WATER MATTERS

WATER MATTERS

Landscape Photography | Kelvin YUEN

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Hong Kong Major Events

1841
Hong Kong was founded. In the first census the population was 7,450.

1844
Hong Kong set-up the Surveyor General's Office, responsible for the city's infrastructure. The first appointed Surveyor General was Alexander GORDON.

1851
Hong Kong's population rapidly increased following the outbreak of the Taiping Rebellion in China.

1860
The Kowloon Peninsula, south of Boundary Street, became part of the British colony.

22 September 1874
The third deadliest typhoon ever recorded in Hong Kong killed over 2,000 people, equivalent to nearly 8% of the population at the time.

1882
The Colonial Office appointed Consulting Engineer, Osbert CHADWICK, to undertake a comprehensive review. His report on Hong Kong's sanitation of the living environment and water supply was published.

1883
The government established the Sanitary Board, whose duties included the collection of waste buckets, commonly known as "night soil".

In the same year, the Surveyor General's Office was renamed as the Public Works Department.

1890
The Water and Drainage Department was established under the Public Works Department and responsible for relevant capital works.

Waterworks Ordinance enacted.

1892
The position of Surveyor General was renamed the Director of Public Works.

1894 – 1896
Hong Kong suffered a large outbreak of bubonic plague. The plague was most serious in the Tai Ping Shan district of Sheung Wan, where the Chinese population was particularly concentrated.

1898
Britain leased the New Territories from China.

1902
The Colonial Office commissioned Osbert CHADWICK to conduct a study on the sanitary conditions of Hong Kong.

CHADWICK recommended to divide the Water and Drainage Department into two independent departments. This was deemed unfeasible by the Director of Public Works, who instead proposed the appointment of two Executive Engineers to oversee waterworks and drainage respectively.

1902 & 1903
Amendments to the Waterworks Ordinance introduced volumetric charging, using meters and the rider main system.

1912
Establishment of The University of Hong Kong - the first university in Hong Kong.

July 1928 - June 1929
A serious shortfall in rainfall occurred during the summer of 1928. During the next 12 months, the total rainfall in Hong Kong amounted to only 946.7 mm, a 60% decrease in the average annual rainfall.

1928
The government's Administrative Report for the year noted that the Public Works Department comprised 13 sub-departments, including a separation of the waterworks and drainage departments.

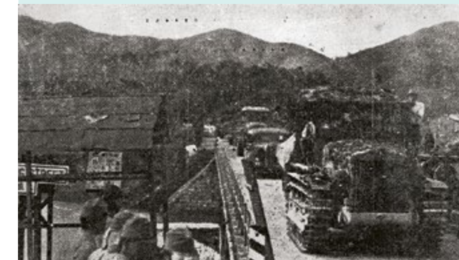
1929
The Public Works Department is underpinned by 14 sub-departments, including the Construction of Waterworks and the Maintenance of Waterworks.

1937
The outbreak of the Second Sino-Japanese War resulted in significant migration to southern China. As a consequence, Hong Kong's population exceeded one million people.

1938
The Waterworks Ordinance was amended. The water-related divisions of the Public Works Department reorganised as the Waterworks Office in the following year. Operating on a separate budget and self-financed, the Waterworks Office was partially decentralised from the Public Works Department.

25 December 1941
The Japanese army attacked and took control of Hong Kong, which remained under its occupation for three years and eight months.

August 1945
The Japanese army formally surrendered.



December 1953
A large fire broke out in the Shek Kip Mei squatter area, resulting in nearly 58,000 people being left homeless.

1963
Hong Kong experienced an annual rainfall of only 901.1mm.

May - June 1963
As a consequence of the water shortage, the government declared a plan for water rationing. At its most severe, the city's water supply was restricted to four hours every four days.

1979 – 1980
There was a substantial increase in the price of crude oil during the second oil crisis.

June 1982
Hong Kong's final period of water rationing was imposed in May 1982, after which the government announced the lifting of all water restriction measures and restored round-the-clock water supply.

1997
Hong Kong returned to China.

May 2008
After the Sichuan earthquake on 12 May, the Water Supplies Department (WSD) joined the HKSAR Government's public health professional team to assess the water quality of affected areas.

August 2008
The Central Government formulated the 'Water Resources Distribution Plan in the Dongjiang River Basin of Guangdong Province', stipulating upper limits of water supply for each region.

2015
Tap water samples of some housing estates were found to have an excessive lead content. The HKSAR Government established a task force to investigate and carried out a comprehensive review of the water safety monitoring system for improvement.

2017
The HKSAR Government launched the "Hong Kong Smart City Blueprint".

2022
The 25th Anniversary of Hong Kong's return to China.

1841 - 1899 Development of water resources after the founding of Hong Kong

1901 – 1969 Establishment of a systematic water supply strategy

1970 - 2021 Entering a period of stable water supply

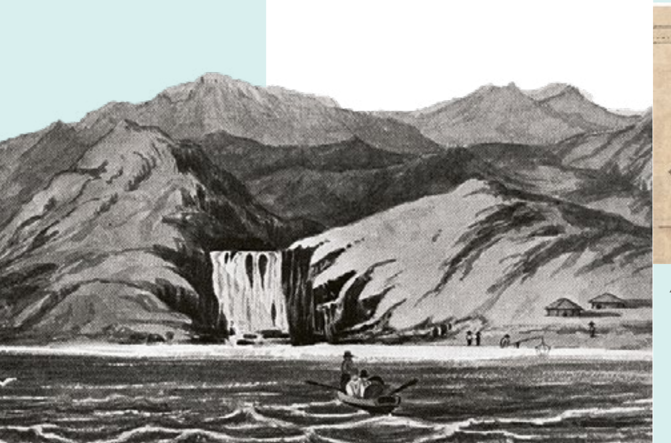
The Development of Hong Kong's Water Supplies

1840s – 1850s

1840s – 1850s
Hong Kong lacked fresh water resources. Local residents mainly relied on mountain streams or wells for daily use and farming irrigation.

1851
The government allocated funds to excavate wells for free water supply to the public.

1859
The government invited plans for proposals for the development of fresh water supply, offering a prize of £1,000. The proposal put forth by S.B. RAWLING, a Clerk of Works in the British Royal Engineering Department, advocating a reservoir in the Pokfulam Valley was accepted.



1860s – 1870s

October 1860
The government introduced a 'water rate', levied annually at 2% of the gross annual value of a property, to fund the construction of waterworks.

1863
Construction of the first impounding reservoir in Hong Kong was completed, the Pokfulam Reservoir at the western side of Hong Kong Island.

1871 – 1877
The Pokfulam Reservoir extension and construction of the Pokfulam Conduit were undertaken to enhance the water supply.

1880s

1883 – 1888
Construction of the first phase of the Tai Tam Group of Reservoirs, located in the southern part of Hong Kong Island.

▲ Tai Tam Reservoir Dam, photographed in 1888

1888 – 1889
Albany filter beds under construction.

1889
Water treatment was introduced.

▲ The design of the Yau Ma Tei Pumping Station

1890s

1895
The first water supply system for Kowloon was completed with a water pumping station at Yau Ma Tei. Part of this water pumping station still stands at 344 Shanghai Street as a Grade I historical building.

