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MANAGING USED WATER

Access to sanitation is deeply connected to virtually all the Millennium Development Goals, in particular those involving the environment, education, gender equality and the reduction of child mortality and poverty.

United Nations Secretary General Ban Ki-Moon at the launch of the International Year of Sanitation, November 2007[1]

Singapore's journey in used water management started during the early twentieth century when the country was faced with the urgent need to tackle its hygiene and sanitation problems — issues brought about by rapid population growth in its tropical environment and concerns over public health.

After independence in 1965, the government realized that the development of a world-class used water management system was crucial not only in improving the quality of life for its people but also in sustaining the economic growth of the country. A comprehensive Sewerage Master Plan was thus developed and the necessary investments made to extend the used water infrastructure so that 100 per cent of the population would have access to modern sanitation.

Increasing water demand has also necessitated reclaiming water from used water to augment water supply. Singapore's fully sewered system offered the opportunity for large-scale used water recycling and water reclamation to be carried out. Recent breakthroughs allowed for the development of more advanced water reclamation facilities, namely, the NEWater factories, which are located adjacent to the Water Reclamation Plants (WRPs). These were formerly known as Sewage Treatment Works but they were renamed WRPs in 2001 to reinforce the idea that used water is a resource to be reclaimed. The NEWater factories receive the treated used water effluent and treat (reclaim) it further using advanced membrane technology. The resulting product is high-grade water known as NEWater, which is channelled for both direct non-potable and indirect potable uses. Chapter 5 elaborates on NEWater.

This chapter provides insights into how the management of used water in Singapore evolved over the years and the key considerations behind the government's decisions in adopting various solutions as the country progressed from a simple fishing village to one which was rapidly industrializing, and eventually to the modern, cosmopolitan city of today.

KEY DESIGN FEATURES OF SINGAPORE'S USED WATER MANAGEMENT SYSTEM

There are several key features in the design of Singapore's used water management system, namely: (1) clear separation of storm water and used water streams and systems, (2) leveraging technological developments, and (3) strict regulation through legislation. The effective implementation of these key features has served Singapore well through the years and instilled the discipline that shaped its approach to the management of this municipal service. These are elaborated on in the sections below.

Separation of Storm Water and Used Water Streams and Systems

First, ensuring that used water goes into a central used water system and is kept separate from storm water has been critical in keeping the waters in and around Singapore clean. This system, inherited from the colonial days, is a more effective and economical approach in the long run as it ensures that the inland waterways, reservoirs, and the sea surrounding Singapore are not polluted through the indiscriminate discharge of untreated or semi-treated used water and trade effluent; and can be collected to produce potable water. The separation of the systems also prevents storm water from entering the used water systems and causing overflows, as may happen in the case of combined storm sewers.

Over the years, sewerage engineers continued to improve the sanitary system to enhance its efficiency and functions. These include having distinct and separate piping systems, provision of water seals in bathrooms and kitchen sinks, and proper certification for all water-service professionals. This proved to be a wise and life-saving move as seen from Singapore's experience during the Severe Acute Respiratory Syndrome (SARS) outbreak in 2003 (see details later in this chapter).

Leveraging Technological Developments

Second, greater value was derived from used water systems and their environmental impact minimized by leveraging technological developments. These are put into the planning and design of used water facilities to optimize land use, minimize the level of nuisance to the public, and reduce negative impact on the environment. Examples include: (1) effective treatment of used water to recognized international standards prior to its discharge into the sea, (2) adoption of advanced sludge treatment technology to recover energy and minimize waste generated, (3) use of compact-and-covered designs for the WRPs and equipping them with odour treatment facilities so as to reduce the footprint and buffer zones, and (4) employment of "trenchless" technologies for the laying of sewers and the renewal of old pipes under the sewer rehabilitation programme to save costs and minimize disruption to users. As described later in this chapter, these efforts were inter-related and introduced in a coordinated fashion.

Strict Regulation through Legislation

Third, in addition to putting in place good infrastructure, legislation was also enacted to ensure that the infrastructure is properly used. For instance, all premises are required to connect to public sewers where these are available. Developers of housing and industrial estates have to incorporate a central used water facility to collect and convey used water effectively into the public used water system. Proposals for development are scrutinized to ensure that they do not encroach on the public used water system (i.e., sewers, pumping, mains, etc.). This helps to avert any potential damage to the public used water system and, in turn, prevents pollution resulting from overflow or leakage of used water. In addition, stringent pipe laying and sanitary work requirements are also imposed through legislation enacted by the PUB.

