THE SINGAPORE WATER STORY

"I had a unit in my office which coordinated the whole of government. This dominated every other policy-making. Every other policy has to bend at the knees for our water survival"

– Lee Kuan Yew, at the inaugural Singapore International Water Week (2008) [1]

ACKNOWLEDGEMENTS

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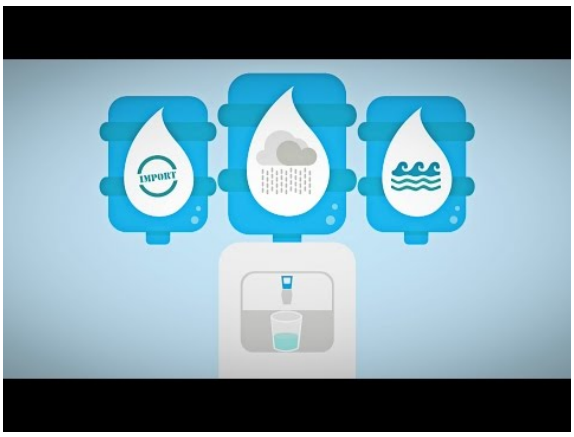
[1] Khoo, Teng Chye (2013). *Water Management: Lessons learnt from Singapore* . Retrieved from http://www.as-coa.org/sites/default/files/KhooTengChye-Presentation.pdf/

INTRODUCTION



Please watch: "The Singapore Water Story" https://www.youtube.com/watch?v=5BGUT7BjPl0

Within a short span of just 50 years, Singapore underwent a rapid transformation from a small, backwater fishing village into one of the world's leading global hubs for trade and finance. This remarkable development is a contributing factor to the rising population – more than 5 million people, along with the emergence of new industries. Together, these factors further add to the demand for the already limited water supply. The current water demand in Singapore is about 430 million gallons a day, which is projected to almost double by 2060[2]. Under such circumstances, it was unlikely that Singapore could emerge as a global leader in water sustainability. In 2015, the Water Resources Institute (WRI) ranked Singapore as one of the most water-stressed countries in the world. It thinks that, by 2040, Singapore would be one of eight countries in the world, most vulnerable to disruptions to water supply[3].

Nonetheless, despite the tough challenges ahead, by 2061, Singapore is expected to become self-sufficient for its water needs[4]. Furthermore, Singapore has even won the recognition of the world as a model city for water management and an emerging global hydro hub[5].

Such outstanding achievements would unlikely be attainable if not for a clear vision right from the start, "a clean and good quality environment", as well as a strong determination to

[2] PUB. (2016). The Singapore Water Story. Retrieved from PUB: https://www.pub.gov.sg/watersupply/singaporewaterstory
[3] PUB. (2016). Our Water Our Future.
[4] Shah, V. (2015, March 25). Lee Kuan Yew: The architect of Singapore's water story. Retrieved from Eco-Business: http://www.eco-business.com/news/lee-kuan-yew-the-architect-of-singapores-water-story/
[5] PUB. (2016). The Singapore Water Story. Retrieved from PUB: http://www.pub.gov.sg/water/Pages/singaporewaterstory.aspx

implement it – to continuously improve and innovate on both the policy and technological/engineering fronts, turning our vulnerability into strength[6].

PAST WATER CHALLENGES IN SINGAPORE

Between the 1960s-1970s, Singapore maintained only two sources of water supply, mainly from local catchments and imported water from Johor. Although they supplied everyone with sufficient water, the reliability of water supply was subjected to weather and political uncertainties.

BOX STORY 1: PUBLIC UTILITIES BOARD (PUB)

"The Public Utilities Board (PUB) was set up as a statutory board under the Ministry of Trade and Industry (MTI) on 1 May 1963 to coordinate the supply of electricity, piped gas, and water for Singapore.

In 2001, recognizing that Singapore's water catchment and supply systems, drainage systems, water reclamation plants, and sewerage systems are part of a comprehensive water cycle, the PUB was reconstituted to become Singapore's national water authority, overseeing the entire water loop. The sewerage and drainage departments from the then Ministry of the Environment were transferred to PUB. The regulation of electricity and gas industries, formerly undertaken by the PUB, was transferred to a new statutory board, the Energy Market Authority (EMA)."

"PUB integrates the management of each of the key components of Singapore's entire water cycle, from sourcing and collection, purification and supply of drinking water to the treatment of used water and its reclamation into NEWater, as well as the drainage of stormwater."

Excerpts from:
PUB. (2016). PUB and PUB Logo. Retrieved from PUB: http://www.pub.gov.sg/about/Pages/PUBLogo.aspx
PUB. (2012). INNOVATION IN VVATER SINGAPORE. Singapore: PUB.

[6] Clean, Green and Blue – Tan Yong Soon, Lee Tung Jean and Karen Tan

BOX STORY 2: THE SINGAPORE RIVER SYSTEMS

The Singapore River has a maximum navigable length of 2.95 km from where it starts at Kim Seng Bridge to its mouth at Marina Basin. The river has a width that varies from 160 m at Boat Quay to 20 m at Kim Seng Bridge.

The Kallang River, the longest river in Singapore, flows for 10 km from the Lower Peirce Reservoir to the sea. The Kallang Basin drains five main rivers: Bukit Timah/ Rocher, Sungei Whampoa, Sungei Kallang, Pelton and Geylang.

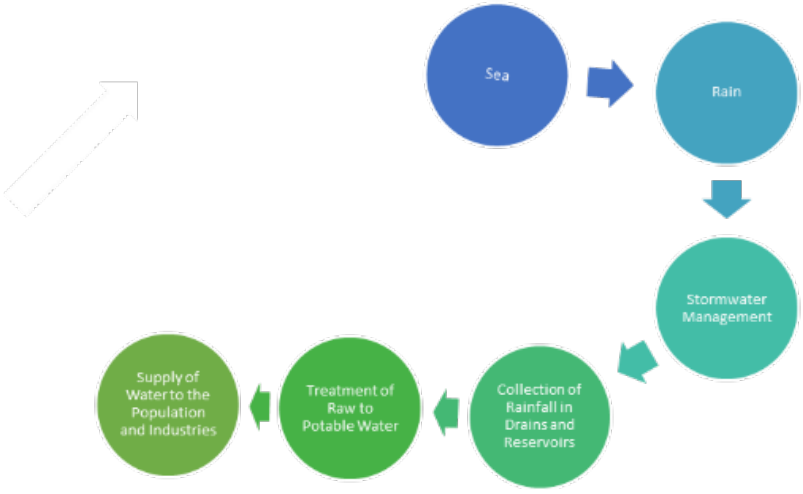


FIGURE 3.1 INCOMPLETE WATERLOOP (1960S-1970S)

'UNSIGHTLY' SINGAPORE RIVER SYSTEMS

Without knowing the history of Singapore, one would unlikely guess that the Kallang River and the now "hottest after-hours destination", the Singapore River, were for the most part of their history heavily polluted, smelly and unsightly water basins.

For more than a century, the Singapore River was a place where traditional trading and business activities took place. As early as the 1800s, migrants from abroad came and settled along the quays and river; and industries (e.g. seaweed processors) sprang up along the Singapore River,

contributing to the pollutants in the water body. Later, these were replaced by port activities, e.g. ship building and repairs at the Kallang Basin[7]. As a result, rivers were further polluted by oil and sullage water. In the 1900s, markets and street hawkers emerged along the river, often 'depositing' their used water and food into the drains or directly into the river. As a result, a strong stench pervaded the area surrounding the river[8].

By the 1960s, all rivers in Singapore became open sewers and were grossly polluted, without signs of any aquatic life.

Please watch: "Dirty, but he still loves it" https://www.youtube.com/watch?v=Y6eCvp_4wu8

A SINGAPORE 'FULL OF WATER'

FIGURE 3.2 FLOODING IN SINGAPORE IN 1978

FIGURE 3.3 FLOODING IN SINGAPORE IN 1978

[7] Clean, Green and Blue Tan Yong Soon, Lee Tung Jean and Karen Tan
[8] Joshi, Y., & Tortajada, C. (2013). Cleaning of the Singapore River and Kallang Basin in Singapore: Economic, social. Singapore: Lee Kuan Yew School of Public Policy, National University of Singapore.