1897
The government introduced a water metering and charging system in Kowloon.

1899
Wong Nei Chung Reservoir was completed.

1900s

1902
The government commenced the construction of Kowloon Reservoir.

The government introduced a new provision in the Waterworks Ordinance mandating the installation of water meters for all consumers in Hong Kong and a "user pays" policy, which was opposed by the local Chinese community in Hong Kong Island.

1903
In addition to the implementation of a water metering system, the government also introduced a rider main system to supply water to its users free of charge. In case of insufficient fresh water supply, the rider mains would be the first to be shut off. Affected areas would then be supplied with water by rotation.

1904 – 1907
Tai Tam Byewash Reservoir and Tai Tam Intermediate Reservoir were completed.

1910s

1910
Kowloon Reservoir was completed for harvesting rainwater. Kowloon's first reservoir-based water supply system replaced the previous system of three wells and the Yau Ma Tei Pumping Station.

1917
Tai Tam Tuk Reservoir was completed. Its main dam was 1,200 feet long. At the time, it was recognised as "Asia's Number One Dam."

▲ Tai Tam Reservoir Dam in 1937, 20 years after its completion

1920s

1925
Shek Lei Pui Reservoir was completed.

1926
Kowloon Reception Reservoir was completed.

▲ Kowloon Reception Reservoir was completed in 1926

1929
In the second half of the year, the government implemented Stage VII water rationing, its highest-level of water rationing.

1930s

1930
The first cross-harbour submarine pipeline was completed. It transferred rainwater gathered from reservoirs in the New Territories to Hong Kong Island.

▲ The first cross-harbour submarine pipeline was completed in 1930

1931
Kowloon Byewash Reservoir was completed.

Aberdeen Upper and Lower Reservoirs were completed.

1932
The government enacted regulations to abolish the rider main system.

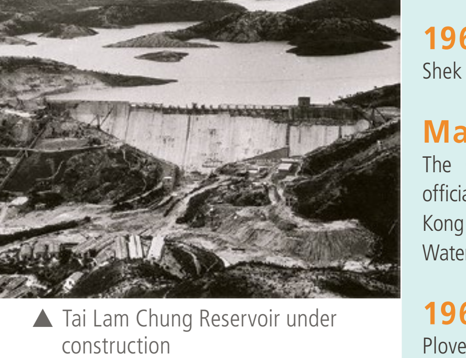
1937
Shing Mun Reservoir was completed.

1938
The licensing of plumbers was first introduced in the Waterworks Regulations under the Waterworks Ordinance.

1940s

1950s

1957
Tai Lam Chung Reservoir was completed.



▲ Tai Lam Chung Reservoir under construction

1957
The Water Authority proposed installation of seawater flushing systems for the resettlement areas at Shek Kip Mei and Lei Cheng Uk.

1959
The government amended the Regulation 19 of the Buildings Ordinance, mandating newly built private buildings to be equipped with a flushing sewerage system. This led to a gradual expansion of the seawater flushing network.

1960s

November 1960
The government reached an agreement with the Guangdong authorities to provide 22.73 million cubic metres of water per year from the Shenzhen Reservoir.

1963
Shek Pik Reservoir was completed.

March 1965
The Guangdong Provincial Government officially began to supply water to Hong Kong through the Dongjiang-Shenzhen Water Supply Scheme.

1968
Plover Cove Reservoir was completed, making it the second largest reservoir in Hong Kong, and the first reservoir in the world built in the sea.

▲ In 1960, a substantial 48-inch diameter water pipeline was installed in the New Territories to receive water from the Shenzhen Reservoir.

◀ Shek Pik Reservoir under construction, August 1963

1970s – 1980s

1972
Flushing seawater was supplied free of charge.

October 1975
Lok On Pai Desalter at Castle Peak was officially commissioned. At that time, it was the largest of its kind in the world.

1978
High Island Reservoir was completed. It is the largest reservoir in terms of capacity in Hong Kong.

▲ High Island Reservoir's West Dam under construction

1982
Lok On Pai Desalter was decommissioned due to the rise in fuel prices.

The Waterworks Office was formally upgraded to the Water Supplies Department.

1990s

1990
In its first ever decline, Hong Kong's industrial water consumption decreased by 1.7%.

1991
Water supplied from the mainland accounted for 80% of Hong Kong's total water consumption.

▲ After its decommissioning, Lok On Pai Desalter was progressively dismantled after 1991.

2000s

April 2000
The Advisory Committee on the Quality of Water Supplies was founded.

2001
The WSD's seawater flushing project was presented the Chris Binnie Award from the Chartered Institution of Water and Environmental Management in recognition of its achievements in sustainable water management.

2005
The government endorsed the Master Metering Policy.

2006
The Agreement for the supply of Dongjiang water to Hong Kong adopted a "package deal lump sum" approach, which guaranteed Hong Kong an annual supply of up to 820 million cubic metres of Dongjiang water.

2007
The WSD implements its own Water Safety Plans in accordance with World Health Organization's recommendations.

2008
The HKSAR Government implemented the Total Water Management Strategy.

2009
Forty-one waterworks structures were declared monuments.

The WSD's first two service reservoirs built in a cavern, Western Salt Water Service Reservoir and Western No.2 Salt Water Service Reservoir, were commissioned.

◀ Replacement and Rehabilitation Programme

2010s

2011
The WSD enhances water quality monitoring at impounding reservoirs with an unmanned surface vessel system.

April 2012
The Advisory Committee on the Quality of Water Supplies was renamed the Advisory Committee on Water Resources and Quality of Water Supplies.

2013
The Biosensing Alert System is awarded the Silver Prize of the Team Award (Internal Service) in the Civil Service Outstanding Service Award Scheme. The system also received the Bronze Prize of the Departmental Service Enhancement Award (Large Department Category).

A hydropower system was introduced at the Tuen Mun Water Treatment Works.

Expansion of Tai Po Water Treatment Works commenced.

2016
The WSD launched the Voluntary Continuing Professional Development Scheme for Licensed Plumbers.

April 2016
The Advisory Committee on Water Resources and Quality of Water Supplies was renamed the Advisory Committee on Water Supplies.

February 2017
The first floating solar power system installed at Shek Pik Reservoir.

September 2017
The HKSAR Government launches an Action Plan for Enhancing Drinking Water Safety in Hong Kong. This plan includes the introduction of the "Hong Kong Drinking Water Standards".

2017
The WSD launched its Smart Water Model.

January 2018
The Drinking Water Safety Advisory Committee was established.

2019
The construction of the Tsuen Kwan O Desalination Plant commenced, aiming to expand fresh water supply in Hong Kong by 5-10%.

Following the completion of its strategy review and update, the WSD launched the Total Water Management Strategy 2019 with the formulation, evaluation and recommendation of strategic options.

December 2019
H_2OPE Centre at Tin Shui Wai, a water resources education centre, opened to the public.

2020s

2020
The masonry bridge of Pok Fu Lam Reservoir was declared a monument.

May 2021
Regulation 47 of the amended Waterworks Regulations enacted, to regulate landlords against overcharging tenants for water.

July 2021
Q-Leak Underground Water Mains Leak Detection Training Centre opened.

