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Water Reuse in Singapore: The New Frontier in a Framework of a Circular Economy?

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Abstract

As part of the circular economy, there is increasing interest internationally in water reuse, reclaimed water or recycled wastewater. This interest responds to water scarcity concerns at present and to demands projected for the resource by all sectors in the future, which will surpass freshwater available. It also responds to the incentive to close the water loop and extend the lifetime of water resources through longer use, with the related economic, social and environmental benefits. In this chapter, we discuss water reuse in Singapore where it has been implemented since 2003 for potable and non-potable uses, putting in practice the concept of circular economy. We argue that water reuse is part of a comprehensive framework of water security in the city state that considers long-term policy, planning, management, governance and technological developments. As essential foundations for a reliable water reuse system, we discuss water resources management related institutional and legal frameworks and their evolution over time. We conclude that water reuse is one of the most important pillars for Singapore to provide safe and reliable water sources at present and looking towards the future.

Keywords

Water reuse, recycled wastewater, potable applications, non-domestic users, Singapore

01
Introduction

The circular economy approach seeks to recover and reuse as much as possible of the resources that are used for socio-economic development in any given place. It has the objective to reduce pressure on the use of resources and protect the environment within a framework of sustainability (Byrne *et al.*, 2016). In the case of water resources, when properly planned and implemented, recycling and reuse can produce additional sources of clean water for the increasing number and types of uses. Applications include potable water supplies, urban non-potable applications (e.g. landscape irrigation, street cleaning), irrigation for agriculture production, groundwater storage and recharge, barriers to avoid saltwater intrusion, environmental restoration (e.g. wetland remediation), industrial processes, onsite non-potable use, etc. (USEPA, 2017).

The potential sources of wastewater for water recovery are municipal and industrial. In the case of municipal sources, they are treated to the level required for the intended use, and reused for potable and non-potable applications in the broad economy. In the case of industrial sources, they are reused for on-site purposes. In both cases, drivers for water reuse are related to water quantity and quality concerns and include actual and potential water scarcity risks, and also to the need for discharging wastewater effluents to the environment within certain quality limits with the associated fines and penalties if discharges are above the norms. Instead, by treating wastewater to higher quality standards, resulting water can be reused for different uses increasing the amount of water available (USEPA, 2012).

> *“In the case of water resources, when properly planned and implemented, recycling and reuse can produce additional sources of clean water for the increasing number and types of uses.”*

Water recycling and reuse applications depend on the short and long-term needs and resources of the specific cities, water utility operators and industries. They also depend on the possibility to respond to strict laws and regulations, to be able to cover high-capital expenditure costs in the long-term, and to address potential risks to human health and the environment as well as public perception concerns, among others.

Our analysis focuses on water reuse (recycled wastewater or reclaimed water) from municipal wastewater in Singapore to augment and diversify water resources for all uses. NEWater, as it is known locally, is part of broad, comprehensive water resources policy, planning, management, governance and technological development security framework. Water reuse covers up to 40 percent of the water needs at present and this percentage is expected to increase to 55 percent by 2060. Therefore, the reason for its importance.

We also discuss how Singapore has put in practice the circular economy concept by reusing water for potable and non-potable applications, instead of discharging the wastewater to the sea after treatment. With this, the water loop has been closed and the lifetime of water resources has been extended through longer use, with significant economic, social and environmental benefits.

02

Water Resources Management

Singapore is a city-state of 725.7 km^2 in Southeast Asia situated 137 km north of the equator at the southern end of the Malay Peninsula. It has a total population of 5.7 million and a population density of 7,866 persons per km^2 (Singapore Department of Statistics, 2020). Even though it has an average annual rainfall of around 2,340 mm, it is unable to store it due to the limited land area that can be allocated for reservoirs and the absence of aquifers. Instead, Singapore has to rely on imported water from the state of Johor, Malaysia, and to produe reused and desalinated water.

Total water demand in the city-state is projected to double by 2060 from approximately 1.9 million m^3/d at present. In order to respond to the expected demand, in addition to water conservation strategies, water reuse and desalination capacities are being increased to supply up to 85 percent of the water needs at that time (PUB, 2018d).

Singapore's long-term water security strategy started in 1965 after independence due to physical scarcity of water resources. Throughout the years, it has developed a comprehensive water resources management system that considers catchment management (including land use), infrastructure development, treating and storing local and imported water sources (from Johor, Malaysia), developing pricing and non-pricing mechanisms for conservation purposes for domestic and non-domestic users, wastewater management, production of reused water from municipal sources since 2003 (known as NEWater), and desalinated water since 2005. For both non-conventional sources of water (NEWater and desalination), major investments have been made since the 1970s in research and development to support technological developments such as membrane technology, reverse osmosis, and lower energy-intensive processes, among others.

Fundamental components of water management in Singapore have included long-term planning horizons, effective legal and regulatory frameworks, and strong political will (Tortajada *et al.*, 2013). Following is the analysis of institutional and legal frameworks for water resources management, indispensable for NEWater production.

03

Institutional and Legal Frameworks

The objectives of the Clean Water Policy in the city-state include: ensuring supply of water for all, conserving water resources, and encouraging ownership of waterways. Key targets comprise increasing supply of water from non-conventional sources of water (reused and desalinated water) to cover up to 85 percent of water needs in 2060; reducing daily per capita domestic water consumption to 130 ℓ/capita/day by 2030; and working with the public and private sectors as well as the society as a whole to create greater awareness of the importance of water conservation.