Unlike today, floods were a common sight in Singapore between the 1960s - 1970s, especially within the city areas during the monsoons seasons. This was attributed to the poor drainage system and also the fact that the city occupies low lying areas in Singapore[9].

In 1969, Singapore was struck by a brutal rain - 300 millimetres of rain that fell in a 24-hour period, leaving many areas in Singapore submerged up to the chest-level. More than 3000 people lost their homes and five people lost their lives. Furthermore, many vegetable farms were destroyed, and many livestock were trapped and killed by the rain[10].

Another brutal flood hit Singapore on 2nd December 1978 – 512.4mm of rain recorded over a 24-hour period - and killed six people, many whom fell into monsoon drains and were being swept away by the water. The flood in 1978 incurred a damage cost of up to $10 million[11].

"He(Haji Zainal Bin Ahmad) remembers feeling terribly scared during times of flooding , fearing being swept away by the waters. His family would make their way to Kaki Bukit during floods to stay with their relatives as it was safer due to its higher ground. When asked about how the food supplies were affected during these floods, he told us that he did not have any refrigerators at home and thus little food was kept at home or affected by the flood. We also asked if there was any preparation done in view of these floods but was told that his family did no preparation whatsoever as the occurrence of floods was highly unpredictable and its only indication was the rise in water levels during heavy downpours[12]."

Please watch: "The Newton Circus flood of 1969" https://www.youtube.com/watch?v=lsfIvLx7jbM

[9] SG50Home. (2015). THE BIG FLOODS IN SINGAPORE. Retrieved from sg50home: http://www.sg50home.sg/the-big-floods-in-singapore.html
[10] SG50Home. (2015). THE BIG FLOODS IN SINGAPORE. Retrieved from sg50home: http://www.sg50home.sg/the-big-floods-in-singapore.html
[11] SG50Home. (2015). THE BIG FLOODS IN SINGAPORE. Retrieved from sg50home: http://www.sg50home.sg/the-big-floods-in-singapore.html
[12] Ahmad, H. Z. (2016). Memories of Geylang Serai by Haji Zainal Bin Ahmad. Retrieved from singaporememory: http://www.singaporememory.sg/contents/SMA-5405a88d-4f55-4beb-9874-aceda4643d6d

A SINGAPORE 'SHORT OF WATER'

In the 1960s, a severe drought struck Singapore and resulted in acute water shortages, forcing the nation to go into water rationing. This crisis reflected Singapore's vulnerability to water shortages.

"If I remember correctly, water supply was turned off from 8.00 am to 8.00 pm. Before the tap ran dry, we collected as much water as we could. Every pail, basin, pot and earthen jar was used as a receptacle to store water for the day. We would use the water in these containers for cooking or washing utensils only. For our daily showers, we have to wait until the water supply was restored in the evening. For some of us boys who did not want to wait until evening, we proceeded to a natural spring outside the Peirce Reservoir for our bath. I remember that there was water flowing even at the height of the drought. As the drought continued, I remember that there was talk of cloud seeding."
- Chun See Lam [13]

FIGURE-3.4 WATER RATIONING IN 1962

In fact, the scarcity of water in Singapore is to a large extent attributed to the above mentioned problems of polluted rivers and floods, which further strained the supply of potable water (During floods, clean rain water is washed off the roads and is not captured for drinking in the reservoirs).

According to WRI, today Singapore has the highest water stress ranking of 5.0, characterized by a dense population with no freshwater lakes or aquifers and a high demand for water which far exceeds its natural occurring supply[14]. This has always been the case, even 6 decades ago (1950s)

[13] Neo, F. (2009, October 16). Water Rationing (by Freddy Neo). Retrieved from goodmorningyesterday: http://goodmorningyesterday.blogspot.sg/2009/10/water-rationing-by-freddy-neo.html
[14] Femer, M. (2013, December 18). These Are The Most Water-Stressed Countries In The World. Retrieved from HUffingtonpost: http://www.huffingtonpost.com/2013/12/13/water-stressed-countries_n_4434115.html

when less than a million people resided within Singapore. The shortage of water in Singapore created a strong dependence on the imported water from Tebaru River in Johor (even in the 1950s). In response to the need for water, Singapore went into two water agreements with Malaysia in the 1960s to safeguard a temporary supply of water.

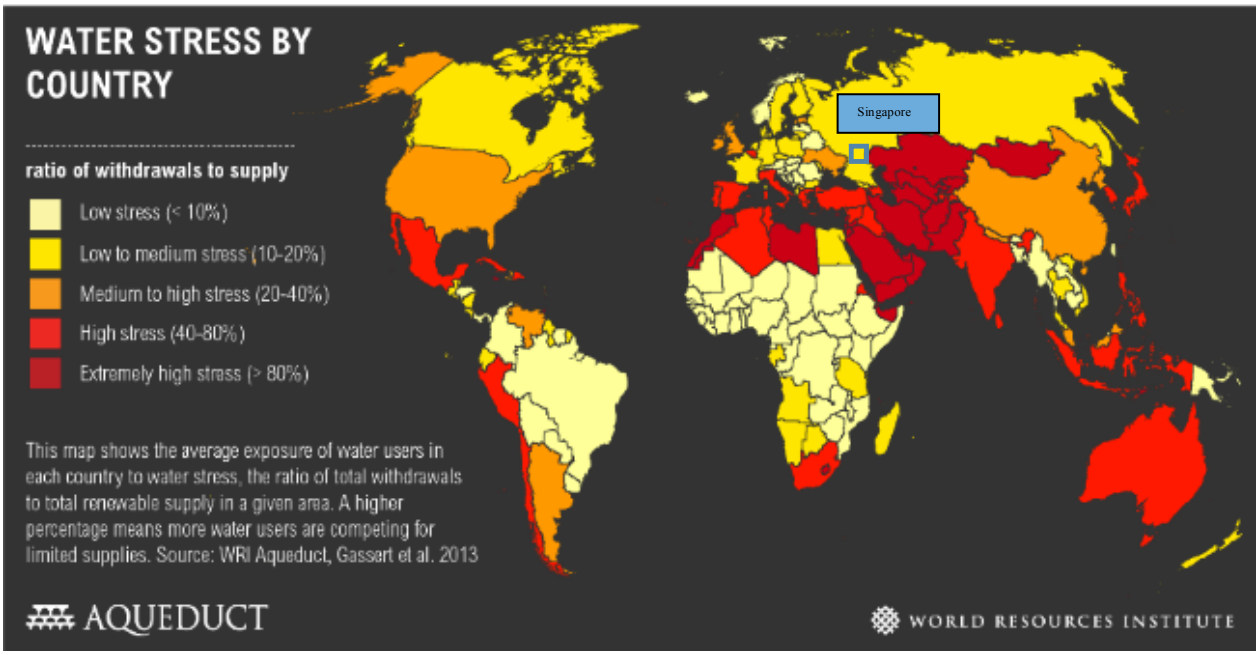


FIGURE 3.5 WATER STRESS BY COUNTRY

Today, Singapore continues to rely heavily on Malaysia for its water supply despite the separation from Malaysia in 1965. However, this one-sided reliance on Malaysia is identified as the biggest threat to Singapore's water security. The issue of supplying water to Singapore has, at times, been brought to the forefront of the Malaysian and Singapore political arena[15]. Now and then, disputes would arise between the two nations, and Malaysia would threaten to terminate the water supply to Singapore. For instance, recently, former Prime Minister Mahathir Mohamad publicly called for a review of the price of water, disapproving of selling the water from Johor at a low price of RM 0.03 sen/4.546 m^3[16]. Furthermore, once the water agreement expires, Malaysia is no longer obligated to supply Singapore with water. Thus, Malaysia dictates the price of water and most importantly, the decision of maintaining its supply of water to Singapore, leaving Singapore as a nation ever more vulnerable.

[15] Lee, P. O. (2003). *The water issue between singapore and malaysia: No solution in sight?* ISEAS Working Papers.Economics and Finance, , 1-40

[16] Teng, N. (2014, March 31). Vulnerability to Strength: the Singapore Water Story. Retrieved from aseantoday: http://www.aseantoday.com/2014/03/vulnerability-strength-singapores-water-story/

BOX STORY 3: IMPORTED WATER FROM MALAYSIA

Tebrau and Scudai River Agreement: In 1961, The City Council signed a Water Agreement with the state of Johor in Malaysia to give Singapore the 'full and exclusive right and liberty" to take, impound and use all the water within Gunong Pulai and Pontian catchments and Tebrau and Scudai rivers until 2011.