SINGAPORE'S USED WATER SYSTEMS THROUGH THE YEARS

Used water management systems in Singapore have progressed from relying on the primitive night soil buckets of the early 1900s, to the shallow sewers cum pumping network of the pre-independence years, and finally to the modern deep tunnel sewerage system of today. Despite these changes over the years, the underlying motivation for these systems has remained the same, that is, to find practical and sustainable solutions for Singapore.

In the early years, sanitation and used water management systems focused mainly on tackling pollution to watercourses, to prevent the spread of water-borne diseases and maintain a high standard of public hygiene. The early solution to the sanitation problem was through the night soil (that is, human waste) collection service where night soil would be collected by bucket for disposal, sometimes indiscriminately. It was not until the 1910s that the first water-borne sanitation system was constructed to handle, treat and properly dispose the waste. Consisting of sewers in a small section of the city, this system conveyed used water to a central Sewage Disposal Works at Alexandra via three pumping stations at Park Road, Albert Street, and River Valley. At the Alexandra Sewage Disposal Works, the used water was treated through trickling filters and humus tanks before being discharged into the Singapore River.

Although various extensions and improvements were made to the Alexandra Sewage Disposal Works, it was often overloaded as the flow increased, resulting in odour which proved offensive to other developments in the vicinity. It was then decided that a used water system and disposal works be established for the eastern sector of Singapore, away from the congested city vicinity. As a result, the Rangoon Road and Paya Lebar Pumping Stations, the Kim Chuan Sewage Treatment Works, and the Serangoon Sludge Treatment Works were designed and constructed towards the end of the 1930s. These facilities served the growing population well until the early 1960s, when further construction works were required to expand and enhance the used water system.

Effective treatment of used water at the treatment works was necessary to minimize pollution, not only to the waterways but ultimately the coastal waters. With this in mind, proper treatment of used water by the activated sludge method had been introduced to improve the quality of the treated effluent. Rapid population growth and development plans for the island in the 1950–60s called for new satellite towns to be built in the then rural areas and new sewage treatment works in the western part of Singapore. The used water system was fast becoming overloaded. Thus, in 1955, the City Council commissioned the development of a new sewage treatment works, that is, Ulu Pandan Sewage Treatment Works, which was constructed on a completely new site well away from the city centre. At this new facility, used water was treated fully before being discharged into the Jurong River.

After Singapore achieved independence in 1965, rapid industrialization, the sprouting up of new housing estates, and intense urban redevelopment propelled the further development of its used water infrastructure. With the City Council (of pre-independence days) dissolved, the fledgling government undertook major investments in used water infrastructure development as it realized that this was necessary to improve the quality of life for Singaporeans and to facilitate further housing and industrial development.

DEVELOPING A BLUEPRINT — THE USED WATER MASTERPLAN

The Sewerage Master Plan (later renamed the Used Water Master Plan) was therefore conceived in the late 1960s, and tied to Singapore's overall land-use Concept Plan, which was developed using a multi-agency approach involving urban planners and housing and economic agencies, amongst others. Drawing from the apportionment of proposed land uses under the Concept Plan, the Used Water Master Plan served as a detailed guide for the development of used water facilities, specifying corresponding projected used water flows based on pre-determined zoning, and even micro-level design considerations of sewers and the layout of the used water facilities. It formed the foundation for planning the management of used water in Singapore.

Under the Master Plan, Singapore was divided into six used water catchment zones, based on the contours of the island. Each zone was served by a centralized water reclamation plant where the used water was treated to international standards before the treated effluent was disposed to the sea. Within the used water catchments, pumping stations were installed to transfer used water flows to the plants.

These plans were implemented through the 1968–73 and 1973–78 investment programmes, with assistance from the World Bank. As a condition for the loans, the World Bank required that the Government of Singapore adopt a proper charging mechanism that would sufficiently recover costs from consumers so as to ensure sustainability. In doing so, financial discipline was instilled from the outset, thus facilitating the smooth implementation of the used water plans.

These significant investments led to the provision of a comprehensive used water network and treatment services to about 98 per cent of premises by 1991. By 1997, 100 per cent of Singapore was served by a modern sanitation system. In comparison, just thirty-two years earlier in 1965, proper sanitation was available to only about 45 per cent of the population.