PUB, the National Water Agency, a statutory board under the Ministry of Environment and Water Resources (MEWR), manages water supply, water catchment and wastewater in an integrated way. Two other statutory boards under MEWR are the National Water Agency (NEA), and Singapore Food Authority (SFA). NEA is responsible for ensuring a clean and green environment and the sustainable development of Singapore. Key roles are to protect natural resources (including water resources) from pollution, maintain a high level of public health and provide timely meteorological information (NEA, n.d.). The recently created SFA is responsible for ensuring and securing safe food supply for the city-state (Singapore Food Agency, n.d.).

The Public Utilities Act, The Public Utilities (Water Supply) and the Sewerage and Drainage Act provide the legal framework for the water sector. The following sections present a historic view of some of the legal instruments that support efficient water resources management.

3.1. Public Utilities Act

The Act to reconstitute the Public Utilities Board and matter connected therewith is the Public Utilities Act. This was first enacted in 1963 as the Public Utilities Ordinance, when Singapore was still a British colony. The Ordinance was necessitated by the peculiar structure which the Singapore government inherited from the British administration – Singapore had both a Central Government and a City Council, which existed "side by side and [were] duplicating each other's functions and activities". For efficiency purposes, various functions of the City Council, including streets, sewage, and public health, were absorbed by the Central Government ministries. In the case of water, this was transferred from the water departments of the City Council to the newly created Public Utilities Board (now PUB National Water Agency) (Parliament of Singapore, 1962).

In 1972, the Public Utilities Act (having become an Act upon Singapore's independence in 1965), was amended to

allow PUB to cut off supplies of gas and electricity in case of emergency, fire and in certain other circumstances and also to cut off supply of water in case of misuse or waste (Singapore Government, 1972). Two years later, in 1974, the Act was amended as Singapore began to licence water service workers, e.g., workers who design, install, construct, erect or repair, or carrying out of any other work on pipes, water fittings, apparatus or appliances which supply fresh water (Singapore Government, 1974).
In the same year, electrical workers and contractors were licensed under the Electrical Workers and Contractors Licensing Act (Singapore Government, 1998). This Act would be repealed in 2001, and the licensing scheme brought under section 82 of the Electricity Act (Singapore Government, 2002a).

In 1991, the Public Utilities Act was amended again to implement a licensing scheme for gas service workers, and to provide for a list of water services works that could be done by non-licensed workers (Singapore Government, 1991). The Act was repealed and re-enacted in 1995 (Singapore Government, 1995) to allow for the Public Utilities Board to transfer its Electricity and Gas Departments to a private company, Singapore Power Pte. Ltd. Privatisation was part of a plan to allow Singaporeans to buy shares of this new company. The PUB would become a regulator for the electricity and gas service industries (Parliament of Singapore, 1995).

In 2001, the Act was again repealed and re-enacted (Singapore Government, 2001a). This time, the PUB took over the Ministry of Environment's Drainage and Sewerage Departments. The Act gave the Board a mandate, and the resources, to manage the entire water cycle optimally, opening the way for the Board to begin treating and recycling wastewater.

The Act was amended in 2012 to provide for a new function of the PUB in regulating and managing activities in and around reservoirs and waterways, including the management and maintenance of any dam or boat transfer facility in or connecting to a reservoir (Singapore Government, 2012a). This new regulatory function was required as a prerequisite for the Board to open up water bodies for community and recreational uses. It allowed the Board to draw up rules and regulations for the proper use of water bodies by the public. The Act was also amended to properly reflect the Sanitary Appliance Fee and the Waterborne Fee as a tax contribution to the sewerage system (Singapore Government, 2012b). These fees were previously justified as part of the government's general taxation power (Parliament of Singapore, 2012). Additionally, the Act now included a list of costs that may be included in the price of water supplied by the Board (Singapore Government, 2012b).

In 2018, the Act was amended once again. The water service worker licensing regime was reformed to bring sanitary plumbers into the scheme (who were previously not subject to licensing) (Singapore Government, 2018). This was done over concerns of cross-contamination of the drinking water supply and the sewerage systems, citing the case of Alameda City, California, where a cross-connection between the city's drinking water supply and a non-potable irrigation well rendered parts of the city's water supply undrinkable (Parliament of Singapore, 2018).

Institutionally, in 2004, the Ministry of Environment became the current Ministry of the Environment and Water Resources (2019) in charge of law and policy making in the environmental and water fields. Its two statutory boards, the Public Utilities Board and the National Environment, are in charge of implementing its policy directions (Tortajada *et al.*, 2013).

At present, the PUB is the primary statutory agency which manages Singapore's water supply, as well as its sewerage and drainage networks. Its statutory functions include providing, constructing and maintaining water catchment areas, reservoirs and other works; managing and working water installations; securing and providing adequate supply of water at reasonable prices; regulating the supply of piped water for human consumption; collecting and treating used water (as wastewater is known locally); promoting water conservation; regulating the construction, maintenance, improvement, operation and use of sewerage and land drainage systems; regulating the discharge of sewage and trade effluent[1]; and regulating and managing activities in and around reservoirs, waterways, and water catchment areas (Singapore Government, 2002n-v).

3.2. National Environment Agency (NEA)

NEA was created in 2002 under the National Environment Agency Act by the merger of the then-Ministry of Environment's Environmental Public Health and the Environment Policy and Management divisions, and the Meteorological Service Department (Tortajada *et al.*, 2013). This was to prepare for the streamlining of the Ministry of Environment to become a policymaker in 2004, while the NEA and the PUB would implement Ministry of Environment policies (Singapore Government, 2003a).