Johore River Water Agreement: In 1962, another agreement was signed to supply up to 250 million gallons of water per day to Singapore from the Johor River until the year 2061.

Excerpts from:

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

OVERCOMING THE CHALLENGES

In the 1960s-1970s, Singapore's inability to store and harvest 'clean rainwater' and the insecure water supply from Malaysia enhanced the country's vulnerability; and, paradoxically, these challenges drove Singapore towards water self-sufficiency. Singapore worked assiduously towards the goal of sustainable development with the help of pragmatic policies, clear visions, long-term planning, forward-looking strategies, and most importantly, a strong political will[17].

Lee Kuan Yew, Singapore's first prime minister, is accredited by many as the "architect of the Singapore water story". Since independence, the visionary leader had already set water as a top priority in government policies[18].

"Every other policy has to bend at the knees for our water survival," – Mr Lee Kuan Yew

[17] Tortajada, C., Joshi, Y., & Biswas, A. K. (2013). The Singapore Water Story: Sustainable Development in an Urban City-state. Oxon: Routledge.

[18] Shah, V. (2015, March 25). Lee Kuan Yew: The architect of Singapore's water story. Retrieved from Eco-Business: http://www.eco-business.com/news/lee-kuan-yew-the-architect-of-singapores-water-story/

"Water is a precious resource; without it you die. You can live without energy ... But without water you dehydrate and die," – Mr Lee Kuan Yew

This vision led to Mr Lee's challenge for the civil servants and engineers to find ways to make Singapore's water supply sustainable and to "capture every drop of rain" that fell on the island. Thus, civil servants and engineers are pushed to work to clean up the polluted waterways and increase the country's catchment areas[19].

CLEANING UP THE RIVERS (THE SINGAPORE RIVER STORY)

As part of an effort to lay the foundations for a successful industrialised nation, Mr. Lee was determined to clean up the grossly polluted River System in Singapore, hoping to improve the environment and quality of life. In the early years of independence, there were already talks of cleaning up the rivers. However, due to financial constraints, committees and commission were unable to carry out the operation[20].

In March 1969, Mr. Lee called upon the drainage engineers in the Public Works Department and water engineers in the Public Utility Board (PUB) to resolve the environmental problems associated with the waterways. His aim was to manage the river pollutants and to restore the river banks. The team was quick to identify the source of pollution and solutions to clean-up the river. By the early 1977, much of the mission to clean up the river had already been planned[21].

On 27 February 1977, Mr. Lee challenged the Ministry of Environment to clean the Singapore River and Kallang Basin within ten years:

"It should be a way of life to keep the water clean, to keep every stream, every culvert, and every rivulet free from unnecessary pollution. In ten years let us have fishing in the Singapore River and fishing in the Kallang River. It can be done." – PM Lee[22]

[19] Shah, V. (2015, March 25). Lee Kuan Yew: The architect of Singapore's water story. Retrieved from Eco-Business: http://www.eco-business.com/news/lee-kuan-yew-the-architect-of-singapores-water-story/

[20] Joshi, Y. K., Tortajada, C., & Biswas, A. K. (2012). Cleaning of the Singapore River and Kallang Basin in Singapore: Human and Environmental Dimensions. Springer.

[21] Joshi, Y. K., Tortajada, C., & Biswas, A. K. (2012). Cleaning of the Singapore River and Kallang Basin in Singapore: Human and Environmental Dimensions. Springer

[22] National Environment Agency. (n.d.). SINGAPORE RIVER CLEAN UP: AGAINST THE ODDS. THE SINGAPORE RIVER STORY, pp. 14-17.

The clean-up operation comprises two major tasks: Putting an end to the (communal and industrial) activities that produced pollutants in the Singapore River; and the cleaning of the rivers. "The enormity of the task and the physical and social difficulties" involved called for an intimate coordination between various ministries and government agencies, e.g. the Ministry of the Environment, the Ministry of National Development and the Housing Development Board[23].

One of the greatest challenges involved in this operation was the attempt to resettle people whose livelihood depended on the rivers. The government drew out a master plan identifying the sources of pollution and facilitated the relocation of the affected people to other parts of Singapore. Throughout the entire process, the Resettlement and Planning Department coordinated closely and effectively to ensure that the alternative housing was constructed in time for the squatters to move in. Fortunately, majority of the people cooperated with the operation and moved into the alternative settlements (i.e. HDB) provided by the government, giving them access to proper sanitation, clean water and electricity[24].

To be sure, there were also many who opposed this operation as the relocation meant having to readapt to an unfamiliar environment. Moreover, many business owners were unsatisfied with the new sites offered by the state. However, the government did its best to compensate those affected; and in the long run, the resettlement proved to be beneficial for the population, providing them with a safer living environment[25].

The clean-up operation was a huge success. By 1987, the Singapore River was completely transformed. "The waters flowed freely, the fishes returned and people could engage in recreational activities there"[26].

CLOSING THE WATER LOOP

[23] National Environment Agency. (n.d.). SINGAPORE RIVER CLEAN UP: AGAINST THE ODDS. *THE SINGAPORE RIVER STORY*, pp. 14-17.

[24] Joshi, Y. K., Tortajada, C., & Biswas, A. K. (2012). Cleaning of the Singapore River and Kallang Basin in Singapore: Human and Environmental Dimensions. Springer

[25] National Environment Agency. (n.d.). SINGAPORE RIVER CLEAN UP: AGAINST THE ODDS. *THE SINGAPORE RIVER STORY*, pp. 14-17.

[26] National Environment Agency. (n.d.). SINGAPORE RIVER CLEAN UP: AGAINST THE ODDS. *THE SINGAPORE RIVER STORY*, pp. 14-17.

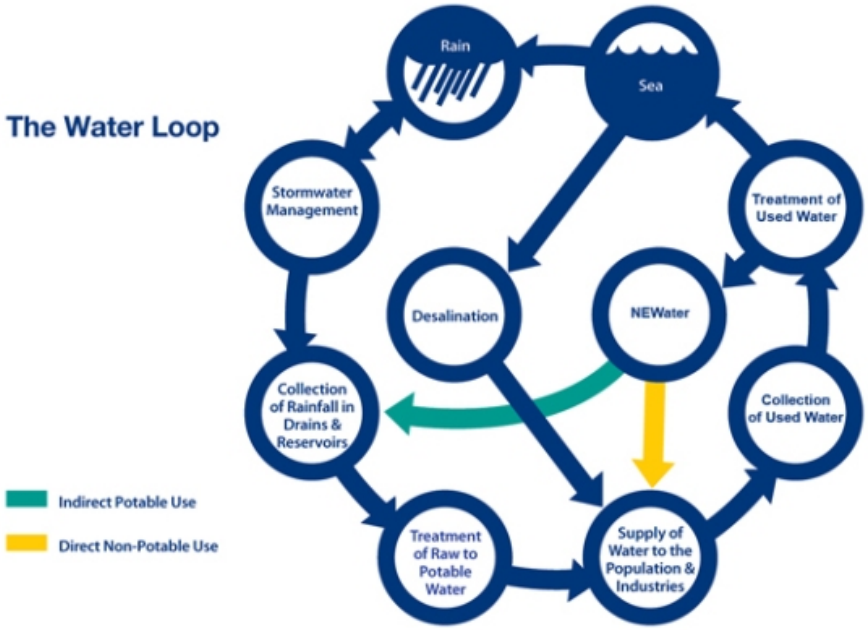


FIGURE 4.1 CLOSED WATERLOOP TODAY

In 1971, Mr. Lee set up the Water Planning Unit (which also reports directly to the PUB Steering Committee on Water Resources) under the Prime Minister's Office to take charge of drawing up Singapore's first Water Master Plan in 1972. This Master Plan aimed to relieve its reliance on imported water, and to look for "new conventional (e.g. unprotected catchments) and unconventional (e.g. water reuse and desalination)" sources of water[27]. Under the guidance of this Master Plan and also heavy investments directed into research and technology, Singapore's national water agency PUB succeeded in developing the four National Taps: 1. Local Catchments; 2. Imported Water from Malaysia; 3. Reclaimed Water/NEWater; 4. Desalinated Water[28].