MANAGING AN EXPANDING AND AGEING INFRASTRUCTURE

With the Used Water Master Plan, Singapore had put in place a comprehensive used water network. Over the years, many of the older sewers have degraded through wear and tear, due to a variety of causes such as ageing, ground movements, or tree-root intrusions. In addition to the risk of structural failure, the infiltration of ground water into the sewer pipe would add to the volume of used water carried. This additional volume increases the risk of overflows in the network system. Renewal is, therefore, needed to restore the structural integrity of the sewer pipes and mains, as well as to prevent infiltration so as to preserve the capacity of the sewers, pumping stations, and treatment facilities. As part of the effort to ensure a sustainable sanitation system, Singapore has, since the 1980s, been renewing its ageing used water infrastructure.

The Sewer Rehabilitation Programme

Sewer rehabilitation in the early days involved large amounts of excavation work. Back then, sewers were rectified mainly by the open trench method which involved excavating the affected site and creating an open trench so as to access the segment of sewers that required rehabilitation. The operation, while necessary, was time-consuming and often caused inconvenience to the public. To minimize the inconveniences, PUB has, since the early 1980s, been exploring the use of "trenchless" technologies. These technologies can be grouped into two main types. First, pipe laying technologies such as pipe-jacking, where new pipes are installed with minimal excavation under the new sewer schemes. Second, *in situ* renewal processes are used where existing pipes are restored. Some of these methods include Cured-In-Place Pipe lining (CIPP), pipe bursting, and spiral wound lining methods.

The more common method of CIPP cleverly uses a process involving inserting a flexible resin-impregnated felt liner via a manhole into the existing host-pipe under water pressure. Once in place, the soft material forms a lining against the original pipe. The lining is then cured using hot water. Once cured, the liner forms "a pipe-within a pipe", functioning like a new pipe. CIPP requires no excavation, resulting in minimal site disturbance and no adverse environmental impact. "Trenchless" technologies such as these have greatly saved time and costs, resulting in cost reductions of as much as 40 per cent. Employing these methods has also lessened the inconvenience to the public as most of the work happens underground, with less disruption to traffic flow and no significant interruption to used water services for the residents living in the vicinity.

The development of new reservoirs in highly urbanized areas such as the Marina Reservoir brought new challenges for sewer maintenance. Diffused leaks, especially from shallower sewers, had to be minimized to reduce the adverse impact on the aesthetic and recreational quality of the water bodies after the regular seawater flushing is removed with the completion of the Marina Barrage. To meet these challenges, a new phase of the sewer rehabilitation programme was launched in 2006, to focus on rehabilitating the shallower public sewers that were found to be leaking.

Whilst it is the government's responsibility to maintain public sewers, a significant portion of the ageing sewers are under private ownership, channelling used water from individual premises to the public sewers. To assist private owners in ensuring that their sewers are functioning properly, PUB also embarked on a Private Sewer Rehabilitation Programme as part of the overall sewer rehabilitation programme to conduct free checks on the condition of private sewers and advise owners on any rectification work required. As a start, these efforts focus on developments that are more than ten years old and located within the highly urbanized water catchment of the Marina Reservoir. Should repairs be needed, the government helps to defray part of the costs, and the services of PUB's contractors are also made available to the owners of private sewers so as to ensure that cost is kept to the lowest through aggregation. Other forms of financial assistance rendered include allowing owners to pay through monthly instalments if they engage PUB for the rectification works.

Since the implementation of the private sewer rehabilitation programme, leaks were found in the private sewers of many older buildings. These were subsequently rehabilitated, and the leaks fixed. This reduces the pollution load in the Marina catchment, and helps to improve water quality in the Marina Reservoir. PUB will continue with the programme to maintain the operational reliability of the sewerage network and improve water quality.

IMPROVING THE DESIGN OF WRPs

A concerted effort has been made in the planning and design of used water facilities to maximize land use and minimize the level of negative impact to the public.

Reducing the Buffer Zones

The WRPs are located in areas that were once rural. Conventional design meant that open tanks were used, and given the tropical climate, odour nuisance was inevitable. Hence, these WRPs had a 1-kilometre buffer zone within which only limited development was allowed. As the urban area expanded, demand for more land led to a need to reduce the large buffer zones and the footprint of treatment plants. Thus, four of the six WRPs were progressively covered up in the 1990s and the foul air extracted for treatment in specially developed odour control facilities. As a result, the buffer zone for WRPs was reduced from 1 kilometre to 500 metres from the fence line of the WRP.

