Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.23204

129 (2018) 351–357
October

Analysis of the alternative water conservation schemes in the Jiangsu Province

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Received 18 September 2017; Accepted 3 June 2018

ABSTRACT

Fresh water is a vital resource of the modern civilization but comprises less than 3% of the world's water. It is recognized that the next decades are likely to see a considerable rise of world population and as a result, the water supply will need to increase, thus raising concerns of an imminent shortage. Water conservation methods, such as the recycling and reuse of water, can improve the water quality and reduce both the stress on water supplies and the human impact on the freshwater ecosystems. This paper provides a comprehensive analysis of the water recycling process applied to the Jiangsu Province by the use of representative simulations. Each model considers different processes of wastewater treatment along with various requisites for improving water quality and cost of facility. A case scenario of recycled water indicates that this advanced model is cost-effective and could play a leading role in Jiangsu Province. Furthermore, we believe that our model might be useful for solving the water scarcity of other urban developments.

Keywords: Utilization model; Recycled water; Jiangsu Province; Miscellaneous use; Case study

1. Introduction

Considerable attention must be paid when dealing with water shortages, if mankind is to achieve a sustainable development [1,2]. The expected rise of population, rapid urbanization and climate change effects will increase the water stress and deteriorate the water quality [3,4]. Many countries and cities recognize the significance of both water demand management and modern water infrastructure. As a result, several long-term strategies of water supply are being contemplated [5,6], ranging from control and development schemes to more complex processes which involve the wastewater reuse, water quality recovery and reduction of the human impact on the environment [7,8]. It is becoming recognized that the increased water demand around the world [9] may be resolved from alternative water resources: capture and storage of water from rain and storm, and reclaimed water. The use of reclaimed water is beneficial and potentially viable for industrial cooling, agriculture and urban use [10,11]. To date, several countries are saving water by conducting thousands of recycled water schemes [12].

Turning now to China, a country with a energy and water demand expected to increase in the next decades, there exist provinces which are currently either rich or poor with water. Hence, it is possible to produce a long-term water distribution management from water-rich to water-poor regions. Some projects particularly, from the Jiangsu province, one of the most water-rich provinces in China, to dry nearby

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Presented at 2017 Qingdao International Water Congress, June 27–30, 2017, Qingdao, China.

regions are still ongoing field trials. The Jiangsu province is surrounded by a body of water: rivers, lakes and sea oceans. It makes up nearly 16.3% of Jiangsu's total area.

The Jiangsu Economic Daily describes the water resource of Jiangsu province with "four abundant and four lacking properties". In other words, the river: has a water resource greater than the region's water needs; contains more polluted than unpolluted water; is more concentrated in the southern than northern region; is greatly increased in the flood and reduced in dry seasons. In the Jiangsu Province, there is a rapid economic growth but the water shortages and the local pollution restrict its further development [13]. As regards to the implementation of alternative water sources [14], the recycling rate of municipal sewage plants is low, about 12%. Unfortunately, there lacks overall motivation among Jiangsu population and as a result, little research is conducted to improve the water demand management.

This paper develops schemes of water conservation for the Jiangsu region for the industrial, environmental and miscellaneous purposes. We consider various factors likely to affect the success of recycled water utilization: water quality, cost of infrastructure, efficiency of recycled water, and environmental impact. A case study is presented in the utilization of recycled water in Jiangsu province.

2. Potential of recycled water utilization in Jiangsu

2.1. Overall condition on utilization of recycled water in Jiangsu

For our analyses of water efficiency, we use the concept of the utilization ratio, the amount of water supply to total wastewater produced [15]. The utilization ratio is directly proportional to the water infrastructure of the city. Fig. 1 compares the utilization ratio for the 13 provincial cities in Jiangsu; being the 3 top cities: Changzhou, Yangzhou and Taizhou. Surprisingly, Wuxi's water infrastructure is currently undeveloped (Fig. 1), but was expected to be at the forefront; its total economic output (2013) was ranked third within the Jiangsu region. With the current strategy for saving water, cities with low utilization ratio are contemplating water schemes such as allocation of water resources and wastewater recycling.