Over the years, Singapore's Four National Taps strategy has created a robust, diversified and sustainable portfolio of solutions.

WATER STRATEGY IN THE 1970S

[27]PUB. (2015). Remembering Lee Kuan Yew and his Role in the Singapore Water Story. Retrieved from PUB: http://www.pub.gov.sg/annualreport2015/remembering-lee-kuan-yew.html
[28] Shah, V. (2015, March 25). Lee Kuan Yew: The architect of Singapore's water story. Retrieved from Eco-Business: http://www.eco-business.com/news/lee-kuan-yew-the-architect-of-singapores-water-story/

In the 1970s, the overall water supply development strategy of Singapore was to "proceed with surface water schemes (i.e. to expand the water catchment area) as fast as possible to increase supply and to keep under sight unconventional supply sources for projects to be implemented when it became technically feasible or necessary" [29].

In 1974, Singapore experimented with technologically advanced wastewater treatment for drinking purposes. ENV's Sewerage Department set up an advanced pilot water reclamation plant. The secondary treated effluent passed through reverse osmosis and other advanced treatments, e.g. ion exchange. This water treatment technology was a success and even met the World Health Organization guidelines for drinking water[30]. Unfortunately, this water reclamation process was evaluated as cost-ineffective due to the high cost membranes. Furthermore, "membrane technology was unreliable given that membrane fouling posed a significant challenge that required frequent cleaning". Thus, in less than 14 months, the reclamation plant faced the fate of closing down[31].

BOX STORY 4: SHOULD SINGAPORE LEARN FROM OTHERS?

"Initially, the Water Planning Unit roped in the Tahal consultants from Israel to draft out the Water Master Plan, believing that Singapore could draw on their expertise in maximizing water resources given their geographical constraints. However, the Water Planning Unit soon realized that the hydrological conditions in Israel and Singapore vary so much that the Israeli consultants could provide little meaningful contribution. For instance, the Israelis were experts on drip irrigation techniques to minimize water usage for irrigation in dry areas. However, Singapore experienced heavy rainfall almost all year round. Thus, the Israel experience could provide little help for Singapore's water problems.

Upon learning that Singapore could not rely on the Israelis to overcome water problems in tropical regions, the Planning Unit terminated their services and embarked on the 1972 Water Master Plan, this time choosing to rely on themselves."

Excerpts from:

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

[29] Tortajada, C., Joshi, Y., & Biswas, A. K. (2013). The Singapore Water Story: Sustainable Development in an Urban City-state. Oxon: Routledge.
[30] Tortajada, C., Joshi, Y., & Biswas, A. K. (2013). The Singapore Water Story: Sustainable Development in an Urban City-state. Oxon: Routledge.
[31] Tortajada, C., Joshi, Y., & Biswas, A. K. (2013). The Singapore Water Story: Sustainable Development in an Urban City-state. Oxon: Routledge.

WATER STRATEGY FROM THE MID-1980S TO 2000S

In 1987, after 10 years of effort dedicated to the clean-up of the rivers, Mr. Lee articulated another vision:

"In twenty years, it is possible that there could be breakthroughs in technology, both anti-pollution and filtration. Then, we can dam up or put a barrage at the mouth of the marina, the neck that joins the sea and we will have a huge freshwater lake. [32]*"*

Again, his vision later came true and transformed the cityscape of Singapore.

NEWATER

FIGURE 4.2 THE INCOMPLETE WATERLOOP (NEWATER INTRODUCED)

[32]SIWW. (2015, March 24). In Memory of Lee Kuan Yew: The Architect of the Singapore Water Story. Retrieved from Singapore International Water Week: http://www.siww.com.sg/sites/default/files/24032015.html

BOX STORY 5: HOW SINGAPORE DISCOVERED NEWATER

"Tan Gee Paw, chairman of PUB, deployed a two-man team to California and Virginia to study water reclamation projects for industrial use and human consumption. Upon assessing their quality and commercial viability, ENV and PUB built a pilot plant in Bedok. This pilot project was challenging and PUB's chief technology officer Harry Seah recalled that "his engineers had to work three shifts, 24 hours a day, just to get the process right".

The team succeeded within just six months, in November 2000. They managed to perfect a treatment method comprising microfiltration, reverse osmosis and ultraviolet radiation, producing water that was "not just good enough to drink, but was of superior quality to what they had seen in the US"."

Excerpts from:
Cheam, J. (2002, August 9). NEWATER IS LAUNCHED. Retrieved from Days that Changed Singapore: http://www.daysthatchangedsingapore.com/newater-is-launched/

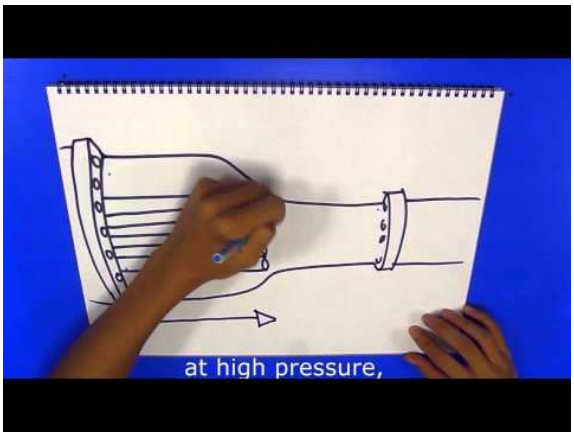
In the 1990s, membrane technology underwent rapid advancement. This technological progress led to the decision of PUB and MEWR to re-initiate the Singapore Water Reclamation Study (NEWater Study) in 1998[33]. Within less than 2 years, the first NEWater plant was completed.

The introduction of NEWater – "Ultra-clean, high-grade reclaimed water" – in 2003 marked a major breakthrough in Singapore's route towards self-sufficiency and water sustainability, moving away from its dependence on the two traditional sources of water – imported water and water from local catchments. NEWater is produced through the reclamation of used water collected via a Deep Tunnel Sewage System. Thereafter, the used water is treated at the water reclamation plants, and then transferred to NEWater plants to further undergo three processes: Microfiltration, reverse osmosis and Ultraviolet disinfection[34].

In Microfiltration, fine particles are removed from the water; in Reverse Osmosis, water molecules are forced through semi-permeable membranes, removing bacteria and viruses; in Ultraviolet Disinfection, all organisms in the NEWater are 'inactivated'[35]. These processes produce ultra-clean and safe drinking water, which went through more than 100,000 scientific tests and even

[33] (NEWater Singapore – a success story, 2015)
[34] PUB. (2013). Our Water, Our Future. Singapore: PUB
[35] PUB. (2013). Our Water, Our Future. Singapore: PUB

exceeds the drinking standards set by the United States Environmental Protection Agency and WHO[36].



Please watch: "The making of new water" https://www.youtube.com/watch?v=YemXWNOU0Kw

In an attempt to overcome the concerns and fear of the 'new' water among the public, PUB repeatedly stressed on the concept and technology of NEWater; and PUB also continuously worked on a common understanding of the role and importance of NEWater in Singapore's long term water supply[37]. Nonetheless, despite PUB's effort to emphasize on the safety of NEWater, it remains a challenge to convince the public to accept NEWater.

Therefore, since its introduction in 2003, NEWater has been mainly used for industrial and air-con cooling purposes at wafer fabrication parks, industrial estates and commercial buildings. This frees up potable water for domestic use. Besides that, PUB has also introduced an 'Indirect potable use', whereby raw reservoir water is blended with a small amount of NEWater before undergoing the treatment to produce drinking water[38,39].

[36] PUB. (2015, January 8). NEWater. Retrieved from PUB: http://www.pub.gov.sg/general/Pages/NotificationCertification.aspx
[37] Howe, C., & Mitchell, C. (2012). *Water Sensitive Cities.* London: IWA Publishing
[38] Howe, C., & Mitchell, C. (2012). *Water Sensitive Cities.* London: IWA Publishing
[39] NEWater. (2009). NEWater. Singapore: National Library Board Singapore 2009.

