Water in Circular Economy and Resilience (WICER)

The Case of Lingyuan City, China

Unconventional Water Resources in a Water-Scarce City: Recycling Treated Municipal Wastewater for Industrial Users and to restore the ecosystem

This case study is part of a series prepared by the World Bank’s Water Global Practice to highlight existing experiences in the water sector. The purpose of the series is to showcase one or more of the elements that can contribute toward a Water in Circular Economy and Resilience (WICER) system. This case study focuses on the experiences of Lingyuan City in China.

Context

Lingyuan City in Liaoning Province, China, is a county-level city with a population of around 650,000 people who have been facing acute water scarcity.¹ The meteorological and hydrological data indicate a decline in precipitation in Lingyuan Municipality over the past three decades. Available freshwater per capita is only 450-500 cubic meters (m³)/year, which is one-fourth the national average and one-fourteenth the world average. The Daling River, which flows through the city, runs dry for about seven months a year on average. The limited availability of surface water, combined with pollution of the Daling River, has led to the overexploitation of groundwater resources. Between 1993 and 2010, exploitable groundwater resources decreased by 40 percent.

Groundwater serves as a vital water supply source for the city (around 85 percent of total water use), which extends to all residents, government institutions, commercial entities, and more than 100 industries (including several large industrial users that consume over 100,000 m³ per year). To mitigate the local aquifer’s
depletion, both the Liaoning provincial government and Lingyuan City government issued regulations in 2011 banning any unlicensed exploitation of groundwater. Under these new regulations, the establishment of any new business projected to consume large volumes of water must be justified. Water scarcity has thus become a major constraint on the city’s economic development.

**Solution**

To meet the increasing water demand resulting from rapid economic development and urbanization, the Lingyuan City government identified wastewater collection, treatment, and reuse as an opportunity to address the city’s water scarcity problem while promoting circular economy principles. Since 1985, Liaoning Province has received a total of US$2.8 billion in loans from the International Development Association (IDA)/International Bank for Reconstruction and Development (IBRD) for 28 projects across environmental protection, urban infrastructure, agriculture, education, and new energy sectors. In 2013, the World Bank approved the Liaoning Coastal Economic Zone Urban Infrastructure and Environmental Management Project (hereafter referred to as “the Project”) to support the province in addressing development challenges in its coastal cities as part of a regional revitalization plan supported by the central government. Improving urban water resilience was among the Project’s efforts to address the water scarcity challenges in the region. Circular economy concepts were envisaged during the design of the Project, in line with China’s legislative enforcement of the Circular Economy Promotion Law and the World Bank initiatives defined in the Country Partnership Framework to green the national economy.

In 2009, Lingyuan City built a wastewater treatment plant (WWTP) with a capacity of 50,000 m³/day. However, as of 2013, less than 50 percent of urban households were connected to the sewerage network and the WWTP treated only about 23,000 m³/day of municipal wastewater. At that time, sewage from a new industrial park was not collected and its untreated wastewater was discharged into the environment, resulting in the severe pollution of the city’s surface and ground water. The Lingyuan City government and the World Bank agreed that the Project would aim to increase wastewater collection and treatment and foster wastewater reuse by: (1) establishing separate drainage systems for stormwater and wastewater, (2) extending networks to increase the amount of wastewater collected and population served, (3) upgrading the WWTP into a tertiary treatment plant to improve the effluent quality of the reclaimed wastewater, and (4) enhancing pumping stations for reclaimed water.

By the completion of the Project in 2017, more than 90 percent of urban households were connected and daily wastewater collection and treatment reached between 50,000 and 58,000 m³/day. Currently, 30,000 m³/day is further treated by the tertiary treatment processes to improve the effluent quality for reuse purposes. 20,000 m³/day of that reclaimed wastewater is reused for the operation of six industries in the new industrial park and 10,000 m³/day is used to replenish the urban lake in order to restore urban biodiversity and maintain the shallow aquifer around the lake. The rest of the effluent, which is subjected to secondary treatment, is directly discharged into the Daling River downstream of the city, improving the river’s water quality.