Overall, the design scale of recycled water in the Jiangsu province requires 1.90 million m³/d [15], however, as of 2015, the water infrastructure can only provide 1.08 million m³/d. Currently, there are 62 sets of recycled water facilities in the constructed pipeline network of 126.36 km length. The scale of recycled water consumption has reached 0.66 million m³/d, of which 0.21 million m³/d is used for industry (32%); 0.38 million m³/d for landscape environment, counting the water supplement for rivers (58.8%); 0.047 million m³/d, for municipal market, counting the municipal street flushing (7.1%); and 0.0132 million m³/d, for other purposes (2%). Fig. 2 shows the distribution of the recycled water by purpose. We observe that the industrial and environmental water accounts for as much as 90.8% of the recycled water.

2.2. Recycled water for industry

The amount of industrial water in Jiangsu province reached 14.4 billion m³ in 2013, about 31.3% of the total water demand [16]. With the rapid development of society, the demand for industrial water will increase. To reduce the water stress, the municipal sewage could be first treated and then implemented to the industry since the industrial water has a low quality in relation to the water used for drinking. Acceptance among population is controversial; yet prices of water are competitive to the traditional water methods (section 2.5)

One potential application of the recycled water is to serve as coolant for circulating–cooling processes, such as the ones employed in cyclic power plants and general industrial processes. The majority of the cyclic power plants are mainly located in the northern area of Jiangsu, having annual water consumption amount of 0.86 billion m³, of which 20% are circulating–cooling water. Thus, the annual amount of cooling water takes up to 0.172 billion m³. In 2013, the water demand for general industrial cooling process in the Jiangsu province was about 5 billion m³. If a recycled water rate of 10% is considered, then about 0.5 billion m³ may be saved per year.

2.3. Recycled water for environment purposes

Nowadays, there is an increase in worldwide effort to develop water schemes for reusing the urban wastewater. This is not only beneficial to the environment and aquatic

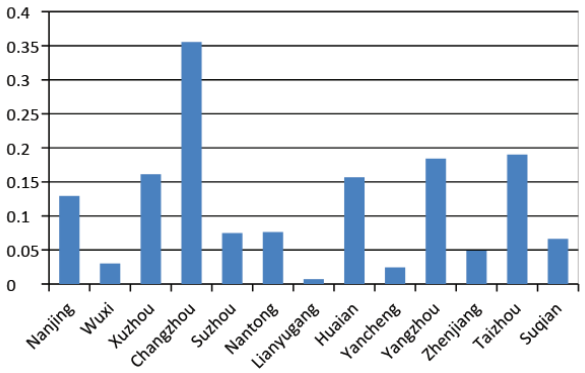

Fig. 1. Utilization ratio in 13 provincial cities in Jiangsu by 2013.

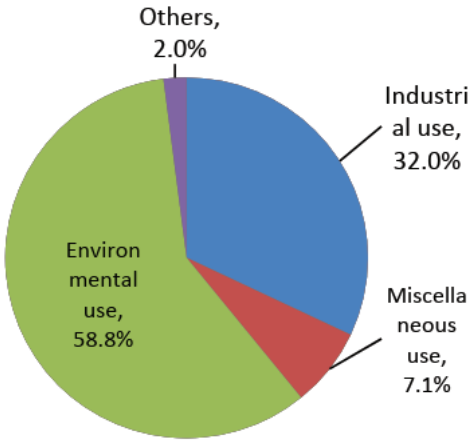

Fig. 2. Distribution of recycled water by purpose.

organisms but also may reduce the visual impact on the landscape. Water for environmental purposes has gradually become the main trend in reclaimed water use. The urban ecological water comprises river, lakes and landscape water. Whilst the landscape, recreational water mainly consists of the city watercourse and the water supplement for garden waters and lakes. The lake water consumption reaches 0.7 billion m^3/year.

With regards to the river system of the Jiangsu province, this is divided into a series of classes (III–V), which correspond to the standard of the water quality. In III class, the water body uses clear water as supplement water, whereas the IV class uses a more purified, water version. The V class uses the secondary effluent emitted by the sewage treatment plants.

2.4. Recycled water for miscellaneous use

Miscellaneous water includes the water used for many purposes: sanitary, ware washing, green construction, air-condition, car washing, street flushing in residential quarter and public buildings, amongst others. Reusing the municipal sewage water for miscellaneous purposes is feasible, since the quality of this water is lower in comparison with the drinking water.