DESALINATED WATER

FIGURE 4.3 COMPLETED WATERLOOP (DESALINATION INTRODUCED)

Two years after the introduction of NEWater in September 2005, Singapore established its first Sing Spring Desalination plant in Tuas, turning on its fourth National Tap. This is PUB's first public-private partnership project involving both Sing Spring Pte Ltd and PUB. Sing Spring Pte Ltd oversaw the designing, building, owning and operation of the plant; and also the supply of water to PUB[40].

The seawater undergoes numerous treatment processes at the Sing Spring desalination plant before producing potable water. In the pre-treatment process, suspended particles are being removed from the seawater; in the subsequent stage, the seawater goes through reverse osmosis; in the third stage, the water produced is purified and remineralised; lastly, the desalinated water is blended with treated water before it is supplied for domestic and industrial uses in Singapore. These processes supply up to 10% of Singapore's current water needs[41].

[40] PUB. (2012/2013). Commemorating 50 Years of Water From the First Drop. Singapore: PUB.
[41] PUB. (2015, September 15). Desalinated Water. Retrieved from PUB http://www.pub.gov.sg/water/Pages/DesalinatedWater.aspx

Please watch: "Drinking from the sea" https://www.youtube.com/watch?v=d0jdlhNCgc4

Nevertheless, desalination comes at a price. Compared to the treatment of rainwater to produce potable water, desalination involves a massive amount of energy and the application of advanced membrane technology, adding to the cost of desalinated water[42].

THE THREE PRINCIPLES TO ENSURE AN ADEQUATE SUPPLY OF WATER

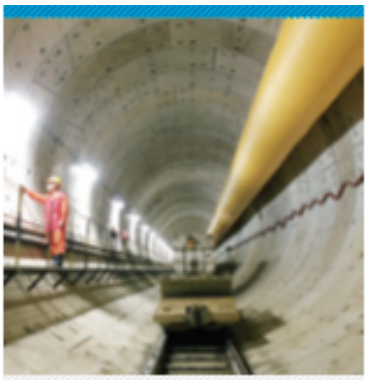
Singapore's water policies have evolved over the years, shifting the focus from survival to sustainability.

Upon the closing the water loop, PUB further developed a holistic approach to water management:

[42] Ministry of the Environment and Water Resources. (2015, April 2). MANAGING OUR WATER: DESALINATION. Retrieved from Ministry of the Environment and Water Resources: http://www.mewr.gov.sg/topic/desalination

to capture every drop of rain that falls on Singapore

As a city where land is scarce, one of our major achievements is being able to maximise urban stormwater harvesting. However, this could only be done with the complete separation of the rainwater and used water infrastructure, good land use planning and strong environmental control, to ensure that the rainwater is not polluted as it flows along the network of drains and canals into the reservoirs. With the catchment area covering two-thirds of Singapore and more people living and working within water catchments, the challenge will be to keep our waterways and water resources clean.



to collect every drop of used water

Not only has technology allowed us to purify water from urban catchments to drinking water standards, it has also short-circuited the natural water cycle. By serving as a superhighway for the collection and treatment of used water, the Deep Tunnel Sewerage System (DTSS) has let us centralise used water treatment and free up land for other uses. The collection of every drop of used water facilitates large-scale water reuse, and is therefore vital to our water supply strategy.

to recycle every drop of water more than once

By allowing every drop of water to be used and re-used, NEWater creates a multiplier effect. PUB's R&D focus is to increase the amount of NEWater that can be produced from the used water we collect, thus increasing the water recycling rate and boosting our water resources.

With this approach, in just a few decades, PUB has turned Singapore's water vulnerability into a strategic asset.

PLANNING AHEAD

The demand for water continues to rise as Singapore undergoes development and growth. In order to stay ahead of the growing demand, PUB has diligently worked on the infrastructure network. This includes the building of new plants, as well as the expansion and upgrading of existing plants

and networks in order to "boost their capacity" for water production. All these can only be achieved with the incorporation of the latest technology[43].

EXPANSION AND ENHANCEMENT

NEWATER

NEWater is the pillar of Singapore's water sustainability. It adds resilience to Singapore's water supply portfolio. In addition to providing industrial water, 2% of NEWater is mixed with surface reservoirs and in such fashion contributed to so-called indirect pottable use. During extended dry period the top up volume to the reservoirs may temporarily increase. The water blended in this fasion is treated at the water works before supplying it to the population.[44]

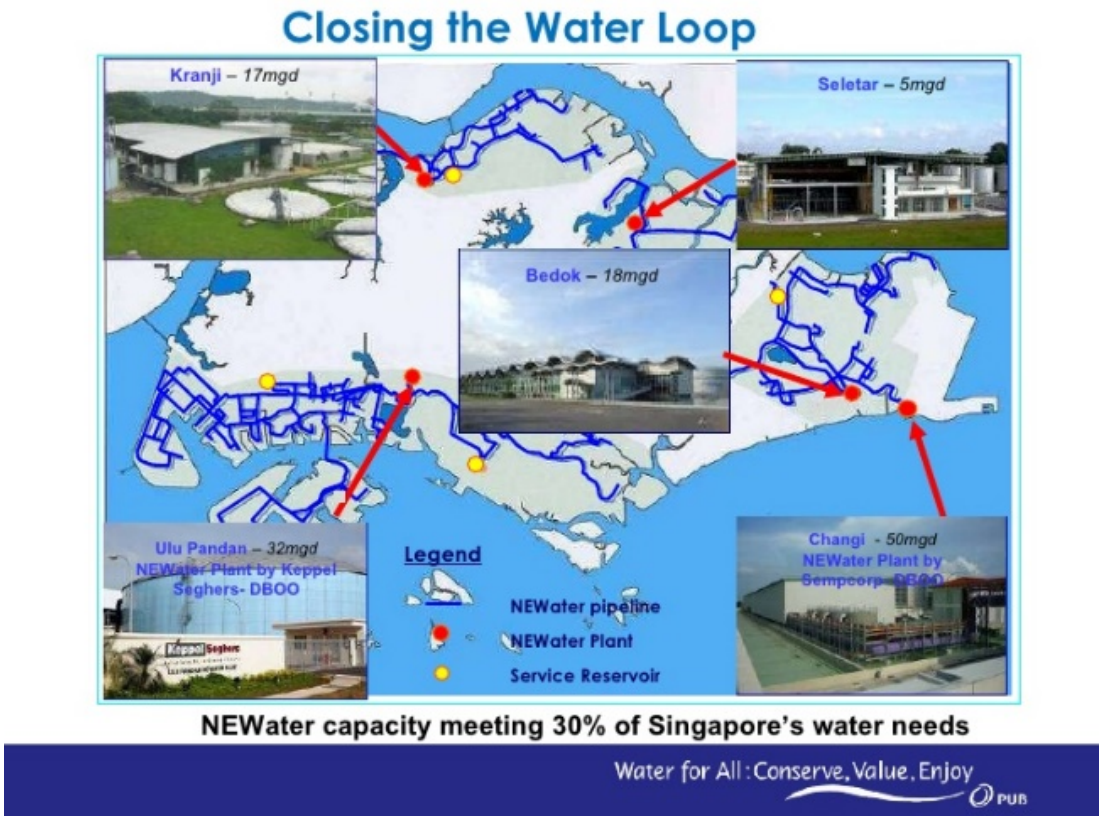


FIGURE 5.1 THE FOUR NEWATER PLANTS IN SINGAPORE

Ever since the establishment of the first NEWater plant in Bedok, the Ministry of Environment proceeded to construct four additional NEWater plants in Kranji, Seletar, Ulu Pandan,

[43] PUB. (2013). Our Water, Our Future. Singapore: PUB.
[44] PUB. (2016). Our Water, Our Future. Singapore: PUB

and Changi (the latest and largest NEWater plant), officially opened in 2003, 2004, 2007 and 2010 respectively[45].

Today, NEWater supplies up to 30% of the nation's water needs. A fifth plant, at Changi, to be completed by 2016 will boost its contribution to 40%. The Tuas NEWater factory, to be built in tandem with the DTSS Phase 2, will be ready by 2025. Thus, By 2060, the NEWater capacity will be expanded four times, to meet 55% of the future water demand[44].