December 2021
The HKSAR Government signed a new agreement with the Water Resources Department of Guangdong Province for the supply of Dongjiang water; the previous "package deal lump sum" approach was enhanced to a "package deal deductible sum".

2021
The Antiquities Advisory Board designated five service reservoirs as Grade I Historic Buildings; and Grade III Historic Building status for a pumping station and a service reservoir tunnel portal.

2023
First stage of the Tseung Kwan O Desalination Plant is expected to be commissioned.

The WSD commenced the mid-term review of the Total Water Management Strategy 2019.

2024
Expected completion of Shek Wu Hui Water Reclamation Plant.

Grey Water Treatment Plant for Development of Anderson Road Quarry to be commissioned in phases from 2024 onwards.

2025
Installation of around 2,400 District Metering Areas for the Water Intelligent Network scheduled for completion.

2026
Expected completion of the reprovisioning of Sha Tin Water Treatment South Works.

2027
Relocation of Diamond Hill Fresh Water and Salt Water Service Reservoirs to Caverns scheduled for completion.

Director's Message

Water is vital for life and urban development. It is our indispensable and scarce resource.

Each drop of water does not come easily! As there is no natural freshwater lakes in Hong Kong, the exploration and management of water resources has always been at the cornerstone of urban development. Over the years, the Water Supplies Department (WSD) has provided the citizens of Hong Kong with a high-quality, reliable and stable round-the-clock water supply by managing the city's water resources through careful planning, collection, treatment and distribution.

Since waterworks projects have continuously been launched in Hong Kong, always deploying the most advanced technology of the time. Some of today's waterworks facilities have been in use since their first commissioning over a century ago. In the 1960s, people badly suffered from water rationing. Nowadays, with the construction of the Dongjiang-Shenzhen Water Supply System, Hong Kong has a stable and reliable water supply sourced from the mainland and serving over 99.9% of its population. Hong Kong people may not be aware of a water shortage crisis. However, it is not just scaremongering in the face of global climate change, but a reality they will eventually face. In 2019, the WSD conducted a review of its Total Water Management Strategy, previously launched in 2008. The key focus of the WSD's work is now a two-pronged strategy that aims to control the growth of fresh water demand while actively exploring new water resources. While Hong Kong is blessed with a stable and efficient water supply, it is also one of the world's most densely populated cities and there will always be challenges that require solutions.

Water Matters is a publication the WSD team has been working on for over two years, following the 2001 publication, *Water for a Barren Rock - 150 Years of Water Supply in Hong Kong*. This publication adopts a popular science approach to introduce readers to the WSD's water supply system and how it has evolved over the years. It covers the planning, construction, operation, repair and maintenance of the WSD's waterworks facilities. It also covers a wide range of topics, from engineering design to the application of technology, accompanied by interviews with frontline professionals for knowledge sharing and fun facts. We hope to deepen the public's understanding of water supply services through detailed and practical stories to illustrate, and raise the community's awareness of water conservation.

I would like to express my gratitude to WSD colleagues for their hard work and dedication over the years. I would also like to thank the public for their trust and support for our work. The WSD will continue to prepare and make improvements to ensure our water supply service meets the challenges of future social development and environmental changes.

Ir Tony YAU Kwok-ting, JP
Director of Water Supplies

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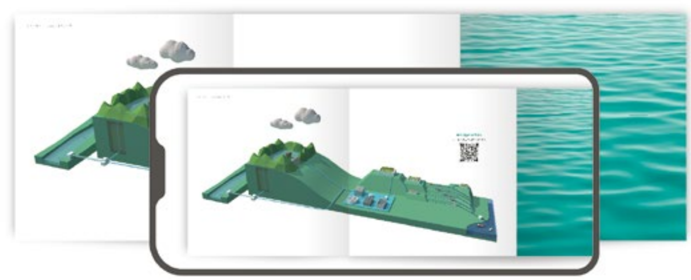
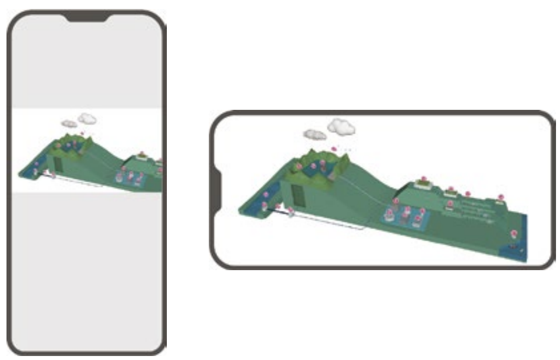
Fresh Water and Seawater Supply Systems

1 Scan the QR code with your mobile phone.

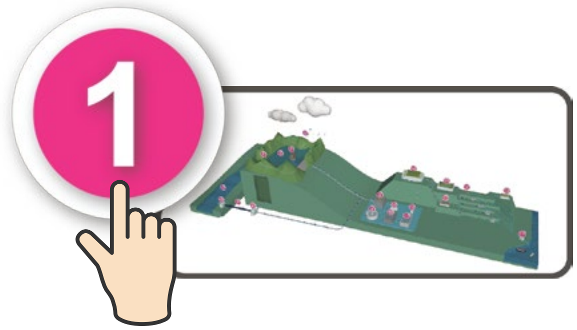
2 You will then enter the online portal where you will find a lens to decode the cross-page image in the book.



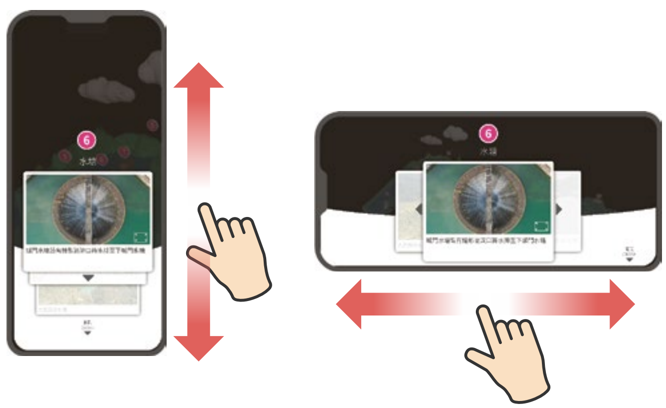
3 A 3D digital model will be displayed interactively in augmented reality (AR).