At present, the NEA is the primary statutory agency which manages Singapore's sanitation facilities, as part of its wider remit to manage and protect the environment. Its statutory functions include, inter alia, monitoring and assessing the water quality of inland and coastal waters, and managing and regulating the discharge of trade effluent, oil, chemicals, sewage and any other polluting matter into water courses or on land; constructing, developing, managing, and regulating refuse treatment and disposal facilities and regulating refuse collection and disposal; controlling land contamination and regulating the remediation of contaminated land; embarking on educational programmes to promote and encourage public awareness of and participation in environmental matters; making regulations on public cleansing, conservancy and the depositing, collection, removal and disposal of dust, dirt, ashes, rubbish, night soil, dung, trade refuse, garden refuse, stable refuse, trade effluent and other filth; and matters relating to the receptacles used or provided in connection therewith; and regulating the provision and maintenance of sanitary conveniences (Singapore Government, 2002m; 2003b-e).

The Public Utilities Act establishes that the PUB is the only entity allowed to supply water, unless the agency gives written approval to another entity (Singapore Government, 2002w). The quality standards of the water supplied are regulated by the NEA under the Environmental Public Health Act (Chapter 95) (Water suitable for drinking) (Part 1) Regulations enacted in March 2019 (NEA, 2019a) and Environmental Public Health (Water Suitable for Drinking) (No. 2) Regulations 2019 enacted in April 2019 (Singapore Government, 2019).

For water quality and safety standards there is a single set of standards stipulated by the National Environment Agency pursuant to the Environmental Public Health Act (Singapore Government, 2002l). These standards are found in the Environmental Public Health (Water Suitable for Drinking) Regulations 2019 (NEA, 2019a).
These Regulations also require piped drinking water quality to be monitored by the supplier (i.e. the PUB). The specific rules are found in the NEA's Code of Practice on Drinking Water Sampling and Safety Plans (NEA, 2019b) under the provisions of the Environmental Public Health (Water Suitable for Drinking) Regulations 2019 (NEA, 2019a). The water safety and water sampling plan, as well as the annual review of these plans, must be approved by the NEA (Singapore Government, 2008a). The laboratory used to test the samples must also be approved by this agency (Singapore Government, 2008b).

Regarding wastewater, the Environment Protection and Management Act provides that "any person who discharges or causes or permits to be discharged any trade effluent, oil, chemical, sewage or other polluting matters into any drain or land", without a written permission from the NEA, is guilty of an offence. Further, it provides for a statutory presumption that "where any trade effluent…[etc.] has been discharged from any premises into any drain or land, it shall be presumed, until the contrary is proved, that the occupier of the premises… had discharged" the trade effluent, etc. Additionally, any trade effluent, etc., which has been allowed to be discharged into any drain or land by the NEA must first be treated to meet the standards in both the Environmental Protection and Management (Trade Effluent) Regulations (for discharge into watercourses) (Singapore Government, 2008c), or the Sewerage and Drainage (Trade Effluent) Regulations (for discharge into sewers) (Singapore Government, 2007a).

Further, in the case of the Sewerage and Drainage (Trade Effluent) Regulations, persons may seek permission from the PUB to discharge trade effluent with a higher amount of TSS, BOD, or COD, subject to a fee in the case of TSS or BOD. Even then, these higher amounts are still subject to absolute caps (Singapore Government, 2007b).

It is the NEA who is responsible for monitoring water pollution through discharge of waste, pursuant to the Environmental Protection and Management Act (Singapore Government, 2002b).

The discharge of effluents into a watercourse or drain or land requires prior permission from the NEA under the Environmental Protection and Management Act (Singapore Government, 2002b). The discharge of effluents into sewerage requires prior permission from the PUB under the Sewerage and Drainage Act (Singapore Government, 2001b).

Permission to discharge effluents may be revoked or suspended at any time, under the Environmental Protection and Management (Trade Effluent) Regulations, or the Sewerage and Drainage (Trade Effluent) Regulations, as may be applicable. The permission can be revoked or invalidated when the relevant Regulation has been breached, or at the discretion of the NEA or PUB (Singapore Government, 2008d).

The NEA is in charge of the administration of penalties for the pollution of watercourses, and the PUB is in charge of the administration of the penalties relating to discharge of effluent into sewerage. Application of fines in Singapore to enforce regulatory measures is very strict. For example, failure to treat effluents before discharging into watercourses, drains or on land results in fines that do not exceed S$20,000 the first conviction and $50,000 the second or subsequent conviction, with possible imprisonment for 3 months.
The damage of any public sewerage system that renders the sewerage system inoperable or severe disruption to the process of treating sewage, trade effluent or the process of water reclamation due to discharging toxic substances or hazardous substance into sewerage systems results in a fine that does not exceed S$200,000 and/or imprisonment not exceeding 2 years. Penalties by both agencies can be seen in tables 1 and 2 in the Appendix.

It is within this legal, regulatory and institutional framework that is continuously adapted to the changing needs, that the PUB, National Water Agency, has produced reused water for potable and non-potable uses since 2003.
This is analysed below.

04

NEWater

Reused water, planned from the 1970s and first produced in 2013, known as NEWater in Singapore, has been successfully implemented due to support from policymakers and the public in general, within a long-term security framework (Tortajada *et al.*, 2013). It has passed more than 150,000 scientific tests and exceeds the World Health Organisation's drinking water quality standards (PUB, 2017a). Tests are supervised by a panel of local and international experts. Table 3 in Appendix shows typical values of NEWater quality.