Compact Covered Plants

The designs of WRPs were further optimized in the late 1990s when three WRPs needed to be expanded to meet the increased used water treatment needs. The extensions for the Kranji, Ulu Pandan, and Seletar WRPs were completed in 1999, 2000, and 2001 respectively, based on the compact-and-covered design concept. This concept allows the rectangular treatment units to be stacked on each other, making the final structure compact. Deep reactor tanks were also used to further reduce the footprint. In addition, these compact units are also enclosed and the odorous air extracted and treated to render it odourless before being discharged into the atmosphere.

Odour Control Facilities

The treatment of foul odour from the WRPs has been extensively carried out to mitigate smell nuisance affecting developments near the plants. At the WRPs, comprehensive odour control facilities comprising odour containment covers over the treatment units, extensive odorous air extraction systems, and odour treatment plants, are introduced to contain and treat the foul air from covered treatment units prior to its discharge. The end result is an improved ambience within the plant and minimized odour nuisance to the surrounding areas. With the odour control systems in place, the odour buffer zone around the WRP is reduced and more land can be released for higher value developments.

In recent years, there has been increasing interest in the use of biomass to treat odour. Replacing the chemical scrubbers with bioscrubbers for odour treatment in the WRPs eliminates the use of hazardous chemicals and reduces the operating cost of odour treatment. In Singapore, bioscrubbers have been installed in the Ulu Pandan, Bedok, and Kranji WRPs. Recently, locally developed biocarbon technology (which combines the odour treatment functions of the bioscrubbers and activated carbon) is being tried out with the installation of three biocarbon scrubbers at the Kranji WRP. It is the first of its kind in the world and further eliminates the need to replenish activated carbon. If successful, it promises to reduce further the capital and operating costs for odour treatment.

THE DEEP TUNNEL SEWERAGE SYSTEM

Despite having achieved 100 per cent access to modern sanitation facilities for its entire population, Singapore is constantly challenged by the demands of its ever increasing population and growing economy. The existing conventional used water infrastructure and systems were reaching their maximum capacities and economic lives. To ensure the long-term sustainability of the systems, one option was to continue expanding and upgrading these conventional water reclamation plants. The second option was to embark on a totally novel approach that would employ new technologies that were both cost effective and able to meet the more stringent environmental requirements. After much deliberation, the government decided in

1995 to opt for the second approach and took the bold step of transforming its used water system by putting in place the Deep Tunnel Sewerage System (DTSS).

To be implemented in two phases, this long-term project consists of two large, deep tunnels criss-crossing the island, two large centralized water reclamation plants located at the eastern and western ends of the island, deep sea outfalls, and a link-sewer network. The two deep tunnels are designed with diameters of up to six metres, making them as big as a typical Mass Rapid Transit (MRT) tunnel! Also, these tunnels are built at depths ranging from 20 to 50 metres below ground, which are deeper than a fifteen-storey building, and are connected to the existing used water reticulation system through a network of smaller link sewers.

Given the scale of the DTSS, it is constructed and implemented in phases. Construction of Phase I, commenced in 1999 and completed in 2008, involved the construction of the North and Spur Tunnels, Changi Water Reclamation Plant, and the Changi Outfall, as well as link sewers diverting the flows to the main tunnel sewers. Phase II, which will be implemented over the next ten to twenty years, will involve the construction of the South Tunnel, a link sewer network, another large water reclamation plant, and an outfall, located at the southwestern part of Singapore. The total cost of Phase I is about S$3.65 billion. The DTSS is considered a great engineering feat, having been awarded the Institution of Engineers Singapore (IES) Prestigious Engineering Achievement Award, as well as the ASEAN Outstanding Engineering Achievement Award in 2005 and the International Water Association's Project Innovation Award in 2008.

Cost-effectiveness, Land-use, and Environmental Considerations

The large and deep sewers of the DTSS allow large volumes of used water from the growing domestic and industrial sectors to be conveyed to large centralized water reclamation plants for treatment.

Population and economic growth were taken into consideration in the sizing of the large tunnels and the design of the water reclamation plants. This also eliminates the need for continual upgrading and expansion of the existing intermediate used water pumping stations, and the six aged water reclamation plants (along with their attendant outfall discharges) to cater to increasing demands while meeting more stringent environmental requirements.

With the completion of the DTSS, used water flows from the sewerage system to the centralized water reclamation plant will be achieved through gravity flow. This will result in the phasing out of 134 sewage pumping installations and smaller water reclamation plants scattered over the island, freeing up some 880 hectares of land, including buffer zones around the facilities, for residential and other high value developments. This is about 1.5 times the size of Choa Chu Kang New Town, located in the northwestern part of Singapore. In fact, the new Changi Water Reclamation Plant takes up only one-third of the land area of the existing plants. Further land savings can be achieved, as the roof of the Changi Water Reclamation Plant is used to house a NEWater plant.