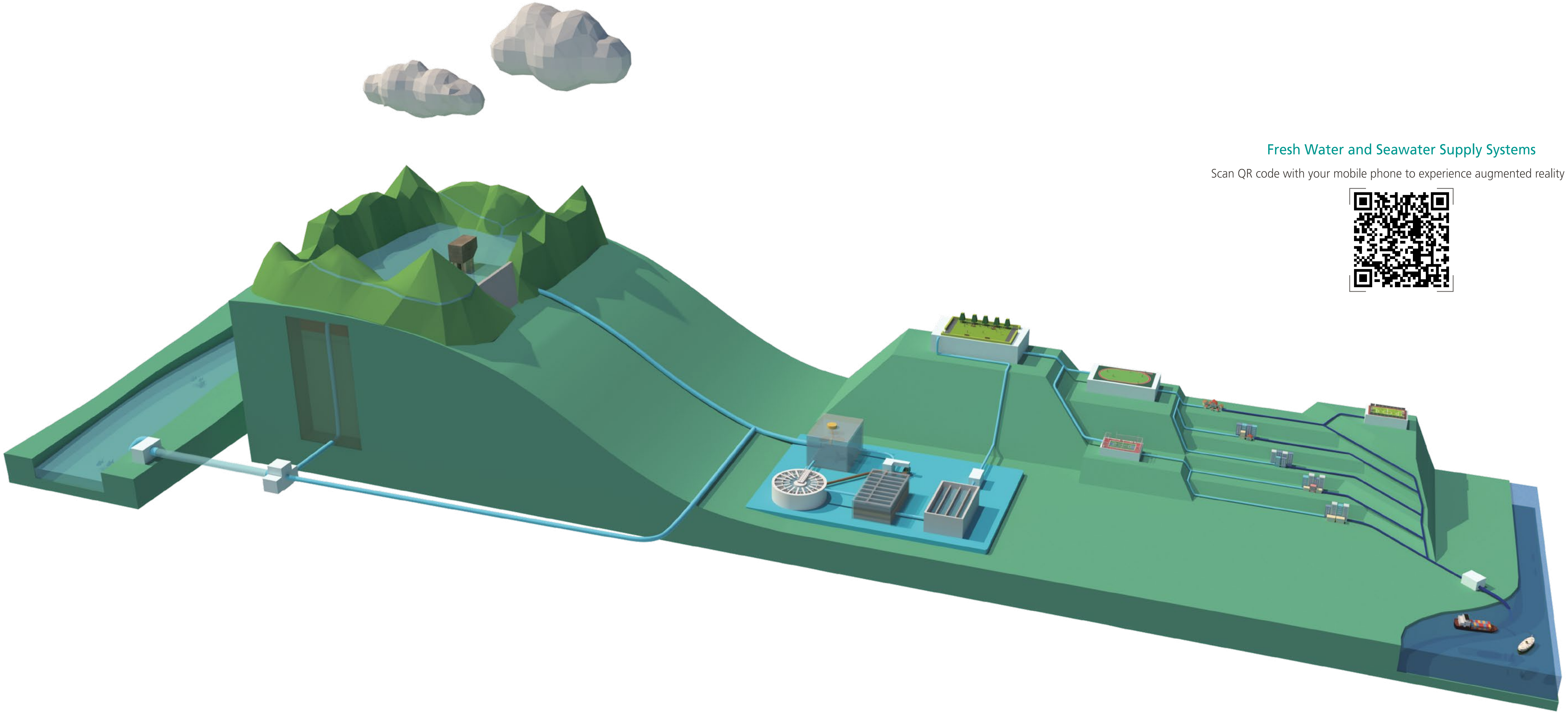


4 The 3D model can be enlarged, moved, and rotated. By pressing the number keys of different facilities on the model, you can get more relevant information.



5 More information is displayed in a pop-up window when you press the number keys. You can scroll vertically (in portrait mode) or horizontally (in landscape mode) to view different information.





Fresh Water and Seawater Supply Systems

Scan QR code with your mobile phone to experience augmented reality (AR).

1

HARVESTING WATER

Building the City's Water Supply Veins

Hong Kong's colonial population was around 12,000[1]. Prior to its founding as a city, the population was mainly engaged in agriculture and fishing and relied on mountain streams and wells for water. Historians have noted that during the 19th century, European merchants travelling to and from Guangzhou via the Pearl River estuary would obtain potable water at Waterfall Bay in Pok Fu Lam. In the 1860s, to meet the water needs of an expanding population, the government diverted the headwaters of Waterfall Bay to Pok Fu Lam Reservoir, Hong Kong's first built reservoir. Today, there are 27 reservoirs still in public use, with one converted for recreational use and nine serving as irrigation reservoirs. The remaining 17 reservoirs are connected to the city-wide water supply system. In addition to collecting rainwater, the city's reservoirs have been receiving Dongjiang water from the mainland since the 1960s. The reservoirs are interconnected and linked to a water supply network that covers 99.9% of the population, making it the lifeblood of the city - although invisible on the surface.

This chapter is an introduction to Hong Kong's water supply system and begins by describing the development of water sources, construction of reservoirs and the operation of the various parts of the water harvesting network at different stages of the city's development. This chapter also outlines how the Water Supplies Department (WSD) plans for the city's future water resources in response to recent socio-economic developments and emerging issues, such as climate change. It includes an introduction to reverse osmosis technology for desalination and the development of reclaimed water and treated grey water. These measures are capable of exploiting new water resources while also containing the demand for water to strengthen the resilience of Hong Kong's water supply.

The WSD's century-old waterworks facilities and the rich vegetation in the catchment areas have become heritage and cultural attractions for local residents and visitors from around the world. These facilities have been regularly maintained and updated, particularly in the areas of water quality control and environmental protection. This infrastructure serves the practical needs of the public while providing them with peace of mind about safe water sources in an "urban oasis". This chapter also presents anecdotes from Hong Kong's water supply history, providing insight into how generations of waterworks professionals have safeguarded the city's lifeblood and delivered outstanding service to the public.

1 Hong Kong. (24 March 1842). "Native Population of Kong Kong". *Hong Kong: The Friend of China and Hong Kong Gazette.* Hong Kong: Government Printer. https://digitalrepository.lib.hku.hk/catalog/9g5546835#?c=&m=&s=&cv=7&xywh=-372%2C1916%2C1770%2C1368

Water Terminology

Raw Water	Untreated water from all sources, including rainwater collected in local catchments and Dongjiang water.
Tap Water	Water supplied to consumers through the water supply network after treatment by public waterworks facilities. This includes both drinking water and flushing water. Currently tap water is supplied to 99.9% of Hong Kong's population; a very small proportion of those living in remote rural and outlying island areas are unconnected.
Water for Domestic Use	Water used by people in their daily lives for a wide range of purposes, including drinking, washing, flushing and bathing.
Drinking/Potable Water	All water treated at a water treatment works in full compliance with Hong Kong Drinking Water Standards (HKDWS) and safe for public consumption. HKDWS are based on the recommendations of the World Health Organization and international experience to suit local context.
Recycled Water	Water collected and treated for reuse, including reclaimed water, treated grey water and harvested rainwater and used mainly for non-potable purposes.
Grey Water	Water collected from baths, showers, wash basins, kitchen sinks and laundry machines.
Reclaimed Water	Water resource generated by further processing treated effluent from sewage treatment works.

▲ High Island Reservoir

A Catchment System Serving Seven Million People

Hong Kong has little flat land and a predominantly hilly coastline topography with many surface streams, but no large rivers or lakes. Its geology is mostly volcanic and granitic, which is not conducive to storing large amounts of groundwater. In its early years, Hong Kong needed to exploit and collect water sources to meet the water needs of the growing population. In 1859, the government offered a £1,000 reward for proposals, and S.B. RAWLING, Clerk of Works in the British Royal Engineering Department, proposed the construction of a reservoir in the Pokfulam valley, which was accepted. The government then sought the private sector to invest in the development of water supply services, but unlike other utility services such as electricity, gas and ferry routes, waterworks projects were an unattractive investment because of the large capital costs and uncertain long term returns. The government decided to publicly fund the development of the city's massive network of water reservoirs over the last century. From these earliest beginnings, the WSD is now one of the few public sector in the world responsible for the city's water supply systems.