**Policy, Institutional, and Regulatory Environment**

The Circular Economy Promotion Law of the People’s Republic of China (the “CE Law”) was first enacted on August 29, 2008; enforced from January 1, 2009; and last updated on October 26, 2018. This law was formulated to promote the development of the circular economy, improve the efficiency of resource utilization, protect and improve the environment, and ensure sustainable development. The importance of water conservation, and of the recycling and reuse of wastewater, is explicitly stated in the law. Following the
publication of the law, the *Guide on Circular Economy Development Planning* was issued in December 2010 by the National Development and Reform Commission (NDRC), to provide guidance to the various levels of government on how to develop circular economy plans. At the technical level, in 2017, the state published a new standard titled “Technical Guidelines of Circular Economy Performance Evaluating.” In the law and regulation system, as mentioned, water efficiency and water recycling are key focus areas. All public investments on circular economy development at the local level must be reviewed and approved by the local Development and Reform Commissions (DRCs) and local finance bureaus. Depending on the scale of investment, review and approval of investments could be the responsibilities of local, provincial, or state DRCs and finance departments or the Ministry of Finance.

As severe water scarcity had already become a bottleneck to achieving sustainable development at the province level, the province issued regulations for the protection and sustainable utilization of groundwater from the beginning of the 21st century. In 2011, the “Ban on Extraction of Ground Water” was issued by the province. In 2016, the city government published its strictest water resource management regulation to date, outlining plans to gradually close all groundwater intakes during the 13th five-year planning period (2016–2020). This was in response to the national government’s request to strengthen water resource management to the most stringent degree, and also the national Water Pollution Prevention Action Plan. The reuse of reclaimed wastewater was proposed as an effective means of resolving economic development and water scarcity conflicts in Lingyuan City.

### Financial and Contractual Arrangements

The wastewater recycling project required a total capital investment of US$40.1 million, which was fully covered by the Lingyuan City government with a loan from the World Bank. The city financed the construction of 37.1 kilometers (km) of stormwater drainage network, 49.9 km of sewage network to collect wastewater from households and from the industrial park after preliminary treatment, 30.7 km of reclaimed treated wastewater network, and two 30,000 m³/day pumping stations, one in the WWTP and another to transport reclaimed wastewater to the industrial park.

In 2014, the city government signed a 30-year concession agreement with a private operator to operate the existing WWTP of 50,000 m³/day capacity, and to build, finance, and operate a tertiary treatment facility with a capacity of 30,000 m³/day to reclaim wastewater for reuse (Figure 1).

Under this agreement, the Lingyuan City government pays the private operator for the following operation and maintenance costs:

- **US$0.17/m³** for secondary treatment, paid as per the actual metered volume of wastewater treated, with a minimum of 30,000 m³/day guaranteed by the local government.

- **US$0.24/m³** for tertiary treatment, calculated as an aggregated operating cost (AOC) that includes the costs of electricity, chemicals, labor, depreciation of capital assets, and maintenance, as well as the necessary profit. The AOC is paid by the Lingyuan City government to the plant operator against the actual volume of reclaimed wastewater supplied and after deducting 10,000 m³/day for the replenishment of the urban lake. The AOC is reviewed each year and may be increased as per the agreed formula in the contract, depending on the increase in the electricity tariffs, labor costs, and inflation index during the concession period. The tariff increase can be proposed by the contracted private operator and needs to be reviewed and accepted by the local pricing bureau after public consultation.

The city government then sells the reclaimed wastewater to industries at a competitive market price of **US$0.36/m³**, which is around 65 percent of the city’s tap water tariff for industries. In order to secure the demand for treated wastewater, the government
signed long-term agreements with six major industrial consumers to provide 20,000 m³/day of reclaimed wastewater. The tariff was calculated by adding taxes and an operating margin to the abovementioned US$0.24/m³. The treated wastewater tariff for industrial users is increased in parallel with the tap water tariff. Tariffs for wastewater treatment and recycled water supply are normally billed together with the tap water tariff. The metering and collection of the water tariff from users is the responsibility of the government, along with the repayment of the US$40.1 million loan and interest to the World Bank.