Furthermore, the risk of used water overflows arising from failures in the intermediate pumping system will be eradicated. The phasing out of the pumping stations and mains will greatly enhance the operational reliability of the used water system, and, in turn, protect water quality, especially in water catchments that will cover two-thirds of Singapore by 2009. Project Director of the DTSS, Chiang Kok Meng, commented:

> Some might also recall that in 1987 both sewage pumping mains from one of our sewage pump stations had ruptured and seriously polluted the Kallang River. Our existing sewerage system is a combination of gravity and pumping mains, and half of these are located in water catchments! Can you imagine the consequences of any breakage?[2]

The treatment processes installed in the Changi Water Reclamation Plant are also able to treat used water to effluent standards that are better than the existing plants so that treated used water effluent discharged through the Changi Outfall will not have any adverse impact on the water quality or ecology in the surrounding waters. With the gradual phasing out of existing WRPs and their discharges of treated effluent, the water quality of the seas surrounding Singapore will be further enhanced for recreational activities.

Opportunities to Develop Singapore's Water Industry

The construction of the DTSS involves excavating and constructing some 48 kilometres of concrete tunnels, of diameters between 3.3 metres to 6 metres and at depths between 20 to 50 metres below ground level. Further work includes lining the tunnel walls with corrosion-resistant membranes, constructing link sewer systems, as well as building a large (800,000 cubic metres a day capacity) centralized water reclamation plant with a 5-kilometre-long deep sea outfall. This mammoth challenge required the dedicated work of 49 main contractors and consultants, more than 300 subcontractors and suppliers, and 4,000 workers, featuring contractors, design consultants, and project supervisory teams from many countries including Singapore, Austria, China, Japan, Korea, Germany, India, the United Kingdom, and the United States.

Rather than packaging the DTSS project into one or two large contracts, PUB decided to carve the project into a number of smaller contracts. This gave more contractors, both local and international, the opportunity to participate, and also built up PUB's close partnership with the local private sector. Under Phase I of the DTSS project, PUB awarded fifteen link sewer contracts, with local contractors participating in twelve of them.

At the DTSS Pumping Station completion ceremony at Changi Water Reclamation Plant on 28 August 2006, Dr Yaacob Ibrahim, Minister for the Environment and Water Resources, said:

> With the completion of this DTSS pumping station, it is yet another step forward in our journey to ensure the long term sustainability of our water resources… It will act like a superhighway, efficiently linking the many intricate but extensive tributaries of public and private sewers in homes and buildings to the water reclamation plant... The impending completion of the whole DTSS (Phase I) is indeed the apex in our ongoing efforts to ensure that Singapore continues to have a first class used water network.[3]

With the completion of Phase I of the DTSS, used water flows in the eastern part of Singapore will be diverted into the DTSS in phases. In tandem, the existing WRPs and pumping stations in this sector will also be phased out (refer to Map 4).

THE SARS OUTBREAK OF 2003 — AVERTING A CRISIS

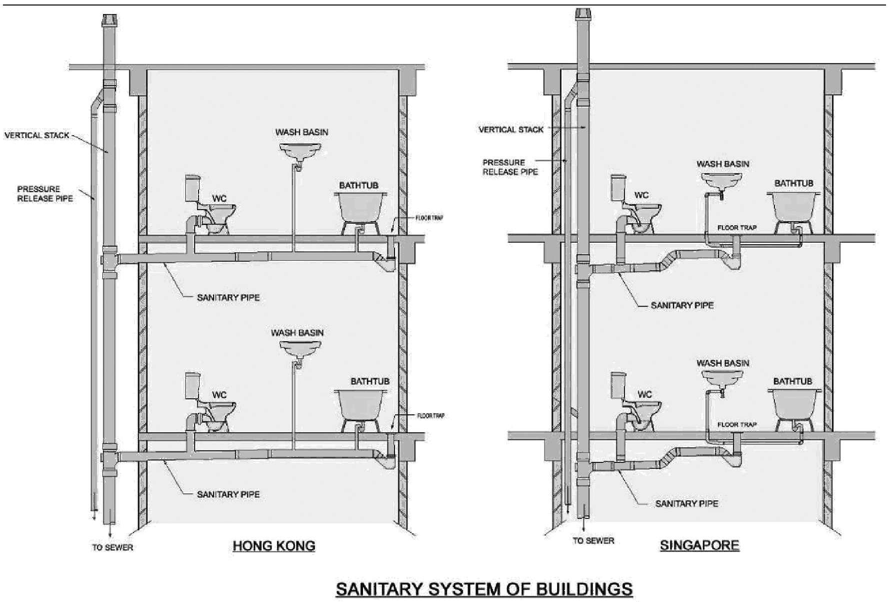
When Singapore was afflicted with the Severe Acute Respiratory Syndrome (SARS) in 2003, the spread of the virus was mainly thought to be via airborne transmission. However the spread of the virus within large residential tower blocks at Amoy Gardens in Hong Kong led authorities to suspect that the sanitary system could be the culprit allowing "faecal droplets" containing the virus to enter bathrooms and apartments.