At present, Jiangsu Province's miscellaneous water is mainly provided by tap water. In terms of car washing, as of 2014, there exist over 11 million civil owned automobiles. The water consumption per car is about 400 L/time. Considering a rate of 20 car washes per year, the total water consumption takes up to 88 billion m^3. Now, the average annual water used for public and urban road greenings in Jiangsu is about 0.3 billion m^3. As for sanitation, the consumption of water is about 0.1 billion m^3. If we consider a recycle water ratio of 80%, 0.24 billion m^3 water can be saved every year.

2.5. Public opinion toward water recycling schemes

There is still some controversy surrounding public's opinion toward the recycling and reuse of water. The community has raised some issues about the economical reliability of such projects, the environmental impacts, the methods used for disinfection, the assessment of the water quality and the health risks associated with drinking that water.

Several authors have attempted to correlate the public opinion against disgust attitudes toward water reuse, through polls and public surveys, but as yet, this evidence is not conclusive. For example, Hurlimann [17], and Dolnicar and Schafer [18] in their studies propose that most public users admit the importance of saving water, and are willing to adopt water reuse schemes. On the other hand, findings by Marks et al. [19], and Baggett et al. [20] in their study do not appear to support this conclusion, suggesting that the public opinion is biased toward the non-use of reclaimed water. In the drinking of recycled water, the public awareness is overwhelmingly negative, although there are exceptions such as the case of Singapore, which represent an initial step toward the sustainability of water resources. Research based on people's interviews [21] and game theory [22] are providing considerable insight into the complex, social and irrational perceptions that lead to the acceptance of treated drinking water. Various factors are linked with the long-term sustainability of the treated water project: adequate information, prices and water security issue, amongst others.

3. Strategy of recycled water in Jiangsu

3.1. Target and method of utilization

An approach to reduce the water shortage for Jiangsu province can be attempted by using two strategies: the first is to increase water quantity and the second is to reduce the human effects on the ecosystems. For the first strategy, the fresh water can be replaced with treated standard water using a two-stage urban sewage plant. As for the second, there needs to be a reduction on the amount of pollutants into rivers and lakes. We note three important steps to achieve both strategies:

(1) The industries (far distances) with large water demand and low water quality can use the simply treated tail water from the wastewater plant. Industrial parks (concentrated area) should reuse the sewage wastewater by using a central treatment, which is distinguished by having a different level of treatment and quality requirement.
(2) Make a full use of the tail water produced by urban centralized sewage treatment plant. Urban ecological and landscape environmental purposes should be met on a priority basis.
(3) Encourage the use of recycled water for urban green sprinkler and miscellaneous applications.

3.2. Industrial use

In the Jiangsu province, the industrial sector is still the largest contributor to the total water consumption. We consider three modes of industrial recycled water, in terms of water quality and treatment processes.

(1) Tail water from urban sewage treatment plants, which is used directly for industrial purposes with medium/high demand and low water quality, such as cooling water systems (Fig. 3). For instance, the recycled water obtained in the sewage treatment plant of Qishuyan district, in Changzhou, serves as cooling water to the industry Zhongtian Iron and Steel Group (Changzhou, China).

    Mode 1 price includes the cost covering the tail water transportation, the profits and taxes. The cost of transportation can be further decomposed into two parts: the cost covering the construction of the supercharging equipment and the promoting pump station; and the cost of operation, maintenance and management of the pipe network and the pumping station.
(2) Tail water from urban sewage treatment plants, which is employed for industrial applications demanding high

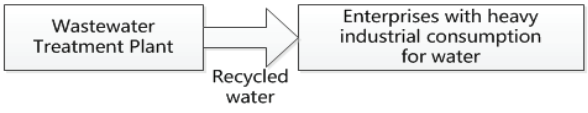

Fig. 3. Mode 1 of industrial use of recycled water.

water quality. The sewage water is processed by using a new technology of two grades (Fig. 4). This technology uses a combined process based either on membrane or activated carbon technology or a technology of ammonia blow off and ozone oxidation.