NEWater is reclaimed municipal water that augments and diversifies water resources for all users. It is supplied directly for non-domestic purposes to wafer fabrication plants (the largest users) and industrial states and commercial buildings, by designated pipes to all users (shown in purple in Figure 3-1). The venture has been highly successful.

NEWater is also used for indirect potable purposes during dry periods by augmenting water sources in the reservoirs. It blends with raw water and is treated by conventional treatment before being distributed as tap water. Its use for indirect potable reuse represents a small proportion of water demand; however, this proportion can increase when and if necessary (Lee & Tan, 2016).

Figure 3-1 shows the water cycle in Singapore, including the NEWater contribution to the circular economy by closing the water loop and extending the lifetime of water resources through longer use (Ng, 2018), with numerous related economic, social and environmental benefits.
Economic benefits include a growing industrial sector that is supplied with NEWater; socially, it is essential because it provides the water for domestic use during dry periods for the population, and because of the jobs it supports in industrial and commercial sectors. Environmentally, its benefits are unquestionably because wastewater is treated properly before being discharged to the sea.

Currently, NEWater meets approximately 40% of Singapore's water demand. It is expected to meet up to 55% of the demand by 2060, mainly by streamlining the water infrastructure to collect 100% of wastewater.
At present, the Deep Tunnel Sewerage System (DTSS) collects and transports wastewater by gravity to centralised water reclamation plants for treatment. Phase One of the DTSS, which covers the eastern and northern areas of Singapore, was completed in 2008, and Phase Two, which will extend to western areas, is projected to be completed by 2025. The expanded system will augment overall water reclamation capacities. Existing intermediate pumping stations will be decommissioned as they will not be necessary any more (PUB, 2017a).

To produce NEWater, clarified secondary effluent from the treatment processes is introduced as feedwater in the NEWater plant. This secondary effluent is micro-screened before passing through microfiltration or ultrafiltration to remove fine solids and particles, and then further purified with reverse osmosis to remove bacteria, viruses and most dissolved salts. The reverse osmosis permeate is finally disinfected by ultraviolet radiation producing a high-grade, ultra-clean reclaimed water end product, NEWater (PUB, 2015). Improving the process and the technology used in its production is one of the key strategies of the PUB for water demand management with S$77.01 million spent in Research and Development for treatment processes since 2002 (PUB, 2018b). For example, in 2018, in the Phase 4 expansion for the management of industrial used water, the treatment capacity the Jurong Water Reclamation Plant was increased from 204,574 to 259,127 m^3/d by implementing a thermal hydrolysis process. Future capacity improvements are projected for other plants such as in the case of the Changi Water Reclamation Plant, the treatment capacity of which is expected to increase from 918,310 to 1 million m^3/d thanks to the use of membrane bioreactors (PUB, 2018a).

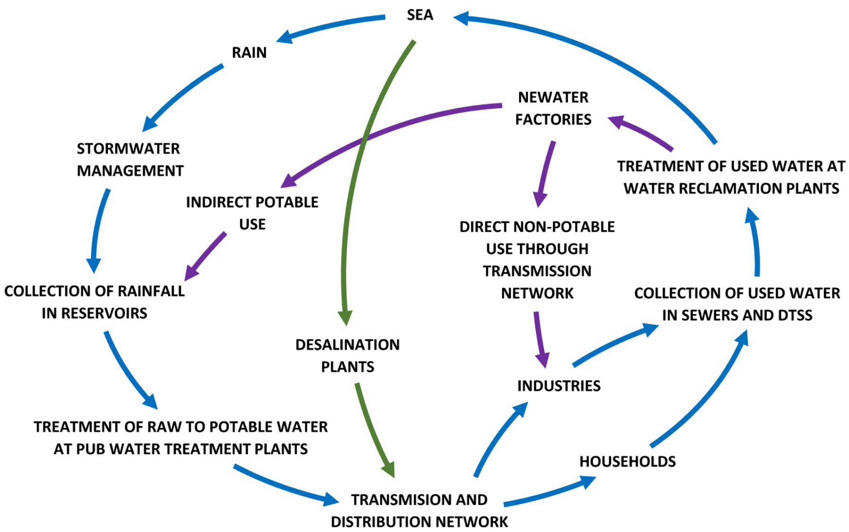

Figure 3-1 *Water cycle in Singapore (adapted from PUB, 2018d)*

The PUB recognises that urban water resilience is reliant on numerous aspects that include, but are not limited to NEWater. One of the most important aspects is water conservation by domestic and non-domestic sectors (Seah & Lee, 2020), followed by expansion and advancement of water networks, and advance in technological development. As part of resilience building, in 2017 alone, the PUB spent S$733 million in capital expenditure to replace, improve and expand water, wastewater, NEWater, and industrial water infrastructure in the order of S$404.6 million, S$294.6 million, S$13.9 million, and S$19.9 million, respectively. It is important to note that infrastructure is funded from cash generated from revenue collected (net of expenses) and borrowings (PUB, 2018a).

For a circular economy, more efficient use and conservation of (all) water resources is essential. In the case of Singapore, according to the current models used, total water use is expected to more than double by 2060 from 1.9 million m^3/d in 2020 to 4.1 million m^3/d. Approximately 70% of it is expected to be for non-domestic use, for which NEWater and desalinated water are the main water sources.
This has enormous implications in terms of energy use as energy requirements to produce NEWater and desalinated water are 5-17 times higher than conventional treatment methods.