Benefits

*Enhanced local economic development.* If the Project’s economic valuation is based on only the costs saved by the price difference between tap water and recycled water, the calculated economic internal return rate at Project completion was 9.1 percent and the expected net present value was US$2.4 million. However, a shadow-price-based valuation can be used to reflect local water scarcity and its impact on the development of local industries, which was largely constrained by the availability of water resources. Based on this shadow-price valuation, the economic value of the Project is US$1.2/m³ for treated wastewater for industrial purposes in the region, leading to an economic internal return rate of 24 percent. With around 7.3 million m³ of water sold to industries annually, the economic value
generated is US$8.76 million/year, which was the key driver for the local government to invest in the water recycling business.

**Lower operating costs for industrial users.** The reclaimed wastewater is cheaper than the urban tap water previously used for industries. Industrial users have saved US$2.83 million of direct operating costs in the past two years. Using reclaimed wastewater also results in secured industrial production by avoiding interruption or reduction in water supply, making industries more resilient to droughts.

**Protected aquifer.** Approximately 7.3 million m³ per year of reclaimed wastewater is sold to industries. This means that the equivalent amount of groundwater is not being extracted from the aquifer for this purpose, resulting in the indirect augmentation of drinking water resources and rehabilitation of the aquifer, and improved urban resilience.

**Enhanced natural amenities and biodiversity.** The newly formed urban lake not only beautifies the landscape but also improves urban biodiversity, replenishes the groundwater, and provides an opportunity to increase the value of urban land (Figure 2).

**Improved city livability.** The municipal wastewater collection rate has almost doubled since the commencement of the Project’s implementation in 2013, increasing the urban population’s coverage from 50 percent to 90 percent. Water pollution, in turn, has been greatly reduced since the amount of untreated sewerage discharged into the environment has decreased. The annual reduction of pollutant loads released into the environment amount to 1,095 tons of biochemical oxygen demand (BOD₅); 1,898 tons of chemical oxygen demand (COD); 1,241 tons of suspended solids (SS); and 116.8 tons of ammoniacal-nitrogen (NH₄-N). Moreover, about 10,000 m³/day of treated wastewater is used to replenish an urban

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**FIGURE 2.** Enhanced Urban Lake That Used to be Polluted and Dry Most of the Year. Source: Lingyuan Municipal Emergency Water Supply Division
lake and the Daling River, which used to be polluted by untreated wastewater. The treated wastewater is helping to restore the urban water ecosystem, bolster riparian habitats, and ultimately increase urban biodiversity.

**An example to other urban water resilience activities.** Based on the financial and economic benefits generated from the Project, the Lingyuan City government has moved forward to construct a second municipal WWTP with water reclamation and recycling infrastructure to support the increasing water demands of industrial consumers.

**Lessons Learned**

- **Government leadership and commitment are critical to success.** The city government leaders who provided strong support to the Project enforced groundwater regulations, helped with institutional coordination, and provided access to technology and finance. They also helped ensure that treated wastewater quality is in compliance with industrial standards and its supply is reliable, and they set a competitive tariff.

- **Regulations can foster wastewater reuse.** In 2011, the Liaoning provincial government stipulated the “Liaoning Provincial Provisions on Prohibition of Groundwater.” From 2013, new extraction of groundwater by industries have been banned and all existing groundwater intakes closed. These regulations forced industries to explore other options and consider alternative sources such as treated wastewater.

- **The tariffs for reclaimed water are best set at competitive rates.** Besides reliable and constant water quality, a competitive tariff is needed to ensure that industrial consumers consider the use of reclaimed wastewater instead of freshwater. In this case, the tariff for reclaimed wastewater is lower than the tariff for urban water supply (US$0.36/m³ compared with US$0.55/m³).