Mode 2 price includes the cost of the advanced treatment on the basis of the standard effluent and the project for transporting the water. The price in details includes: the cost for processing the secondary effluent into reclaimed water of water quality according to user's needs; the cost of reclaimed water transported to the user; and the profits and taxes of the reclaimed water's production and operation.

(3) Sewage wastewater of an industrial park, which is used for industrial users demanding a high water quality after advanced water treatment. An industrial park is mainly composed of several industries: metallurgy, opto-mechatronics, automobile manufacturers, textile dyeing and printing (Fig. 5). The industrial park produces large amounts of effluent and increases the industrial pollution which is difficult to recycle although it can be reduced using deeply treating technology. For example, this kind of model (Fig. 5) has been applying for Nantong Chongchuan Textile Industrial Park.

Mode 2 price includes the cost of the advanced treatment on the basis of the standard tail water and system of water transportation. Mode 2 is usually used in industrial parks or concentrated areas with close water conveyance distance, thus avoiding costs of conveyance project. The price varies significantly by the type of treatment processes and water quality. The conventional treatment costs about 0.4 yuan/m^3 whilst the reverse osmosis can be up to 4 yuan/m^3.

3.3. Environmental use

In the Jiangsu province, there are two main models of recycled water for environmental use.

(1) Standard tail water of sewage treatment plants, which is used as supplement water for landscapes, river and lakes.

As indicated in Fig. 6, the water body of class V can be supplied by the secondary effluent of the sewage treatment plant.

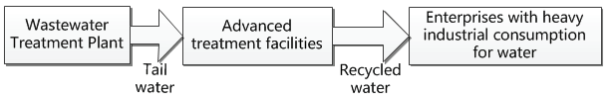

Fig. 4. Mode 2 of industrial use of recycled water.

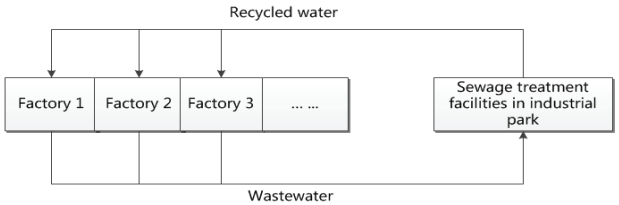

Fig. 5. Mode 3 of industrial use of recycled water.

(2) Standard tail water of sewage treatment plants, which is used as an ecological water supplement after advanced treatment.

As shown in Fig. 7, the tail water of sewage treatment plants can be used as an ecological water supplement, by using the technology of denitrification filter, coagulation sedimentation filtration, micro flocculation filtration. The secondary treatment process of biological denitrification and nitrification is viable. This method can be obtained either by: using anaerobic-anoxic-aerobic biochemistry treatment; increasing anoxic phase residence time and improving internal reflux ratio; amongst others. We believe this approach should be encouraged by city planners and policy makers of recycled water projects.

At present, the tail water of sewage treatment plant in Xuzhou city is adopted to supply the ecological flow of Kui River.

3.4. Miscellaneous use

Urban miscellaneous uses include water for urban greening, building construction, car washing, road watering, toilet flushing water amongst others. Since the miscellaneous water quality is relatively low, its norms are based on the national standard GB18918-2002 for wastewater reuse. However, differences exist as to criteria of the water quality according to the user's need.

Level A and B exist. For the index of biochemical oxygen demand (BOD), level A emission standards meet all the city service standard for miscellaneous use. Whilst the emission standards of level B meet the requirements of urban greening water quality, but not those for the purposes of flushing, road sweeping, extinguishing and protection, vehicle washing and building construction. The BOD of level B needs to be reduced by 50% with subsequent treatment, if it's to be reached at the level of A.

For the index of ammonia nitrogen, the emission standards with first level A and first level B (temperature >12°C) can meet all the city service standard. However, in winter with temperature less than 12°C and the emission standards of first level B cannot meet the requirement for road cleaning, extinguishing and protection and vehicle washing. To overcome this issue, the amount of ammonia nitrogen should be reduced by 20% at a low temperature.

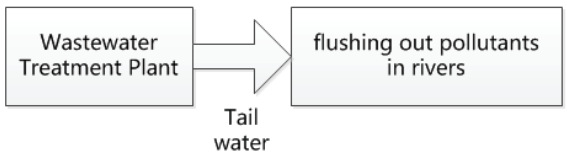

Fig. 6. Mode 1 of environmental use of recycled water.