With the expected increase in non-domestic water use and, if current technology did not improve, the energy footprint to produce both NEWater and desalinated water would increase from the current 1,000 GWh/year to 4,000 GWh/year in 2060 (PUB, 2018c). PUB's target at present is thus to reduce both water consumption of all users (mainly non-domestic) and energy consumption, mainly of the desalination processes, by more than half from the current 3.5 kWh/m^3 to 1.5 kWh/m^3 in the short term, and to 1 kWh/m^3, as a system, in the long-term. Regarding NEWater, PUB's short-term target is to increase its recovery rate from the current 75% to 90% at the same energy consumption of 0.4 kWh/m^3 for its energy-intensive RO treatment stage. In order to improve technology with the previous objectives, between 2002 and 2018, PUB, research partners, and the Singapore National Research Foundation, have invested S$453 million in over 600 water projects (PUB, 2018b).

With the aim to achieve water use efficiency and conservation, PUB provides technological support to all companies.
As a result, there are companies that are now using less potable water; others are replacing potable water use with NEWater use; and some others are using less NEWater and/or replacing it with desalinated water. For example, Systems of Silicon Manufacturing Company (SSMC) reports that their water consumption has reduced, and that water reclamation rates have increased from 50 percent in 2011 to 80 percent in 2015, resulting in an annual reduction of potable water of approximately 1 million m^3 since 2003. Companies like Mitsubishi Heavy Industries-Asia Pacific (MHI-AP) are in the planning stage to reduce consumption of NEWater replacing it with desalinating water for cooling purposes, and diverting surplus NEWater for other uses. The objective is to reduce consumption of potable water, first, and then of NEWater, for efficiency purposes and with the resulting reduction in infrastructure development investment.

There are also companies that are constructing recycling plants to reuse more water in their own processes. In one of the cases, a recycling plant under construction will be able to treat 2,000–2,500 m^3/d, increasing its water recycling rate from the current 18 percent to 41 percent and reducing NEWater consumption by 2,000 m^3/d. A key component of water conservation for non-domestic users has been to understand industries' water needs, which it is done as much as possible.

05

Final Remarks

With the objective to achieve water security, Singapore has diversified its water resource alternatives within a forward-looking, long-term framework, which has ensured it can meet present and estimated future water requirements.
These strategies have included support from the highest political level, within institutional and legal frameworks that are modified and improved when and as required.

> *"Water, being fully recyclable, is the archetypical circular economy resource."*

Singapore implemented water reuse in 2003, at a time when Windhoek, Namibia, and Orange County, California, had already been producing reused water for several decades, in the case of Windhoek for direct potable reuse (Tortajada & van Rensburg, 2020). Singapore studied their experiences and established its own system, achieving industrial large-scale implementation and wide public acceptance for indirect potable use thanks to comprehensive education and communication strategies.

Singapore's framework for water reuse within the concept of a circular economy focuses on implementing a closed system where, instead of discharging treated wastewater into the sea, this resource is treated further to produce NEWater.
This water is used then directly for non-potable uses (industrial and commercial uses) and indirectly for potable reuse (domestic use). Behind the circular economy concept, there are robust legal, institutional, managerial frameworks which aim at a mostly successful system that protects human health and protects the environment.

Water, being fully recyclable, is the archetypical circular economy resource. In the city-state, the trigger to develop a "circular water approach" was the realisation, shortly after independence, that water recovery and reuse through unconventional sources of water, was necessary and was possible. This meant incorporation of water resources management tools within a circular economy approach where wastewater is not discharged to the sea after treating it, but further treating it and reusing it for social and economic applications. This will ensure Singapore water security towards the future.

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References

Byrne, E., Fitzgibbon, K., Minescu, A., & Blanke, J. (2016). Water Reuse in the Context of the Circular Economy. Government of Ireland, Report No. 293, Wexford.

Lee, H. & Tan, T. P. (2016). Singapore's Experience with Reclaimed Water: NEWater. *International Journal of Water Resources Development*, 32(4), pp. 611-621. DOI: 10.1080/07900627.2015.1120188.

MEWR (Ministry of the Environment and Water Resources Singapore). (2019). Our Organisation: History. Retrieved from https://www.mewr.gov.sg/about-us/our-organisation/history.

NEA (National Environment Agency). (n.d.). About Us. Retrieved from https://www.nea.gov.sg/corporate-functions/who-we-are/about-us.

______. (2019a). Environmental Public Health (Water Suitable for Drinking) Regulations 2019 (Part 1, No S 156). Retrieved from https://www.nea.gov.sg/docs/default-source/default-document-library/eph-water-suitable-for-drinking-regulations-2019.pdf.

______. (2019b). Code of Practice on Drinking Water Sampling and Safety Plans. Retrieved from https://www.nea.gov.sg/docs/default-source/default-document-library/code-of-practice-on-drinking-water-sampling-and-safety-plans-(25-mar-2019).pdf.

Ng, P. J. H. (2018). Singapore: Transforming Water Scarcity into a Virtue. In Biswas, A. K., Tortajada, C. & Rohner, P. (eds.) *Assessing Global Water Megatrends*, pp. 179–186. Springer, Singapore.

Parliament of Singapore. (1962). Legislative Assembly Debates: Official Report (9 July 1962, Vol 19, Sitting 1). Retrieved from https://sprs.parl.gov.sg/search/report?sittingdate=9-7-1962.