Hong Kong Geographical Data (2022)

Total land and sea area:
2,754.97 km^2

Total land area:
1,114.35 km^2

Reservoir and catchment areas:
about **300** km^2

Total reservoir capacity:
586 mcm*

Annual volume of rainwater collected from catchments:
288 mcm*

Annual fresh water consumption in Hong Kong:
1,066 mcm*

Imported Dongjiang water:
810 mcm*

*mcm = million cubic metres

Composition of Water Catchment Facilities

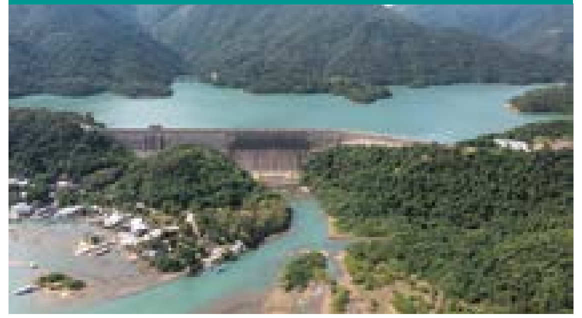
Hong Kong's water catchment facilities managed by the WSD, including its main reservoirs, are: dams which impound raw water; the catchwater systems that channel hillside water towards reservoirs or catchment facilities; gathering ground that collects rainfall; pumping stations that pump raw water from low to higher levels; and, water tunnels transporting raw water to treatment works. The entire water gathering system in Hong Kong covers about one-third of the territory's total land area. Over the years, the partial collection of rainwater within Hong Kong has been the lifeblood of the city.

Major Components of Water Collection Facilities

Reservoir

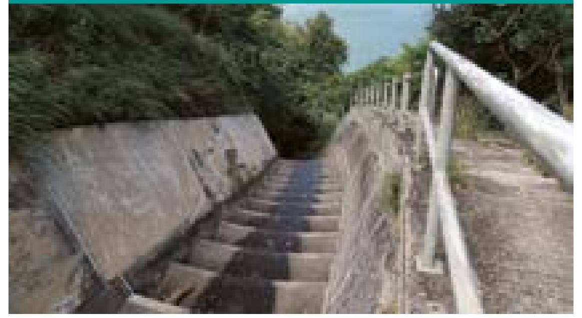
▲ Kowloon Reception Reservoir

Dam



▲ Tai Tam Tuk Reservoir Dam is located near Tai Tam Tuk Village and Tai Tam Bay; the stone bridge outside the reservoir is a popular tourist attraction.

Catchwater



▲ Catchwater feeds the water from gathering ground to the reservoir.

Raw Water Pumping Station

▲ Tai Mei Tuk Raw Water Pumping Station

▲ Tai Tam Tuk Reservoir Dam

Highlights of Hong Kong's Impounding Reservoirs

Completed in 1863[1], Pok Fu Lam Reservoir is the oldest of the 17 existing water supply impounding reservoirs in Hong Kong. The highest is Shek Lei Pui Reservoir (completed in 1925) with the top water level of 195.1 metres above Hong Kong Principal Datum (+mHKPD), an equivalent height as Mount Johnston, located on the southern side of Hong Kong Island. Previously, Wong Nai Chung Reservoir (completed in 1899) was higher, with the top water level of +220.98mHKPD, but its importance diminished as bigger water supply facilities came on stream; in 1986 it was converted into a park with boating facilities. The largest impounding reservoir, the High Island Reservoir (completed in 1978), has a capacity of 281 million cubic metres (mcm), accounting for nearly half of Hong Kong's current total impounding reservoir capacity and more than 1,200 times the capacity of Pok Fu Lam Reservoir, the city's first reservoir.

Hong Kong's population of 124,000 in 1863 has since grown dozens of times over the last one hundred years.

1 Pok Fu Lam Reservoir was inaugurated in 1863. As the capacity of the reservoir was insufficient, in-situ expansion works commenced in 1866 and were completed in 1871.

Top Water Level of Reservoirs by Region Over the Years

Altitude of Reservoir Sites and Their Development

Name of Reservoir	Year of Completion	Capacity (m³)	Top Water Level at Full Capacity (+mHKPD)	Impounding Reservoir/ Irrigation Reservoir	Location
Pok Fu Lam Reservoir	1871	233,000	168.52	Impounding Reservoir	Hong Kong Island
Tai Tam Upper Reservoir	1888	1,490,000	152.31	Impounding Reservoir	Hong Kong Island
Wong Nai Chung Reservoir	1899	109,000	220.98	Decommissioned	Hong Kong Island
Tai Tam Byewash Reservoir	1904	80,000	151.40	Impounding Reservoir	Hong Kong Island
Tai Tam Intermediate Reservoir	1907	686,000	58.17	Impounding Reservoir	Hong Kong Island
Kowloon Reservoir	1910	1,578,000	136.55	Impounding Reservoir	New Territories East
Tai Tam Tuk Reservoir	1917	6,047,000	35.95	Impounding Reservoir	Hong Kong Island
Shek Lei Pui Reservoir	1925	374,000	195.10	Impounding Reservoir	New Territories East
Kowloon Reception Reservoir	1926	121,000	145.54	Impounding Reservoir	New Territories East
Kowloon Byewash Reservoir	1931	800,000	115.80	Impounding Reservoir	New Territories East
Aberdeen Upper Reservoir	1931	773,000	111.25	Impounding Reservoir	Hong Kong Island
Aberdeen Lower Reservoir	1931	486,000	80.32	Impounding Reservoir	Hong Kong Island
Shing Mun Reservoir	1937	13,279,000	190.50	Impounding Reservoir	New Territories West
Shap Long Irrigation Reservoir	1955	133,000	56.83	Irrigation Reservoir	Outlying Islands
Lam Tei Irrigation Reservoir	1956	115,000	45.11	Irrigation Reservoir	New Territories West
Hung Shui Hang Irrigation Reservoir	1957	91,000	85.34	Irrigation Reservoir	New Territories West
Tai Lam Chung Reservoir	1957	20,490,000	60.96	Impounding Reservoir	New Territories West
Ho Pui Irrigation Reservoir	1961	505,000	164.59	Irrigation Reservoir	New Territories West
Wong Nai Tun Irrigation Reservoir	1961	160,500	153.92	Irrigation Reservoir	New Territories West
Tsing Tam Upper Irrigation Reservoir	1962	100,000	111.87	Irrigation Reservoir	New Territories West
Tsing Tam Lower Irrigation Reservoir	1962	57,000	85.75	Irrigation Reservoir	New Territories West
Shek Pik Reservoir	1963	24,461,000	54.03	Impounding Reservoir	Outlying Islands
Lower Shing Mun Reservoir	1964	4,299,000	90.22	Impounding Reservoir	New Territories East
Lau Shui Heung Irrigation Reservoir	1968	170,000	100.58	Irrigation Reservoir	New Territories East
Hok Tau Irrigation Reservoir	1968	180,000	100.58	Irrigation Reservoir	New Territories East
Plover Cove Reservoir	1968	229,729,000	13.41	Impounding Reservoir	New Territories East
High Island Reservoir	1978	281,124,000	60.96	Impounding Reservoir	New Territories East

The most common engineering principle applied in the operation of waterworks is that water flows with gravity. So, from the city's earliest days, the choice of appropriate reservoir sites has adopted this criteria. It aptly follows the Chinese saying that, "Man seeks his way up; water flows down".