Fig. 7. Mode 2 of environmental use of recycled water.

Miscellaneous use of recycled water in Jiangsu province mainly has two categories.

(1) Standard tail water of sewage treatment plants, which is used for miscellaneous purposes (type of point to point as shown in Fig. 8).
(2) Standard tail water of sewage treatment plants, which is used for miscellaneous water users with unified planning and comprehensive utilization (type of tree structure as shown in Fig. 9).

One of the major drawbacks to adopting this system is that the Jiangsu province contains abundant water resources and few other conditions exist for promoting the recycled water for miscellaneous use. Thus, there lacks an overall motivation and a viable solution would be the preplanning of the city's water infrastructure.

As exhibited in Fig. 9, by using a governmental department of urban construction, the layout should be established with a special plan of sewage treatment and reclaimed water process. The focus should be on the overall efficiency of the exploitation and utilization of the reclaimed water. For example, tail water from nearby sewage treatment plants could be used to drive ground-sourced heat pumps, which then can be utilized in the community.

3.5. Cost-benefit analysis

The economic viability of water conservation schemes for industrial applications such as cooling processes have received much attention over the last two decades. Particularly as the technology of water treatment improves, the capital and operational costs of reclaimed water become more competitive to those schemes based in the transferring of water (from water-rich to water-poor areas).

For instance, the company Jiangsu Zhongneng Silicon Industry Technology Development Co., Ltd. (Xuzhou, Jiangsu Province, China) has been using the recycled water since 2011. This company was set up in Xuzhou Jiangsu Province in 2006 and is the third largest professional polysilicon producer in the world by now. The reclaimed water is being supplied by Xuzhou Jinqiao Recycled Water Technology Development Co., Ltd. (Xuzhou, Jiangsu Province, China) with scale of 40,000 m^3/d. The water treatment process of eddy current reactor and fiber filter is employed at the influent water; in order to satisfy the target of the effluent quality.

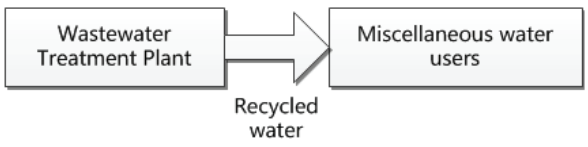

Fig. 8. Mode 1 of miscellaneous use of recycled water.

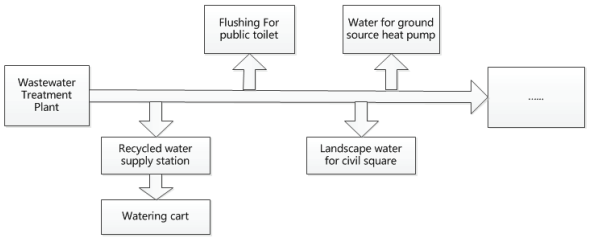

Fig. 9. Mode 2 of miscellaneous use of recycled water.

This case scenario is very important, since we can reinforce the economic viability and the usefulness of reclaimed water at an industrial scale. The project's gross investment was reported as 48.8157 million yuan, which is mainly composed of the plant area construction (33.6190 million yuan) and the pipeline (15.1967 million yuan, length: 9 km), amongst others. At present, the daily water supply is 20,000–40,000 m^3, which saves almost 12 million m^3 of the conventional water per year. According to the initial investment and projections of operational costs, the Xuzhou price department approved the retail price of the recycled water at approximately 1 yuan per cubic meter. This price takes into account the users and the price level of the recycled water. On the other hand, the original consumption of water provided by the Grand Canal from Beijing to Hangzhou is 1.8 yuan per cubic meter. This estimate includes the water resources and sewage treatment fee. So 0.8 yuan per cubic meter could be saved by using the recycled water rather than transporting large amounts of water from the Grand Canal. In recent years, the average recycled water consumption of Jiangsu Zhongneng Silicon Industry Technology Development Co., Ltd. was 20,000 m^3/d. Hence, the annual savings due to the recycled water was about 5.84 million yuan. The company was able to recover its costs after 8 years. Given that our findings are based on a small-medium scale project, the costs should reduce for a project that satisfies the water needs of the whole city.