It was reported that the water seals for floor traps[4] had dried up, allowing passage of foul air into the apartment from the vertical sanitary pipe (called the stack) that links all apartments in the block. In such situations, exhaust fans could even accelerate the extraction of the foul air and circulate it into the living unit.

In a press release titled "Inadequate Plumbing Systems likely Contributed to SARS Transmission" issued by the World Health Organization (WHO) (Press Release WHO/70, 26 September 2003),[5] the Technical Consultation concluded that "inadequate plumbing was likely to have been a contributor to the spread of SARS in residential buildings in Hong Kong". It added that "in the absence of proper maintenance and without consistent monitoring, reviewing, enforcing and updating of building standards and practices, inadequate plumbing and sewage systems could continue to enhance the potential of SARS and some other diseases to spread".

The Singapore Ministry of National Development (MND) and the Environment Ministry took swift action to reassure the Singapore public and issued a joint statement (in April 2003) to explain the intricate differences between the sanitary systems in Singapore and Hong Kong (as shown in Figure 7.1). Although both Hong Kong's and Singapore's sanitary systems had the same roots in the original British design, these systems have developed

FIGURE 7.1
Sanitary Systems of Buildings in Hong Kong and Singapore



Source: PUB.

differently. In Singapore, as the concern was with the possible loss of water in the seal, floor traps were configured to be constantly replenished by discharge from the wash basin and bathroom shower. This ensures that the water seal in the floor trap is maintained and prevents foul air in the sanitary pipes from entering the premises. The sanitary system in buildings in Singapore, therefore, did not pose a SARS risk.

Whilst the Housing and Development Board and Town Councils under MND have standard operating procedures to tackle and address sewage leaks swiftly and appropriately, PUB and the Environment Ministry had adequate measures specified in the Code of Practices on the Sanitary Drainage and Plumbing Systems for the exclusion of foul air from the sanitary drainage system. These include stipulating that water seals of sufficient depths be provided at appropriate sanitary appliances discharge points and floor traps. The design of sanitary drainage and plumbing systems must also avoid the loss of water seals in these traps due to pressure fluctuations. This could be done by providing ventilating pipes/ stacks or adequate sizing of discharge stacks so that the water seals would always be kept in place. This example shows how the two ministries worked together to ensure that public housing sanitation systems are well designed.

EFFECTIVE USE OF LEGISLATION

While the government provides the essential infrastructure required to manage used water, industries and private owners also have to do their part in controlling water pollution and managing their used water. In order to ensure that the various industrial activities do not have an adverse impact on water quality or the management of used water, a number of acts and regulations were enacted, with strict penalties to control pollution of watercourses. These acts and regulations are further elaborated below.

Sewerage and Drainage Act and Its Subsidiary Legislations

The control of trade effluent discharge into sewers and watercourses was first legislated under the Local Government (Disposal of Trade Effluents) Regulations, passed in 1970, and the Environmental Public Health (Prohibition on Discharge of Trade Effluents into Water Courses) Regulations, passed in 1971. These were subsequently consolidated under the Water Pollution Control and Drainage Act (WPCDA), 1975, to improve the effectiveness of overall water pollution control. Later in 1999, the WPCDA was disaggregated into the Sewerage and Drainage Act (SDA) and the Environmental Pollution Control Act (EPCA), administered by the then Environment Ministry, with stipulations on the control of discharge into public sewers and watercourses respectively. The SDA was subsequently transferred to the PUB upon its reconstitution as the national water agency in 2001, while the EPCA (renamed the Environmental Protection and Management Act in January 2008) went under the purview of the National Environment Agency (NEA) in 2002.