Pok Fu Lam Reservoir, Hong Kong's first reservoir applied this principle. Its deliberately selected location was in an upland valley between High West and Mount Kellett on Hong Kong Island's western side. This location was a reasonable distance for water conveyance and did not affect the residential and economic activities of the city of Victoria. As seen from the graph "Top Water Level of Reservoirs by Region Over the Years" on page 24, the highest reservoirs were of a relatively small capacity and built before World War II. Due to population growth and the rapid development of urban areas across Hong Kong, subsequent reservoirs were constructed in larger scale and at locations covered from Hong Kong Island to the New Territories.

It is difficult to have large land areas found for impounding reservoirs due to the scarcity of suitable upland valleys or steep canyons. Alternatively, small-scale reservoirs hardly meet the water needs of a growing population.

Hong Kong's most recently built impounding reservoirs were built on low-lying land along the coastline. Plover Cove Reservoir (completed in 1968) was built directly in the sea, with seawater being drained and replaced with fresh water. Plover Cove was previously a bay surrounded on three sides by mountains, a main dam was built to create the inner lake as a large water storage area. This was lauded as an engineering breakthrough around the world at the time. A similar construction technique laid the foundations for the much larger High Island Reservoir (completed in 1978). These two waterworks projects increased the total capacity of Hong Kong's impounding reservoirs from about 75.2 mcm to 586 mcm, almost an eightfold increase in 15 years; reflecting Hong Kong's rapid economic and population growth after World War II.

#Fun Fact

Hong Kong's Privately Built Reservoirs

Hong Kong's water supply system is predominantly publicly funded. However, in the 19^{th} century and following the lead of industrial development trends in Europe, private reservoirs were developed for some large-scale private manufacturing operations requiring huge quantities of water. These industries included coin minting, sugar refining and paper milling. The former Mint Dam, located in what is now Tai Hang, was built in the mid-1860s to supply water to the coin mint in East Point, Causeway Bay. A sugar refinery built in 1884 in Quarry Bay by the Swire Group was supplied water from three reservoirs, two at Mount Parker, known as Taikoo Reservoir, and one at Braemar Hill, known as the Seven Sisters Reservoir. These operated until 1975, when Swire sold the reservoirs and the adjacent land for the construction of Braemar Hill Mansions and Choi Sai Woo Park.

The only privately built reservoirs that remain operating today are Aberdeen Lower Reservoir and Discovery Bay Reservoir. The former was formerly known as the Tai Shing Paper Mill Reservoir before being acquired by the government in 1929 at a cost of $580,000 to resolve water shortages in Hong Kong Island West, together with the Aberdeen Upper Reservoir which opened upstream in 1932. The Discovery Bay Reservoir is still in use today.

Irrigation Reservoirs

In addition to constructing water supply impounding reservoirs, nine irrigation reservoirs were built in Hong Kong during the 1950s and 1960s. These reservoirs (marked with a green leaf on page 24) were built to compensate local farmers for diverting water sources from nearby farmland during the construction of the city's four largest waterworks projects, Shek Pik Reservoir, Tai Lam Chung Reservoir, Plover Cove Reservoir and High Island Reservoir. Today, these irrigation reservoirs are integrated into the countryside, making the mountains and water beautifully complement each other.

Impounding Reservoirs and Dams

To store water you need a holding vessel. For a person, this could be a 'cup'; for a building, it could be a 'tank'; for a city, it could be a 'pool', a 'lake' or a 'reservoir'. Although differing in size, they all serve as enclosed storage spaces. The deeper and wider they are, the greater their capacity. However, the more water is stored, the greater the weight and corresponding gravity, as well as the impact on the surrounding environment. The construction of impounding reservoirs is a science of mechanics requiring precise calculations.

Impounding reservoirs built in valleys must be surrounded by mountains with dams built as barriers at the gaps, regardless of their elevations. The engineering structure of a dam needs to be designed according to the topography and scale of the site. Hong Kong's impounding reservoirs use two main types of dams: a gravity dam (mainly built with concrete) and an embankment dam (mainly built with earth materials or rocks).

▲ Lau Shui Heung Reservoir is one of the most popular places to enjoy the changing colours of Hong Kong's autumn leaves.

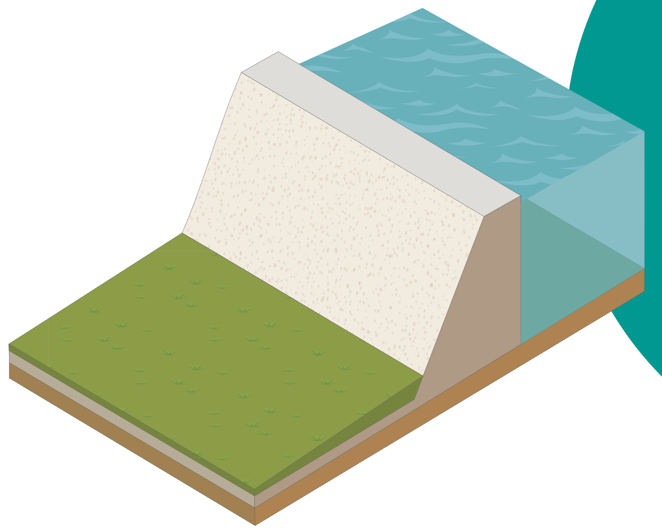
Gravity Dam

Tai Tam Tuk Reservoir and Shing Mun Reservoir, completed in 1917 and 1937 respectively, both adopted a gravity dam design for their main dams. These two challenging projects increased Hong Kong's overall water storage capacity by two-fold. At the time, Tai Tam Tuk Reservoir was described as "Asia's Number One Dam", surpassing even similar projects in the United Kingdom and its then-dependencies.

Situated in an upland gorge, the Shing Mun Reservoir was designed with the top water level of +190mHKPD at its full capacity. It was a large infrastructure project responding to Hong Kong Island and Kowloon's rapid increase in population at the time. As a result of the need to increase the reservoir's storage capacity, the main dam was repeatedly raised to eventually reach a height of 85 metres. Concrete is usually chosen for building gravity dams; however, it is a costly material. Since there was an abundant supply of granite in the vicinity, granite instead of concrete was utilised to create a rockfill. In addition, a pipeline constructed across Victoria Harbour transferred fresh water from the middle of the territory to Hong Kong Island. Nearly 2,500 engineers and workers were hired to work on the entire project which was acknowledged at the time as a significant and groundbreaking feat of engineering.