4. A case study of reclaimed water use for miscellaneous purposes

4.1. Basic situation

A water scheme based on previous analysis is proposed for a New-city residence community, located in the area of Nantong as indicated in Fig. 10. The residence is 2 km away from the sewage treatment center. On one hand, treated tail water will exchange heat with soil in the underground pipeline and get shallow geothermal energy. The system of heat pump (with reversible mode) is able to provide cooling water (6°C–13°C), heat water (45°C–38°C) and domestic hot water (55°C). The recycled water of class A from the sewage treatment plant can then be obtained by using ozone and chlorine dioxide disinfection. This water will be mainly used for recreational and environmental purposes, such as to supply water for wetland park and for sanitary purposes (toilet flushing) in the residential community. Based on the main pipe size, the units along the line have access to the branch, according to their own needs. The project adopts the advanced automatic water supply management system, which provides a good reliability and safety of the water operation.

4.2. Case analysis

The system is reliable under operation since 2008 and shows a marked saving effect of water and electrical power. Over 1,180 residential users have got access to this recycled water system. The utilization water rate is 60%. The average

Fig. 10. Shallow geothermal energy from recycled water in New-city residence community, Nantong.

annual energy consumption from air conditioner use is about 0.3 kW·h and living hot water use is about 13 kW·h. Consumption per person for air conditioner use is about 900 yuan in summer and 800 yuan in winter. It thus appears that 4 million m^3 of fresh water and 4,900 tons of standard coal could be saved every year.

The heat pump system takes tail water of the urban sewage treatment as its resource for the water and the energy. This in term is in compliance with the policy of water saving and emissions reduction. There is no pollution, combustion, smoke evacuation and waste produced by this new clean technology. For this system, more than 70% of the energy is obtained from tail water and the remaining is driven by electrical energy conversion. As a consequence, the heat-pump system leads to substantial energy savings compared with those of oil or gas driven.

This advanced mode of recycled water has the design and construction of a tree-type chart. It focuses on the establishment of multi-target users (instead of individual users). Therefore, this application of recycled water is the foremost leading product for the whole province.

However, people in countries that currently use recycled water are reluctant to use recycled water because of their aesthetic rejection. Here, there are three policies to reduce this resistance. The first is the administrative policy which contains: the guiding policy of sewage treatment and reuse rate; the promotion policy of engineering services and pipeline construction for recycled water project; and the raising of awareness and promotion of usage of reclaimed water for both industrial and drinking purposes. The second policy refers to the economic policy which contains: the price incentive mechanism for the treatment of waste water and usage of recycled water; the investment and financing mechanisms for the reclaimed water utilization; and the preferential policies for the production and operations of recycled water. Last but not least is the technical policy which contains the standard system for recycled water quality and the incentive policy for the research and development of recycled water utilization.

5. Conclusion

Despite of the increasing implementation of water recycling schemes and demonstration projects in Jiangsu province, the water conservation process is still in early stages of development. Comprehensive analyses of water demand management are still lacking. This study proposes an assessment of overall condition and potential of recycled water in Jiangsu Province, indicating that there is a huge room for the development, particularly in the area of miscellaneous use. Different utilization models of recycled water have been put forward. As for industrial use, tail water could be used for industrial users either directly or indirectly (after advanced treatment). Furthermore, the sewage wastewater obtained from an industrial park can be used for industrial users after advanced treatment. As for environmental use, standard tail water could be used as supplement water for natural water (without treatment) and ecological flows (after advanced treatment). As for miscellaneous use, standard tail could be used for miscellaneous water users (type of point to point) or for miscellaneous water users with unified planning and comprehensive utilization (type of tree structure). Finally, a case study based on miscellaneous water use, which plays a leading role in Jiangsu province, has been analysed showing that this advanced model is focused on the establishment of multi-target users. By using this approach, the use of fresh water is reduced and substantial energy savings are thus obtained.

Acknowledgments

The research work was supported by the following funding: National Natural Science Foundation of China (51809083); Natural Science Foundation of Jiangsu Province (BK20180504); Fundamental Research Funds for the Central Universities (No.2017B06914); National Key Research and Development Program of China (2017YFC0405206).

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