Currently NEWater is produced through a three stage process, which has a recovery rate of 75%. This process is one of the most efficient ways to recycle used water. The goal however, is to increase the recovery rate to 90%. PUB, the National University of Singapore (NUS) and Untied States-based GE Water and Process Technologies are currently piloting an Electro dialysis reversal-reverse osmosis (EDR-RO) system at Ulu Pandan Water Reclamation Plant to test an alternative approach to the current process.[46]

[45] Cheam, J. (2002, August 9). *NEWATER IS LAUNCHED*. Retrieved from Days that Changed Singapore: http://www.daysthatchangedsingapore.com/newater-is-launched/
[46] PUB. (2016). Our Water, Our Future. Singapore: PUB

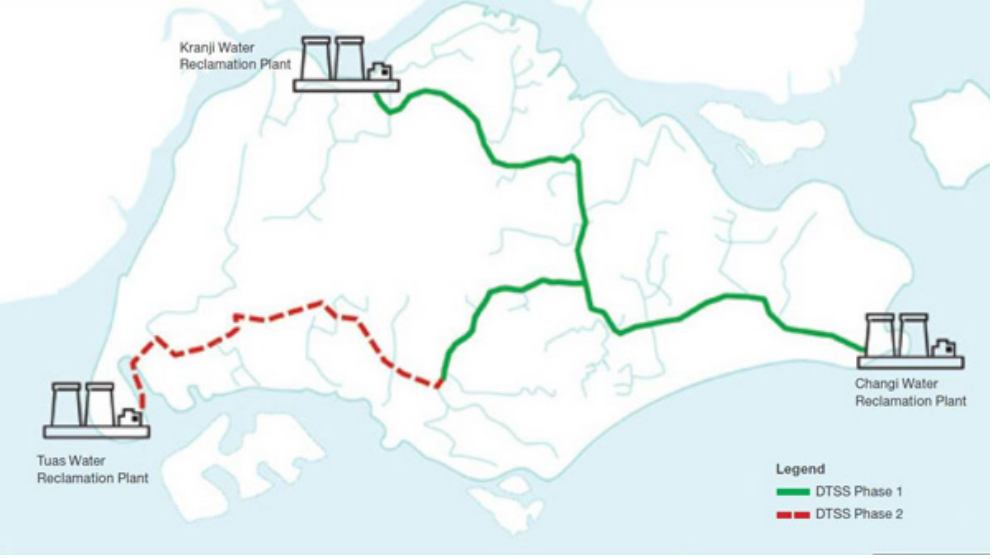


FIGURE 5.2 FUTURE PLANS FOR WRPS IN SINGAPORE

The DTSS was first conceived and introduced in Singapore in the 1990s. DTSS is a long-term solution for used water management in Singapore. This technology will help to overcome the high cost, as well as free up space occupied by the conventional renewal and expansion of the existing used water infrastructure. In the long run, Singapore aims to install only three Water Reclamation Plants on the island: Changi WRP; Kranji WRP; and Tuas WRP. If successful, the DTSS will help to reduce up to 50% of the land-space occupied by the water infrastructure and achieve water sustainability by raising water recycling rate[47].

Phase I of DTSS was successfully completed in 2008. It consists mainly four components: the 48 km long North and Spur Tunnels, 60 km of associated linked sewers, the Changi WRP in the east and deep sea outfall pipes.

Phase II of DTSS is targeted to be completed by 2025. It will also consist four components, and it plans to expand the system to cover the western part of Singapore[48].

With the DTSS, every drop of used water can be collected, treated and further purified into NEWater.

Click to find out more about DTSS.

[47] PUB. (2013). Our Water, Our Future. Singapore: PUB.
[48] PUB. (2013). Our Water, Our Future. Singapore: PUB.

DESALINATION

Currently, 2 plants with a combined capacity of 100 mgd now meet 25% of Singapore's water needs. In order to further boost Singapore's water sustainability, and diversify its portfolio of solutions, it is critical to further expand Singapore's desalination capacity to meet 30% of its water needs by 2060. This will be achieved with the help of R&D and the setting up of additional desalination plants[49]. Two new 30 mgd desalination plants will be completed in the next 4 years, in Tuas and Marina East.[50] PUB will build a fifth desalination plant on Jurong Island to enhance its resilience against the effects of climate change.

Desalinized water not only supplements the water supply, but together with NEWater, also provides Singapore with a drought resilient source of water. By 2060, it is expected that Desalinized water and NEWater will supply 85% of Singapore's water needs.

Singapore's current desalination method is reverse osmosis, which uses 3.5 Wh/m^3. Continual use of this method, however will lead to Singapore's desalination energy use in 2060 to be four times greater, compared to now. Electro-deionization could reduce desalination's energy use and cost. PUB and United States-based Evoqua Water Technologies successfully piloted the technology to demonstrate an achievable energy consumption of 1.65 kWh/m^3 at a 50 m^3/day pilot plant. Plans are in place to further scale up the technology and demonstrate it at a 3,800 m3/day facility in Tuas by the end of 2017[51].

Another exciting research field is based on biomimicry or the mimicking of biological processes by which mangrove plants and euryhaline fish extract freshwater from seawater using negligible amounts of energy. PUB's goal is to halve desalination's energy use.[52]

[49] PUB. (2013). Our Water, Our Future. Singapore: PUB.
[50] PUB. (2016). Our Water, Our Future. Singapore: PUB
[51] PUB. (2016). Our Water, Our Future. Singapore: PUB
[52] PUB. (2016). Our Water, Our Future. Singapore: PUB

BOX STORY 6: HYFLUX

"Hyflux is one of the world's leading fully-integrated water solutions companies, with operations and projects in Southeast Asia, China, India, the Middle East and North Africa. Hyflux is committed to providing cost-effective and sustainable solutions in seawater desalination, water recycling, wastewater treatment, including membrane bioreactor (MBR) and potable water treatment. Hyflux's track record includes Singapore's first water recycling plant and two seawater reverse osmosis (SWRO) desalination plants, and some of the world's largest SWRO desalination plants in China and Algeria.

Hyflux also developed Singapore's first desalination plant, SingSpring Desalination Plant, and has been operating and maintaining the plant since its commercial operation in 2005.

The successful completion of the Tuaspring Desalination Plant strengthens Hyflux's international track record in large-scale desalination plants. "With the spread of largescale desalination to more geographic markets driven by the increasing water scarcity, Hyflux is in a strong position to provide clean, affordable and sustainable water solutions to meet worldwide demand," said Ms Lum.

Hyflux has secured a S$720 million 18-year term loan facility to fund the desalination and power plants. The project financing will be provided by Maybank Singapore and Maybank Kim Eng Securities Pte Ltd as the mandated lead arrangers, sole underwriters and bookrunners. The financial close is subject to condition precedents customary to such deals, including PUB's consent and entry into such agreements as may be necessary."

Excerpts from:

Hyflux. (2013). PUB and Hyflux officially open Singapore's second and largest desalination. Singapore: Hyflux & PUB

LOCAL CATCHMENT: MARINA BARRAGE

The first aim of Singapore's water strategy was to maximize the water yield. With no natural lakes, Singapore once lacked the capability to capture the abundant rain water that fell on its land mass. MacRitchie Reservoir, the first reservoir of Singapore was completed in the late 1860s; it was named after James MacRitchie, who was the Municipal Engineer of Singapore from 1883 to 1895. Since then, Singapore has come a long way. Today, 2/3rds of Singapore landmass serves as a water

catchment. Through a dense network of rivers, canals and drains most of the rainwater that falls onto Singapore is routed to one of Singapore's 17 reservoirs for Storage.

Parallel to the developments in NEWater and Desalination, PUB plans to further enlarge Singapore's water catchment area to 90% by 2060. This will be achieved with the use of technology to harness water from the remaining streams and rivulets near the shoreline[53]. This plan fulfils Singapore's goal of capturing every drop of rain that falls on Singapore, where land is scarce and where there is a need to maximize urban storm water harvesting[54].