______. (1995). Public Utilities Bill. Parliamentary Debates of Singapore: Official Report (7 July 1995, Vol 64, Sitting 13). Retrieved from https://sprs.parl.gov.sg/search/topic?reportid=028_19950707_S0003_T0011.

______. (2012). Public Utilities (Amendment) Bill. Parliamentary Debates of Singapore: Official Report (9 April 2012, Vol 89, Sitting 1). Retrieved from https://sprs.parl.gov.sg/search/topic?reportid=021_20120409_S0003_T0001.

______. (2018). Public Utilities (Amendment) Bill. Parliamentary Debates of Singapore: Official Report (6 February 2018, Vol 94, Sitting 59), Clause 2. Retrieved from https://sprs.parl.gov.sg/search/sprs3topic?reportid=bill-260.

PUB (Public Utilities Board). (2015). *Innovation in Water Singapore*, 7. Singapore. Retrieved from https://www.pub.gov.sg/Documents/vol7.pdf.

______. (2017a). *Innovation in Water Singapore*, 9. Singapore. Retrieved from https://www.pub.gov.sg/Documents/PUB_InnovationinWater_Issue9.pdf.

______. (2017b). NEWater Quality (Typical value). Retrieved from https://www.pub.gov.sg/Documents/PUB_NEWater_Quality.pdf.

______. (2018a). Annual Report 2017/2018. Singapore. Retrieved from https://www.pub.gov.sg/Documents/annualreport2018.pdf.

______. (2018b). *Innovation in Water Singapore*, 10. Singapore. Retrieved from https://www.pub.gov.sg/Documents/Innovation_in_Water_Singapore_Vol10.pdf.

______. (2018c). PUB Pushes the Frontier of Water Technology to Reach Future Energy and Sludge Reduction Targets. Press Release. Singapore. Retrieved from http://sglinks.news/article/81bee7/pub-pushes-the-frontier-of-water-technology-to-reach-future-energy-and-sludge-reduction-targets. .

______. (2018d). Our Water, Our Future: Saving Water is in Our Hands. Retrieved from https://www.pub.gov.sg/Documents/PUBOurWaterOurFuture.pdf.

Seah, H. & Lee, N. (2020). Technological Enablers and Confidence Building for Effective Non-domestic Water Demand Management. *International Journal of Water Resources Development*. https://doi.org/10.1080/07900627.2019.1695587.

Singapore Food Agency. (n.d.). About SFA. Retrieved from https://www.sfa.gov.sg/about-sfa.

Singapore Department of Statistics. (2020). Population and Population Structure. Retrieved from https://www.singstat.gov.sg/find-data/search-by-theme/population/population-and-population-structure/latest-data.

Singapore Government. (1972). Public Utilities (Amendment) Bill (Bill No 31/1972), Clauses 7 and 8. Retrieved from https://sso.agc.gov.sg/Bills-Supp/31-1972.

______. (1974). Public Utilities (Amendment) Bill (Bill No 14/1974), Sections 64A-B, Clause 4. Retrieved from https://sso.agc.gov.sg/Bills-Supp/14-1974.

_______. (1991). Public Utilities (Amendment) Bill (Bill No 20/1991), Clause 7. Retrieved from https://sso.agc.gov.sg/Bills-Supp/20-1991.

_______. (1995). Public Utilities Bill (Bill No 20/1995). Retrieved from https://sso.agc.gov.sg/Bills-Supp/20-1995.

_______. (1998). Electrical Workers and Contractors Licensing Act (Chapter 89, Section 14). Retrieved from https://sso.agc.gov.sg/SL/89-RG2.

_______. (2001a). Public Utilities Bill (Bill No 7/2001). Retrieved from https://sso.agc.gov.sg/Bills-Supp/7-2001.

_______. (2001b). Sewerage and Drainage Act (Chapter 294, 2001 Rev Ed), s 16(4). Retrieved from https://sso.agc.gov.sg/Act/SDA1999.

_______. (2001c). Sewerage and Drainage Act (Chapter 294, 2001 Rev Ed), s 16A(5)(a). Retrieved from https://sso.agc.gov.sg/Act/SDA1999.

_______. (2001d). Sewerage and Drainage Act (Chapter 294, 2001 Rev Ed), s 16A(5)(b). Retrieved from https://sso.agc.gov.sg/Act/SDA1999.

_______. (2001e). Sewerage and Drainage Act (Chapter 294, 2001 Rev Ed), s 16A(6). Retrieved from https://sso.agc.gov.sg/Act/SDA1999.

_______. (2001f). Sewerage and Drainage Act (Chapter 294, 2001 Rev Ed), s 17(4). Retrieved from https://sso.agc.gov.sg/Act/SDA1999.

_______. (2002a). Electricity Act (Chapter 89A). Retrieved from https://sso.agc.gov.sg/Act/EA2001.

_______. (2002b). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 15. Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002c). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 15(5). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002d). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 16(3)(a). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002e). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 16(3)(b). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002f). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 17(1)(a). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002g). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 17(1)(b). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002h). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 18(2). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002i). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 67(1)(a). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002j). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 67(1)(b). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002k). Environmental Protection and Management Act (Chapter 94A, 2002 Rev Ed), s 67(2). Retrieved from https://sso.agc.gov.sg/Act/EPMA1999.

_______. (2002l). Environmental Public Health Act (Chapter 95, 2002 Rev Ed), s 80. Retrieved from https://sso.agc.gov.sg/Act/EPHA1987.