- **Proactive planning is important to build urban water resilience.** Rapid urbanization, growing populations, and rapid economic development will stress water scarcity. Cities should adopt proactive planning mechanisms to forecast economic growth and urbanization patterns. By incorporating climate data, planners can better project available water resources based on the local context. A resilient solution requires early and integrated planning. Unconventional water resources will play more important roles in building urban water resilience and this may involve heavy investment.

- **Focus on the potential end users of reclaimed wastewater.** It is important to identify potential end users and understand their water requirements regarding quantity and quality standards. For example, potential industrial users in Lingyuan are engaged in ferrous metallurgy and construction material production. In this case, the effluents of Lingyuan’s City WWTP met the Class 1A Effluent Discharge Standards, and that reliability and quality were assured by the government were crucial for the Project to be successful.

- **Ensure that infrastructure is adequate.** Comprehensive infrastructure is an essential investment. In this case, it was important that wastewater tertiary treatment plants were adequate to meet industrial users’ demand. Pumping stations and distribution networks for the reclaimed wastewater were also needed. In some cases, these may require heavy investment from water operators, and public funding might be required to enable wastewater reuse.

- **The Bank’s international experience informed the Project process.** The Bank task team provided guidance to local teams throughout the Project cycle, including in setting up the financial models for the wastewater recycling system, identifying industrial users, encouraging the government to engage with industrial users, proposing a reasonable tariff for financial viability, and advising on an optimized operation for better service and cost savings.
Conclusions

Reclaiming wastewater may be a useful alternative to conventional water resources, especially where there is water scarcity (see Table 1). Treating and reusing wastewater can increase a water utility’s resilience and mitigate urban water scarcity pressures, reduce the operating costs of large industrial water users, improve the efficiency of water resources, reduce water pollution, minimize groundwater extraction, and improve water ecosystems. Such practices can be duplicated to build urban water resilience and establish a circular economy. Lingyuan City’s success in recycling city wastewater could not have materialized without strong support from the local government in setting the right policies and enforcing regulations. Meanwhile, demand for reclaimed wastewater had to be stimulated to ensure the financial viability of investments. Lingyuan City offers an example to many other cities looking for green and sustainable solutions to water scarcity.

Notes

1. Water availability per capita between 500-1,000 m³ per year is categorized as acute or severe.
2. See Xukuo (2014); the shadow price of recycled wastewater is derived based on 3 percent of the average US$40 added value from 1 m³ of water supply for local industries on average.

Background Documents

World Bank. 2013. Project Appraisal Document for a Liaoning Coastal Economic Zone Urban Infrastructure and Environmental Management Project funded by the World Bank. Activity relevant to this case study:

- Subproject 2a. Wastewater treatment and reclamation and drainage. This subproject consisted of the construction of a sewage collection and drainage system, reclaimed wastewater pumping stations, and a reclamation network to supply reclaimed wastewater to industrial users.

Challenges

- High demand for water resources intensified due to economic development and rapid urbanization in an already water-scarce city.

Objectives

- Improve drainage services to enhance the quality of life of urban inhabitants;
- Collect and treat domestic wastewater to avoid water pollution; and
- Encourage industrial users to utilize reclaimed wastewater to minimize dependence on groundwater, limit groundwater extraction, and restore the groundwater aquifer.

Benefits of the resilient approach

- Improves the water environment while addressing challenges, thus fostering urban water resilience.
- Improves the utility’s financial viability. The revenues from reclaimed wastewater supply may partially make up for the revenue deficit of wastewater treatment and minimize government subsidies so the utility’s functioning will be more sustainable.
- Guarantees a stable inflow of water supply for local growth (urbanization, industrial expansion, job creation).
- Supports the regeneration of the urban landscape and restoration of the riparian ecosystem, and increased urban ecodiversity.
- Supports the regional development strategy and boosts local economic development.

Table 1. Summary of Lingyuan City’s Resilient, Circular Economy-Centered Approach

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