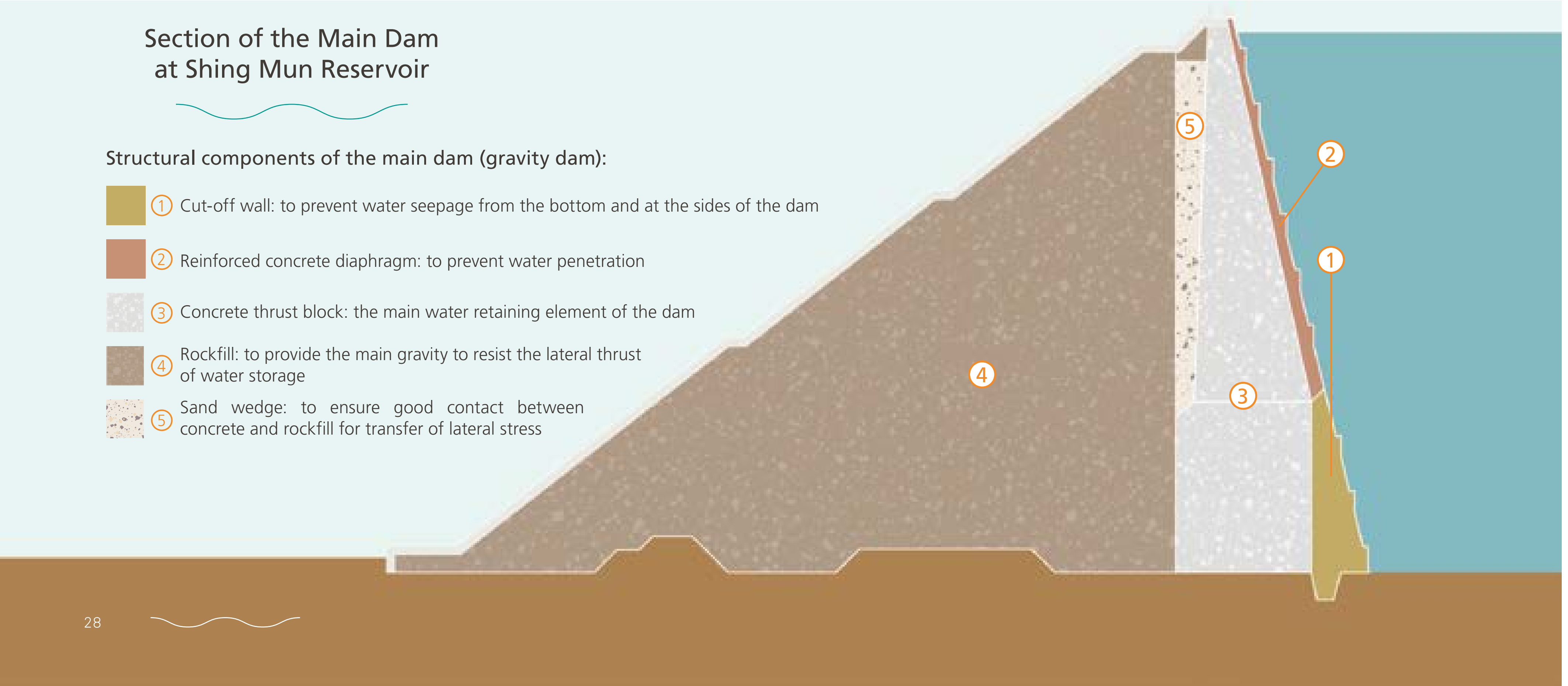
What is a 'Gravity Dam'?

A gravity dam relies on the weight of its building materials, generally concrete, and the resistance of the dam's body and foundation rocks to counteract the lateral pressure of stored water, hence the name 'gravity' dam. It is generally used in gorges, where the two hillsides support the abutments of the dam. In cross-section, the base width of a gravity dam is shorter than that of an embankment dam, and the upstream dam face is much steeper than when facing downstream. Therefore, a gravity dam takes up less space than an embankment dam.



▲ Section of a Gravity Dam

Section of the Main Dam at Shing Mun Reservoir



Structural components of the main dam (gravity dam):

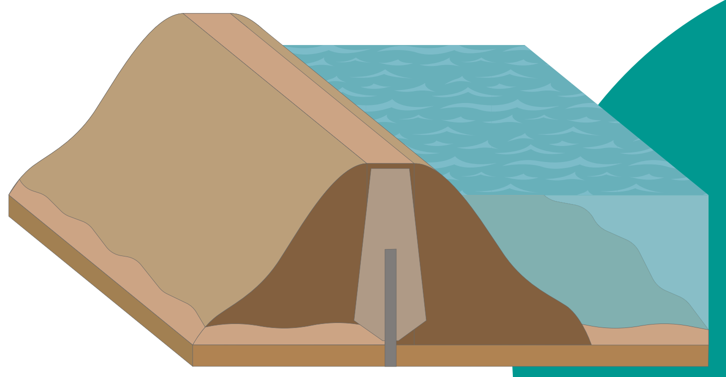
1. Cut-off wall: to prevent water seepage from the bottom and at the sides of the dam
2. Reinforced concrete diaphragm: to prevent water penetration
3. Concrete thrust block: the main water retaining element of the dam
4. Rockfill: to provide the main gravity to resist the lateral thrust of water storage
5. Sand wedge: to ensure good contact between concrete and rockfill for transfer of lateral stress

Embankment Dam

Before the 1970s, Hong Kong experienced such rapid population growth that there was always a shortage of water. It was common to plan for the construction of the next reservoir before finishing the current project, leading to a continuous string of impressive waterworks projects during this period.

Plover Cove Reservoir, conceived in the late 1950s and completed in 1968, was the first reservoir in the world to be built in the sea. Although the site was surrounded by hills on three sides, it required the construction of a two-kilometre-long main dam (plus three shorter subsidiary dams) to create an inner lake that could withstand the pressure of water stored 12 to 13 metres above the average sea level. The dam is twice as long as the distance across Victoria Harbour between the Tsim Sha Tsui and Central 'Star' Ferry piers. To this day, it remains Hong Kong's longest reservoir dam. Its underlying method of construction is also one of the most ancient and commonly used designs in the world. The dam's materials were mainly sand and gravel, piled-up in layers. Although it is a basic engineering principle, it was a magnificent achievement building a 'tower' from sand and forming a dam from stones in the sea.

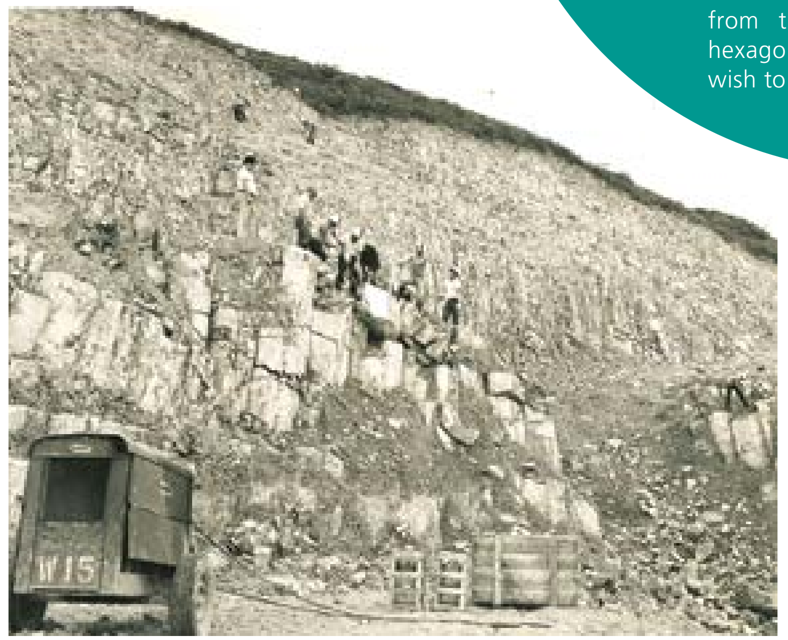
The construction of Plover Cove Reservoir was divided into three stages. The first stage involved the construction of the Sha Tin Water Treatment Works, the associated water tunnels and intake system. The second stage involved the construction of the dam. It was built from materials quarried from Ma Liu Shui, now The Chinese University of Hong Kong and at Turret Hill Quarry in Ma On Shan. The dam was built by digging a deep trench over 207 metres wide to lay the foundations (see photograph next page). This was followed by an alternating layer of gravel and sand, the weight of which was used to reinforce the core foundation. The upstream and downstream faces of the dam are protected by rock armour. Technical instruments were located inside the dam to monitor the condition of the structure. After the completion of the subsidiary dams, it took about four months to drain the seawater out of the enclosure, followed by another four months to fill with raw water before the water supply system could be put into operation. At the final stage in 1970, the government decided to increase the height of the dam. It was completed three years later and raised the water storage capacity by nearly 35% to 230 mcm.