The SDA empowers PUB to control the discharge of used water from domestic, industrial, agricultural, and other premises. Under the Act, the government may require all used water generated to be discharged into public sewers if they are available. The Act also provides for penalties for offences that have resulted in serious water pollution. Regulations made under the Act guide the provision of sanitary works in all premises, provision of small sewage treatment plants (STPs), control of trade effluent discharged into the sewerage system, and collection of fees to maintain the public sewerage system. Some of the regulations that are part of the SDA are described below.

Trade Effluent Regulations (TER)

Trade effluent is defined as "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". The Trade Effluent Regulations, 1977, was enacted to allow certain industries which produced biodegradable waste water to discharge their effluent into the public sewer, as long as they were in accordance with specified water quality limits. The Trade Effluent Tariff Scheme allows applicants to discharge biodegradable used water with higher concentration into the public sewer, subject to a fee. Furthermore, industries could also dispose their organic sludge at designated water reclamation plants for a fee. This provision offers a choice to industries that produce biodegradable wastes of higher concentration, but find it undesirable or impossible to install, operate, and maintain a trade effluent treatment plant on its premises.

Sanitary Works Regulations

The Sanitary Works Regulations explicitly stipulate the separation of rainwater from used water, and the diversion of rain water into a surface storm water drain and away from any opening connected to a used water system. Furthermore, all sullage water from premises such as motor workshops, eating establishments, car washing bays in petrol stations, refuse chutes and bin centres, and backwash water from swimming pool filters are to be discharged directly to the used water system, via a grease trap where necessary. Sullage water should be kept out of the rain water collection system as they contain pollutants such as detergents, organic material (food waste, oil, and grease) and other harmful substances such as heavy metals from scrap metal yards, which will contaminate watercourses and catchments.

Surface Water Drainage Regulations

The Surface Water Drainage Regulations govern discharges into the storm water drainage system. These regulations, first enacted in 1999, prohibit the discharge of silt or suspended solids into open drains in concentrations greater than 50 milligrams per litre. The regulations require that every person carrying out earthworks or construction works should provide and maintain effective earth control measures and take adequate measures to prevent "any earth, top soil, cement, concrete, debris, or any other material to fall or be washed into the storm water drainage system". This is particularly challenging with all the development works that are taking place around the island. Nevertheless, effort has to be made to protect the storm water drainage system from silt and debris, which not only cause siltation and impede the effectiveness of the drainage systems, but also contribute to the unsightly brown water in waterways and reservoirs.

CONTROL OF USED WATER QUALITY AT SOURCE

Used water is no longer a waste product that is treated before release to safeguard the environment. It is now a national resource for the production of NEWater. Used water, particularly trade effluent that does not comply with the legislation, if discharged into sewers can have an adverse impact on the used water reclamation process. Such trade effluent may be potentially toxic to the biological process in the WRPs, or may disrupt the NEWater production process. To ensure robustness and reliability in the production of NEWater, it is critical to have effective source control measures to manage the trade effluent discharged from industries into the sewers.

Discharge of trade effluent into sewers is regulated by legislation and PUB's prior approval is also required. Despite the legislation in place, there is a need to ensure that trade effluent discharged into sewers complies with the requirements. PUB carries out surveillance and enforcement activities to meet this need. However, it is difficult to detect violations as such surveillance is not continuous. One approach to enhance the surveillance of trade effluent discharged into sewers is to leverage technology.

Organic solvents are one of the main groups of substances of concern. There are no direct instruments to detect these solvents. But as these solvents are volatile, they can be detected indirectly by volatile organic compounds (VOC) meters. VOC meters are the best available detection technology for solvents now. PUB has installed VOC meters at strategic locations in the used water network. Such locations include pumping stations that serve significant industrial clusters, and at the WRP inlets. The meters are configured as online VOC monitoring units that measure the VOC level at regular intervals. They will also set off alarms at certain preset levels. The readings are sent to a central monitoring system for data logging. Together, this constitutes a remote VOC monitoring and warning system. PUB also has a few mobile VOC monitoring units that can be set up at different locations, including factory clusters and factories. These movable units also have a sampling pump system to collect a sample in the event of high VOC, and will send alerts to the central monitoring station. The samples can also be analysed for other substances of concern besides VOCs, and will facilitate taking enforcement action where appropriate.

Use of technology and legislative enforcement aside, PUB also conducts dialogue sessions with factories to share with them good practices pertaining to trade effluent discharge.

The evolution of Singapore's environmental legislation reflects efforts to address the changing needs of used water management — from the early days of providing basic sanitation, to controlling used water discharged and maintaining effluent quality for water reclamation.