_______. (2002m). Environmental Public Health Act (Chapter 95, 2002 Rev Ed), s 111(1). Retrieved from https://sso.agc.gov.sg/Act/EPHA1987.

_______. (2002n). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(a). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

_______. (2002o). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(b). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

_______. (2002p). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(c). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

_______. (2002q). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(d). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

_______. (2002r). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(da). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

_______. (2002s). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(e). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

_______. (2002t). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(g). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

______. (2002u). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(h). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

______. (2002v). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 6(1)(ja). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

______. (2002w). Public Utilities Act (Chapter 261, 2002 Rev Ed), s 41(1). Retrieved from https://sso.agc.gov.sg/Act/PUA2001.

______. (2003a). National Environment Agency Act (Chapter 195, 2003 Rev Ed). Retrieved from https://sso.agc.gov.sg/Act/NEAA2002.

______. (2003b). National Environment Agency Act (Chapter 195, 2003 Rev Ed), s 11(1)(h). Retrieved from https://sso.agc.gov.sg/Act/NEAA2002.

______. (2003c). National Environment Agency Act (Chapter 195, 2003 Rev Ed), s 11(1)(i). Retrieved from https://sso.agc.gov.sg/Act/NEAA2002.

______. (2003d). National Environment Agency Act (Chapter 195, 2003 Rev Ed), s 11(1)(j). Retrieved from https://sso.agc.gov.sg/Act/NEAA2002.

______. (2003e). National Environment Agency Act (Chapter 195, 2003 Rev Ed), s 11(1)(p). Retrieved from https://sso.agc.gov.sg/Act/NEAA2002.

______. (2007a). Sewerage and Drainage (Trade Effluent) Regulations (Rg 5, 2007 Rev Ed). Retrieved from https://sso.agc.gov.sg/SL/SDA1999-RG5.

______. (2007b). Sewerage and Drainage (Trade Effluent) Regulations (Rg 5, 2007 Rev Ed), para 11. Retrieved from https://sso.agc.gov.sg/SL/SDA1999-RG5.

______. (2007c). Sewerage and Drainage (Trade Effluent) Regulations (Rg 5, 2007 Rev Ed), para 14(2). Retrieved from https://sso.agc.gov.sg/SL/SDA1999-RG5.

______. (2007d). Sewerage and Drainage (Trade Effluent) Regulations (Rg 5, 2007 Rev Ed), para 4(5). Retrieved from https://sso.agc.gov.sg/SL/SDA1999-RG5.

______. (2008a). Environmental Public Health (Quality of Piped Drinking Water) Regulations 2008, ss 5-6. Retrieved from https://sso.agc.gov.sg/SL-Supp/S35-2008/Published/20080129?DocDate=20080129#legis.

______. (2008b). Environmental Public Health (Quality of Piped Drinking Water) Regulations 2008, s 7. Retrieved from https://sso.agc.gov.sg/SL-Supp/S35-2008/Published/20080129?DocDate=20080129#legis.

______. (2008c). Environmental Protection and Management (Trade Effluent) Regulations (Rg 5, 2008 Rev Ed). Retrieved from https://sso.agc.gov.sg/SL/EPMA1999-RG5.

______. (2008d). Environmental Protection and Management (Trade Effluent) Regulations (Rg 5, 2008 Rev Ed), para 3(5). Retrieved from https://sso.agc.gov.sg/SL/EPMA1999-RG5.

______. (2008e). Environmental Protection and Management (Trade Effluent) Regulations (Rg 5, 2008 Rev Ed), para 12(a). Retrieved from https://sso.agc.gov.sg/SL/EPMA1999-RG5.

______. (2008f). Environmental Protection and Management (Trade Effluent) Regulations (Rg 5, 2008 Rev Ed), para 12(b). Retrieved from https://sso.agc.gov.sg/SL/EPMA1999-RG5.

______. (2012a). Public Utilities (Amendment) Bill (Bill No 7/2012), Clauses 3 and 26. Retrieved from https://sso.agc.gov.sg/Bills-Supp/7-2012.

______. (2012b). Public Utilities (Amendment) Bill (Bill No 7/2012), Clause 5. Retrieved from https://sso.agc.gov.sg/Bills-Supp/7-2012. To see current prices: https://www.pub.gov.sg/sites/assets/PressReleaseDocuments/WPR2017-AnnexA.pdf.

______. (2018). Public Utilities (Amendment) Bill (Bill No 4/2018), Clauses 2, 4, 8, and 9. Retrieved from https://sso.agc.gov.sg/Bills-Supp/4-2018.

______. (2019). Environmental Public Health (Water Suitable for Drinking) Regulations 2019 (Part 2 No s 274). Retrieved from https://sso.agc.gov.sg/SL-Supp/S274-2019/Published/20190401?DocDate=20190401.

Tortajada, C. & van Rensburg, P. (2020). Drink More Recycled Wastewater. *Nature*, 577, pp. 26–28. DOI: 10.1038/d41586-019-03913-6.

Tortajada, C., Joshi, Y. & Biswas, A. K. (2013). *The Singapore Water Story: Sustainable Development in an Urban City State*. Routledge, London.

USEPA (US Environmental Protection Agency). (2012). Guidelines for Water Reuse. EPA/600/R-12/618. Washington, D.C. Retrieved from https://www.epa.gov/sites/production/files/2019-08/documents/2012-guidelines-water-reuse.pdf.

______. (2017). 2017 Potable Reuse Compendium. EPA/810/R-17/002. Washington, D.C. Retrieved from https://www.epa.gov/sites/production/files/2018-01/documents/potablereusecompendium_3.pdf.