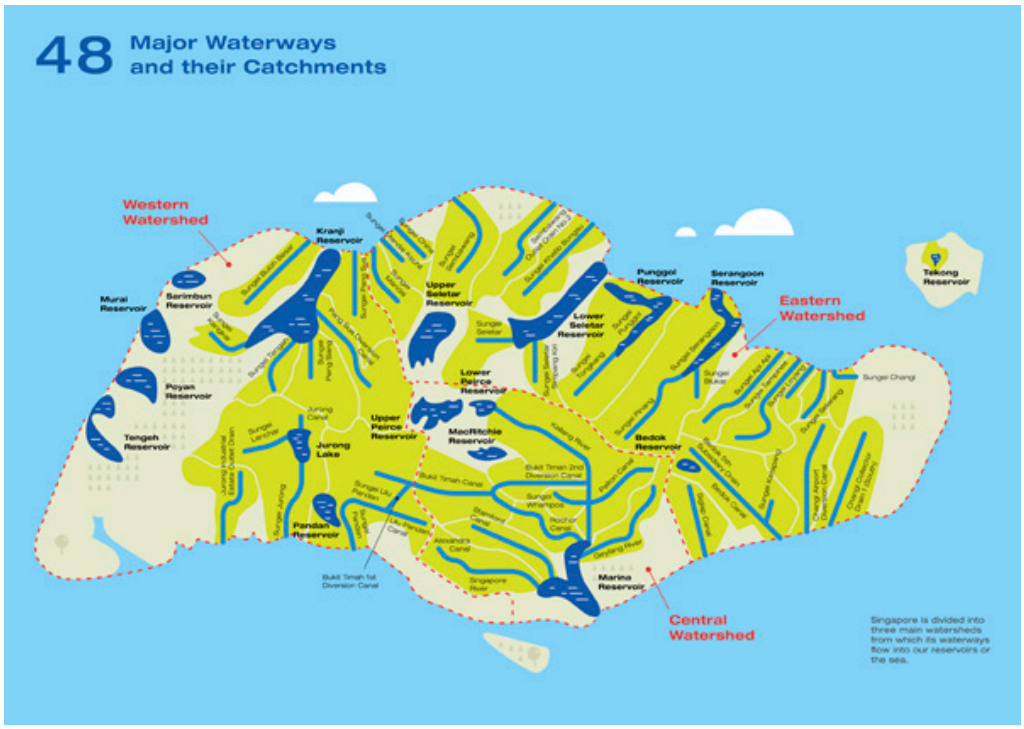
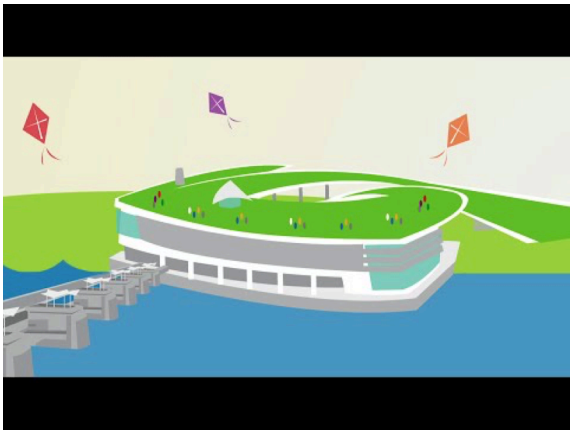


FIGURE 5.3 WATER CATCHMENTS IN SINGAPORE

[53] PUB. (2015, March 11). Local Catchment Water. Retrieved from PUB: http://www.pub.gov.sg/water/Pages/LocalCatchment.aspx

[54] PUB. (2013). Our Water, Our Future. Singapore: PUB.

BOX STORY 7: MARINA BARRAGE



Please watch: "Marina Barrage" https://www.youtube.com/watch?v=EaRULQompEk

The project of building the Marina Barrage started off in 2002, overseen by Koh Brothers Building & Civil Engineering Contractor Pte Ltd. In less than three short decades, Mr. Lee's vision to close off the mouth of the Marina Channel came true. In 2008, a dam was built across the 350 meters wide Marina channel to keep out seawater, marking a major engineering triumph in Singapore1.

Flood Control: As mentioned in the video, the two parallel systems (the nine hydraulically operated gates) help to keep the reservoir water level constant, serving as a flood control system to alleviate flooding in the low lying areas in the city, i.e. Chinatown, Boat Quay, Jalan Besar and Geylang. Through this development, as well as a comprehensive and continuous drainage improvement program, PUB successfully managed to reduce the flood prone area from 3,200 hectares in the 1970s to about 32 hectares today.

Water Supply: The development of Marina Reservoir alone is able to meet up to 10% of the nation's water needs; and together with Punggol (16th reservoir) and Serangoon (17th reservoir) Reservoirs, Singapore's water catchment enlarged from half to two-thirds of its land area in 2011.

Please watch: "ABC Waters Learning Trails" https://www.youtube.com/watch?v=f9N44EzN6vc

Singapore targets to further expand its water catchment area to 90% of the land area, and soon, all Singaporeans will live, work and play in water catchments. PUB sees this as an opportunity to transform Singapore into an environmentally sustainable city – City of Gardens and Water. This vision gave birth to the Active, Beautiful, Clean Waters (ABC Waters) Programme in 2006. PUB taps on the built waterways and reservoirs to host recreational and community activities. Through these activities where Singaporeans come into close contact with water, the ABC Waters Programme hopes that Singaporeans will enjoy and bond with water, learning to appreciate and cherish these precious resources[55].

Currently, 32 locations have successfully carried out this project; and more than a hundred locations have been nominated for the implementation of this programme by 2030. Examples of these projects include green design features such as rain gardens, bio retention swales and wetlands, which filter pollutants from the rainwater, ensuring that the water that flows into the drains, canals and reservoirs is fairly clean. These features also serve to stall the flow of water into the drains and canals, enhancing the overall drainage management. In order to improve on the quality of our living environment in an urban city that constantly develops and grows, PUB encourages developers to "implement these features within their developments, and integrate their developments with adjacent watercourses, while satisfying the engineering requirements for drainage"[56].

[55]PUB. (2013). Our Water, Our Future. Singapore: PUB.
[56] PUB. (2013). Our Water, Our Future. Singapore: PUB.

These waterways can also be used as outdoor classrooms where students can appreciate how ABC Waters design features such as rain gardens use plants natural cleansing properties to improve the quality of the rainwater runoff. PUB is also working with schools to incorporate rain gardens within their compounds, providing students with an outdoor educational tool within the school setting.

Some of the ABC Waters projects are also pilot sites for test-bedding new ABC Waters design features. PUB, the National University of Singapore and Deltares will testbed an ABC Waters design feature called in-stream wetlands. This is slated for completion by 2016. This trial will look at the wetland's ability to clean dry weather flow before it drains into the pond.

EVER RISING IMPORTANCE OF R&D IN SINGAPORE'S WATER MANAGEMENT STRATEGY

Since 2006, Singapore's water management strategy began to make a turn, gearing towards ensuring a secure and sustainable supply of water to fulfil the growing demands for water in Singapore. Water and environment technologies have been identified as a key growth sector[57]. This involves an extensive investment in R&D, as well as the integration of the best management practices[58].

The Water Research and Development in Singapore is headed by PUB, in collaboration with Environment & Water Industry Programme Office (EWI) - established in 2006 to strengthen Singapore's environment and water technology industry - Economic Development Board (EDB), International Enterprise Singapore (IE Singapore) and enterprise development agency SPRING Singapore. This team aims to transform Singapore into a global hydrohub with a thriving water ecosystem. Today, Singapore has a thriving cluster of more than 130 water companies and 26 research centers like the Singapore Delft Water Alliance, the Nanyang Environment and Water Research Institute (NEWRI), DHI, NUSDeltares etc.

[57] PUB. (2016, January 8). The Singapore Water Story. Retrieved from PUB: http://www.pub.gov.sg/water/Pages/singaporewaterstory.aspx

[58] PUB. (2012). *INNOVATION IN VVATER SINGAPORE.* Singapore: PUB.

The leadership of PUB in this project has given birth, and continues to give birth to innovative solutions in the areas of NEWater treatment technologies and methodologies to overcome water shortages[59].With the incorporation of R&D and a close collaboration between the private and public sectors, Singapore continues in its search for new and innovative methods in "containing the rising costs of treating and producing water, and identifying new sources" [60].

BOX STORY 7: SINGAPORE INTERNATIONAL WATER WEEK

"The Singapore International Water Week (SIWW) is the global platform to share and co-create innovative water solutions. The biennial event gathers stakeholders from the global water industry to share best practices, showcase the latest technologies and tap business opportunities. SIWW is part of the strategic programme of the Singapore Government to grow the water industry and develop water technologies.