HARNESSING NEW TECHNOLOGIES

PUB is constantly on the lookout for new and emerging technologies that would enhance its existing used water management processes. The DTSS alone has provided immense opportunities for PUB to partner industry players in R&D work, as well as employ new groundbreaking technologies, processes, and equipment. In addition, PUB's keen and forward-looking attitude towards test bedding and pilot testing new technologies in its existing WRP facilities enhances its efforts to be at the forefront of used water management and operations. In addition to the technological innovations that have been described earlier in this chapter, the following sections highlight more of such initiatives.

Sludge Management

The solid by-product of used water treatment, or sludge, has to be properly treated and disposed of so it does not cause contamination to the environment. Since the commissioning of the Kim Chuan WRP in 1948, the raw sludge collected from the primary sedimentation tanks and excess activated sludge from the secondary treatment process were treated using anaerobic sludge digesters to break down the organic matter in the sludge to render them inoffensive for disposal. This produces biogas that enables electricity to be generated in the plant and thus reduces electricity required from the grid. In fact, the biogas produced at the WRPs is presently able to generate, through PUB's dual-fuel generators, up to 25 per cent of their plants' electricity needs.

Prior to 1980, treated sludge was dried under the sun at the sludge drying beds. This was possible then as the only two sites at Ulu Pandan and Serangoon were located in remote rural areas. By the end of the 1970s, as the volume of sludge had significantly increased and more developments encroached towards the facilities, the drying beds were phased out with the installation of mechanical sludge dewatering facilities.

Up to the 1980s, the treated sludge could be disposed of via its use as a soil conditioner for reclaimed land, landscaping, and tree planting. However, towards the 1990s, this sludge disposal process was re-evaluated in view of the need to protect surface water quality within the expanding water catchment areas, and to minimize odour nuisance. Also, land application at reclaimed sites outside the water catchments is not sustainable as these sites are fast running out.

This prompted PUB to search for alternative sludge disposal methods to reduce the overall sludge volume. Incineration of sludge is also adopted to reduce further the sludge to ash for disposal at the Semakau Landfill.

Membrane Bioreactor

The development of membrane bioreactor (MBR) technology bridges conventional used water treatment and the water reclamation process. The membrane barrier in the MBR process retains most of the micro-organisms and solids, resulting in effluent of excellent quality without the need for additional filters. In addition, the effluent produced is clean enough to be fed directly into the reverse osmosis system for the production of high grade industrial water, or even for NEWater production. This would eliminate the need for the micro-filtration or ultra-filtration step, further compacting the NEWater treatment process and reducing the amount of valuable land needed.

The existing process of aeration, final sedimentation, and microfiltration pretreatment can be effectively replaced by a single-stage MBR. This results in a significant reduction in total retention time, improved effluent quality, and cost savings. The MBR technology also supports much higher biomass for more effective aerobic biological treatment and reduced aeration-basin volume, thus reducing the surface area required at a WRP. In fact, with promising results from the demonstration MBR plant at Ulu Pandan WRP, there are plans to introduce the MBR process to other WRPs. Similarly, pilot testing for other treatment methods are also carried out to search for better and more efficient ways to treat and manage used water.

CONCLUSION

Singapore has come a long way in its bid to provide effective modern sanitation and used water management systems for its population. From the early days of open dumping into waterways to the night soil collection system, disposal works and sewage treatment works, the country has progressed to the present-day water reclamation plants and the integration of used water management under the DTSS.

Long-term planning led to the development of a comprehensive Used Water Masterplan. Equally important was the discipline to adhere to the key features in designing used water management systems, which allowed Singapore to achieve 100 per cent access to modern sanitation within a short span of time. In addition, the search for longer term, sustainable solutions led to the bold and innovative approach of managing used water through the DTSS. Singapore's fully sewered system also made possible large-scale used water recycling, with recent breakthroughs in technologies allowing for reclaimed water, in the form of NEWater, to be channelled to augment water supply.

The journey in managing used water may be arduous and never-ending, but it is definitely eventful. Going forward, Singapore will face new challenges that will require further improvements and innovative solutions. It will have to review the sustainability of its used water systems constantly, in tandem with economic development, and consider the best means of collecting every drop of used water for recycling, as this would contribute towards its water self-sufficiency over the long term.

Singapore hopes to share its experience in used water management with other nations as they embark on their used water management development plans. At the same time, this may also facilitate and trigger further sharing of knowledge and expertise among nations in the common pursuit of more sustainable and environmentally friendly ways to manage used water.