measures outlined above will be optimized as the project progresses towards scheduled completion in 2010.

REFERENCES

Lettinga, G. 1996 Sustainable integrated biological treatment. *Wat. Sci. & Technol.* **33**(3), 85–98.

Li, Y. & Zhang, J. B. 1999 Agricultural diffuse pollution from fertilizers and pesticides in China. *Wat. Sci. & Technol.* **39**(3), 25–32.

Novotny, V. 1999 Diffuse pollution from agriculture—a worldwide outlook. *Wat. Sci. & Technol.*, **39**(3), 1–13.

Oswald, W. J. 1991 Introduction to advanced integrated wastewater ponding system. *Wat. Sci. & Technol.* **24**(5), 1–7.

Oswald, W. J. 1995 Pond in the 21 century. *Wat. Sci. & Technol.* **31**(21), 1–8.

Pearson, H. W. 1996 Expanding the horizons of pond technology and application in an environmentally conscious world. *Wat. Sci. & Technol.* **33**(7), 1–9.

Pettygrove, G. S. & Asano, T. 1985 *Irrigation with reclaimed municipal wastewater—A Guidance Manual*. Lewis Publishers, Inc., Chelsea, Michigan.

Von Sperling, M. 1996 Comparison among the most frequently used system for wastewater treatment in developing countries. *Wat. Sci. & Technol.* **33**(3), 59–72.

Wang, B. Z., Dong, W. Y., Zhong, J. L. & Wang, L. 1996 Experimental study on high rate pond system treating piggery wastewater. *Wat. Sci. & Technol.* **34**(11), 125–132.

Wang, B. Z., Wang, L. & Yang, L. Y. 1999 Case studies on pond ecosystems for wastewater treatment and utilization in China. World Market Service, Business Briefing. *Global Wat. & Wastewat. Technol.*, 64–71.

Wang, B. Z., Li, G. Q. & Wang, L. 2000 Design and operation of a domestic wastewater treatment plant with submerged biofilm process. *China Wat. & Wastewat.* **16**(3), 16–19 (in Chinese).

Yin, C. Q., Yang, C. F. & Wang, B. Z. 2001 Non-point pollution from China's rural areas and its countermeasures. *Wat. Sci. & Technol.* **44**(7), 123–128.

Zhao, Q. L. & Wang, B. Z. 1996 Evaluation on a pilot scale attached growth system treating domestic wastewater. *Wat. Res.* **10**(1), 242–245.

First received 1 February 2002; accepted in revised form 21 March 2003