Held in between the main SIWW editions, the SIWW Spotlight series are exclusive by-invitation events to continue the dialogue from SIWW and foster ongoing exchanges on pressing challenges faced by the water industry worldwide. This meeting of minds focuses on critical issues and discussions in greater depth, where the outcomes will shape the programme and content for SIWW.

A leading event on the global water calendar, SIWW delivers a range of flagship programmes where industry players share the latest in business, scientific and technological innovation, and policy developments in water.

The Water Leaders Summit, Water Convention, Water Expo, Business Forums and the prestigious Lee Kuan Yew Water Prize present valuable opportunities for participants to network, exchange information and co-create innovative water solutions."

Excerpts from:
SIWW. (2016). About SIWW. Retrieved from Singapore International Water Week: http://www.siww.com.sg/about-siww

[59] PUB. (2012). *INNOVATION IN VVATER SINGAPORE.* Singapore: PUB.
[60] PUB. (2013). Our Water, Our Future. Singapore: PUB.

FUTURE CHALLENGES

Today, the demand for water in Singapore stands at 400 million gallons a day. It is forecasted that our NEWater and Desalination capacity will continue to rise. Together, these advancements will be able to meet up to 80% of Singapore's water demand by 2060.[61]

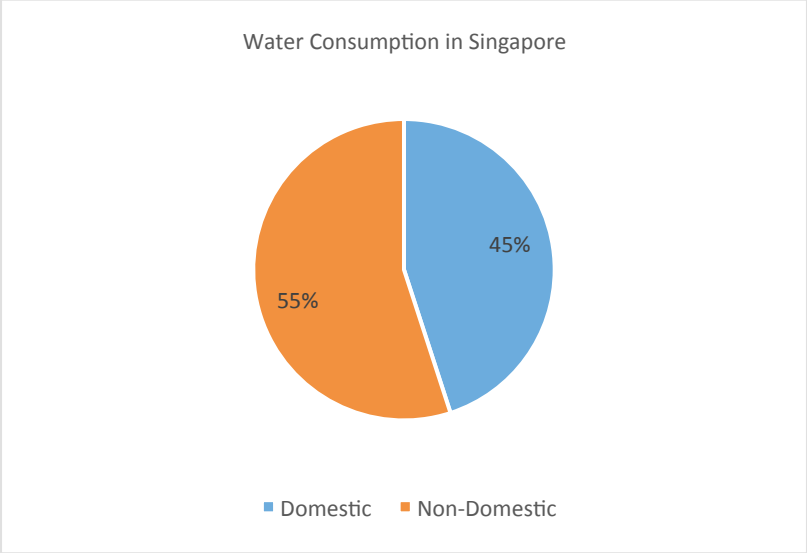


FIGURE 6.1 WATER CONSUMPTION IN SINGAPORE

FORECASTING AND PREPARING FOR THE FUTURE

In 2013, the Meteorological Service Singapore established the Centre for Climate Research Singapore (CCRS) to strengthen in-house capability in climate science and climate modelling. The CCRS also translates global climate change findings into their implication for Singapore.

Knowing what the future will bring is only half the battle. Climate change adaptation plans to take time to implement, so Singapore has started in its preparations. PUB as the lead agency for

[61]PUB. (2016, January 22). Overview. Retrieved from PUB: http://www.pub.gov.sg/water/Pages/default.aspx#sthash.od7jiYf6.dpuf

water resources and drainage, has crafted plans to help ensure enough water for all even during extreme droughts, reduce the flood risks from more intense rainfall events and rising sea levels, and minimize disruptions to water and used water services.

THE CHALLENGE OF WATER ENERGY NEXUS

Please watch: "The Water Energy Nexus – P 1" https://www.youtube.com/watch?v=z2Fgnyj0g8k

Please watch: "The Energy Nexus" https://www.youtube.com/watch?v=tADo9U-Iq8I

Singapore's ambitious goal of boosting its water production capacity requires a huge amount of energy, which is scarce and expensive just like water. The two resources, water and energy, are inextricably linked and interconnected. On the one hand, a large volume of water is used in the production of energy. On the other hand, excessive energy is utilized in treating, distributing and generating water. Singapore's development in the future decades further adds on to the demand for

water and energy. Thus, it is ever more important for Singapore to produce both clean energy and water in order to achieve economic, political and social stability[62].

[62] IDA. (2010). THE WATER-ENERGY NEXUS . Singapore: IDA.

FIGURE 6.2 JURONG ISLAND

Jurong Island is the cornerstone of Singapore's energy and chemicals industry and home to a vibrant portfolio of more than 100 leading global petroleum, petrochemical and specialty chemical companies.

Jurong Industrial Water Works (JIWW) was set up to reclaim wastewater effluent of the Ulu Pandan Water Reclamation Plant (UPWRP). The purpose of wastewater effluent reclamation is to provide an alternative source of water for industries in the Jurong and Tuas Industrial Estate. From an original capacity of 45,000 m3 per day, the current capacity is increased to 125,000 m3 per day over the years to cater for industries set up on Jurong Island and Tuas South.

With effect from April 2007, PUB has stopped supplying industrial water to the industries in Jurong/Tuas Industrial Estate as NEWater has replaced industrial water as an alternative source of water. Currently, industrial water is only supplied to the industries on Jurong Island[63].

PUB is currently looking into the following possibilities:

1. To ‘sustainably’ tap on Jurong Island’s groundwater (PUB discovered Jurong Island’s fresh groundwater in 2010)

[63] PUB (2016) : Retrieved from https://www.pub.gov.sg/usedwater/treatment/industrialwaterworks

"The island is composed of seven islands, made up of the sedimentary rock in the Jurong Formation, joined by reclamation. Rainwater seeps into the ground and is less dense than seawater, so it forms a freshwater lens atop the saltier ocean and can thus be tapped. Singapore's national water agency PUB supported by researchers from the National University of Singapore carried out several studies aimed at the development of a better understanding of national groundwater potential. The project, among other objectives, leads to a better understanding of how much groundwater can safely be tapped, and at what rate (depending on rainfall) can the groundwater supplies be recharged. As industry expands on the island, demand for water for cooling and industrial processes is expected to double rise from 35 million gallons per day to double over the next 10 years. Thus the extracted groundwater can serve not only as another source of water for Jurong Island's industries but also serve as a "water bank" for drought periods.

2. To tap on the heat waste from the industrial processes for the production of NEWater and Desalinated Water.

   Groundwater aquifers are attractive thermal reservoirs. They are characterized by minor environmental impact and can reduce greenhouse gas emissions[64]. Recent developments in underground thermal storage technology enable the storage of thermal energy for the purpose of later extraction. As such, heat is either injected for later use (heat storage) or extracted from the ground (cold storage) which is later used for cooling. Among the different energy storage methods, the one of particular interest here is Aquifer Thermal Energy Storage (ATES). The operation of ATES means that water is extracted from a well and is heated or cooled before it is re-injected into the same aquifer. So, the thermal energy is stored in the groundwater and in the matrix around it.

3. Public, privatized or a hybrid form of business model for water supply and treatment

PUB has issued a Groundwater Study tender that has accumulated four bids from consultants like Camp Dressser and Mckee and the National University of Singapore[65].

CONCLUSION

[64] (Blum et al., 2010; Saner et al., 2010)
[65] Chua, G. (2013, January 3). PUB looks at Jurong Island water needs. Retrieved from Asia One: http://www.asiaone.com/print/News/Latest%2BNews/Singapore/Story/A1Story20130101-392832.html

Singapore's ambitious goal to provide a secure and sustainable supply of water can only be achieved with the use of innovative technologies. To be sure, engineers are crucial to the accomplishment of this goal. Nonetheless, engineers cannot work alone. For example, we need engineers for the creation of NEWater. However, we also need the expertise of psychologists and sociologists to convince the public to accept NEWater. Therefore, Singapore needs to unite everyone – e.g. engineers, social workers, psychologists and business developers – to work together and persevere in the search for better innovative technological solutions to produce water for the people of the global village[66].

[66] Vonhögen-Peeters, L., Baaren, E. V., & \Lange, G. D. (2015). 964 - JURONG ISLAND GROUNDWATER MODELLING AND RISK ASSESSMENT STUDY. Singapore: Aqua 2015 - 42nd IAH Congress

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