Notes

1. “Trade effluent” means any liquid, including particles of matter and other substances in suspension in the liquid, which is the outflow from any trade, business or manufacture or of any works of engineering or building construction.

Appendix

Table 3-1 ***Penalties according to the National Environment Agency***

Offence	Penalty
Failure to inform the National Environment Agency of a discharge of effluent into watercourse/drains or on land without permission	Fine not exceeding $5,000 (Singapore Government, 2002c)
Failure to obtain permission from the National Environment Agency prior to discharging effluent into watercourse/drains or on land	First conviction: Fine not exceeding $20,000; and a further fine not exceeding $1,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2002i) Second or subsequent conviction Fine not exceeding $50,000; and a further fine not exceeding $2,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2002j) The National Environment Agency may also seek compensation through the courts for amount of any expense in connection with the execution of any work, with interest (Singapore Government, 2002k)
Failure to treat effluent to the standards in the Environmental Protection and Management (Trade Effluent) Regulations	First conviction: Fine not exceeding $10,000; and a further fine not exceeding $300 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2008e) Second or subsequent conviction Fine not exceeding $20,000; and a further fine not exceeding $500 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2008f)
Failure to treat effluent before discharging into watercourse/drains or on land	First conviction: Fine not exceeding $20,000 / imprisonment for a term not exceeding 3 months, or both; and a further fine not exceeding $1,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2002d) Second or subsequent conviction Fine not exceeding $50,000 / imprisonment for a term not exceeding 3 months, or both; and a further fine not exceeding $2,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2002e)
Discharging toxic substances or hazardous substances into watercourse/drains or on land	First conviction: Fine not exceeding $50,000 / imprisonment for a term not exceeding 12 months, or both (Singapore Government, 2002f) Second or subsequent conviction Fine not exceeding $100,000 and imprisonment for a term not less than one month and not more than 12 months (Singapore Government, 2002g)
Failure to comply with a notice by the National Environment Agency to remove/clean up toxic substance or trade effluent, oil, chemical, sewage, hazardous substance or other polluting matters which that person has discharged	Fine not exceeding $50,000 (Singapore Government, 2002h)

Table 3-2 Penalties according to the Public Utilities Board

Offence	Penalty
Failure to obtain permission from the Public Utilities Board prior to discharging effluent into sewerage system	Fine not exceeding $20,000; and a further fine not exceeding $1,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2001b)
Failure to treat effluent to the standards in the Sewerage and Drainage (Trade Effluent) Regulations	Fine not exceeding $15,000 / imprisonment for a term not exceeding 3 months, or both; and a further fine not exceeding $500 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2007c)
Discharging toxic substances or hazardous substances into sewerage system	First conviction: Fine not exceeding $50,000 / imprisonment for a term not exceeding 12 months, or both; and a further fine not exceeding $2,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2001c) Second or subsequent conviction: Fine not exceeding $100,000 / imprisonment for a term not exceeding 12 months, or both; and a further fine not exceeding $2,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2001d)
Causing (a) injury or death to any person; (b) damage to any public sewerage system which renders the sewerage system inoperable; or (c) severe disruption to the process of treating sewage or trade effluent or the process of water reclamation, by discharging toxic substances or hazardous substances into sewerage system	Fine not exceeding $200,000 / imprisonment for a term not exceeding 2 years, or both (Singapore Government, 2001e)
Failure to comply with an order by the Public Utilities Board to stop discharge of trade effluent containing dangerous or hazardous substance into sewerage system	Fine not exceeding $40,000 / imprisonment for a term not exceeding 3 months, or both; and a further fine not exceeding $1,000 for every day or part thereof during which the offence continues after conviction (Singapore Government, 2001f)

Table 3-3 PUB NEWater Quality (Typical value) (Source: PUB, 2017b)

PUB NEWater Quality (Typical value)			
Characteristics	**Unit**	**WHO 2016 GV** (First Addendum to 4th Edition)	**Typical value**
Microbiological Parameter			
Escherichia coli (E. coli)	cfu/100 mℓ	<1	<1
Heterotrophic Plate Count (HPC)	cfu/mℓ	-	<1
Physical Parameters			
Colour	Hazen	-	<5
Conductivity	uS/cm	-	<250
Chlorine	mg/ℓ	5	<2
pH Value	Units	-	7.0-8.5
Total Dissolved Solids (TDS)	mg/ℓ	-	<150
Turbidity	NTU	5	<5
Chemical Parameters			
Ammonia (as N)	mg/ℓ	-	<1.0
Aluminium	mg/ℓ	-	<0.1
Barium	mg/ℓ	1.3	<0.1
Boron	mg/ℓ	2.4	<0.5
Calcium	mg/ℓ	-	4-20
Chloride	mg/ℓ	-	<20
Copper	mg/ℓ	2	<0.05
Fluoride	mg/ℓ	1.5	<0.5
Iron	mg/ℓ		<0.04
Manganese	mg/ℓ		<0.05
Nitrate (as N)	mg/ℓ	11	<11
Sodium	mg/ℓ		<20
Sulphate	mg/ℓ		<5
Silica (as SiO_2)	mg/ℓ		<3
Strontium	mg/ℓ		<0.1
Total Trihalomethanes Ratio		<1	<0.04
Total Organic Carbon (TOC)	mg/ℓ		<0.5
Total Hardness (as $CaCO_3$)	mg/ℓ		<50
Zinc	mg/ℓ		<0.1