▲ Section of an Embankment Dam

What is an Embankment Dam?

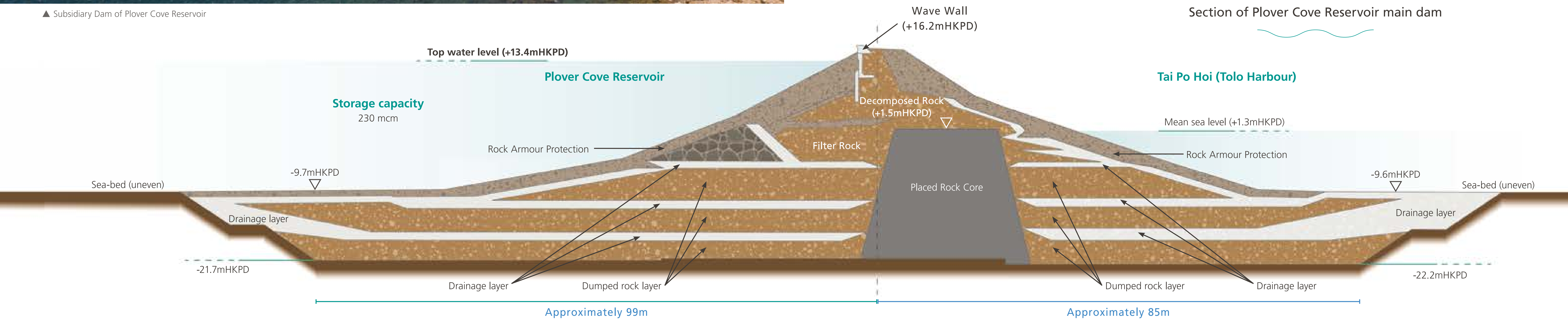
These dams are constructed by stacking soil and/or rock fragments. The core of the dam has an impermeable layer from the bottom to the top, which blocks water seepage from the dam and enhances stability. It has a gently sloping trapezoidal profile with a wide base area to match the natural cohesive properties of the soil or stone. As embankment dams require more natural earth materials for construction, the availability of materials in the vicinity of the reservoir is often taken into account when selecting a site. In the case of High Island Reservoir, for example, a large stone wall at the east side of the dam was quarried. The cut marks differ from those of the adjacent natural hexagonal columns, which visitors may wish to note.



▲ As with Plover Cove Reservoir, when High Island Reservoir was being built, engineers explored the nearby hillside for materials. Traces of these excavations can still be seen today.

▲ Subsidiary Dam of Plover Cove Reservoir

Section of Plover Cove Reservoir main dam



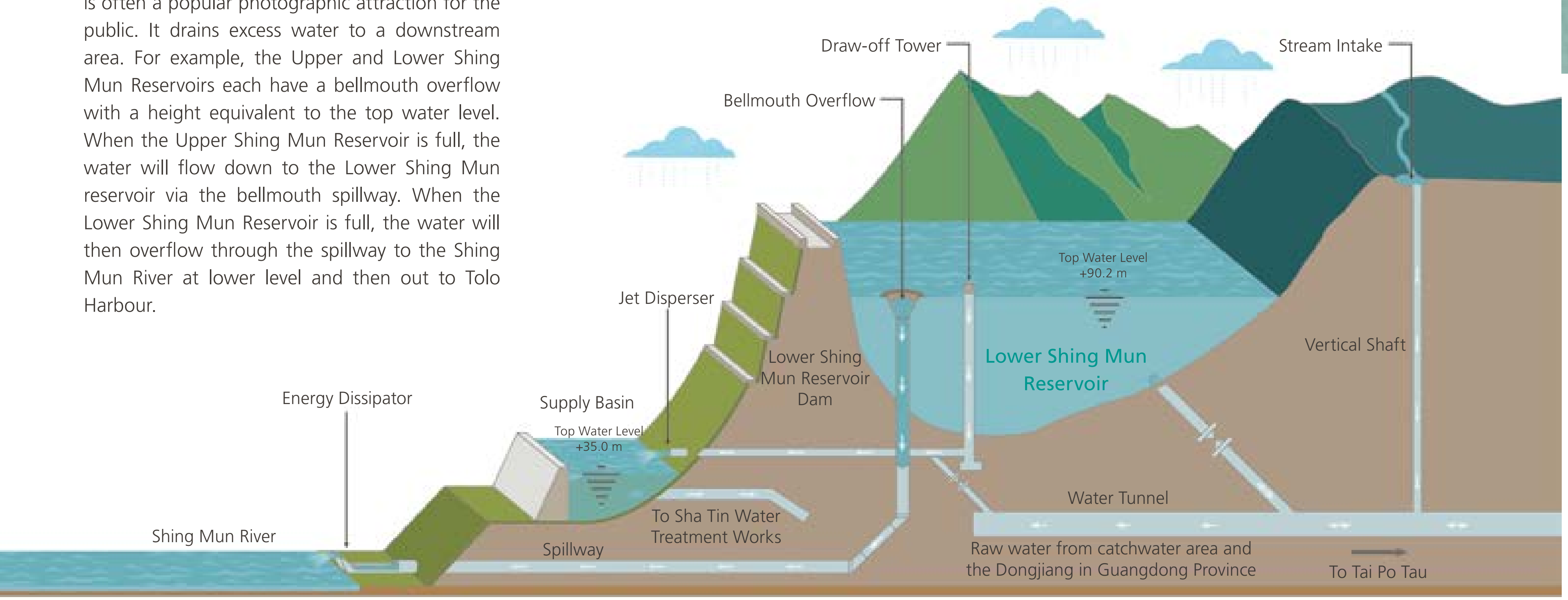
Overflow Facilities – Spillways

As a territory-wide water storage system, the basic function of a reservoir is to store water. It is also designed to drain and transfer the excessive inflow when the reservoir is overloaded. A spillway is designed to allow excessive water to be released away from the reservoir in a controlled manner. It prevents high water levels in the reservoir from endangering facilities or access roads on a dam crest, and prevents overtopping that washes the downstream dam face not designed to run water. In some cases, a road is placed above the spillway for pedestrian or vehicular traffic.

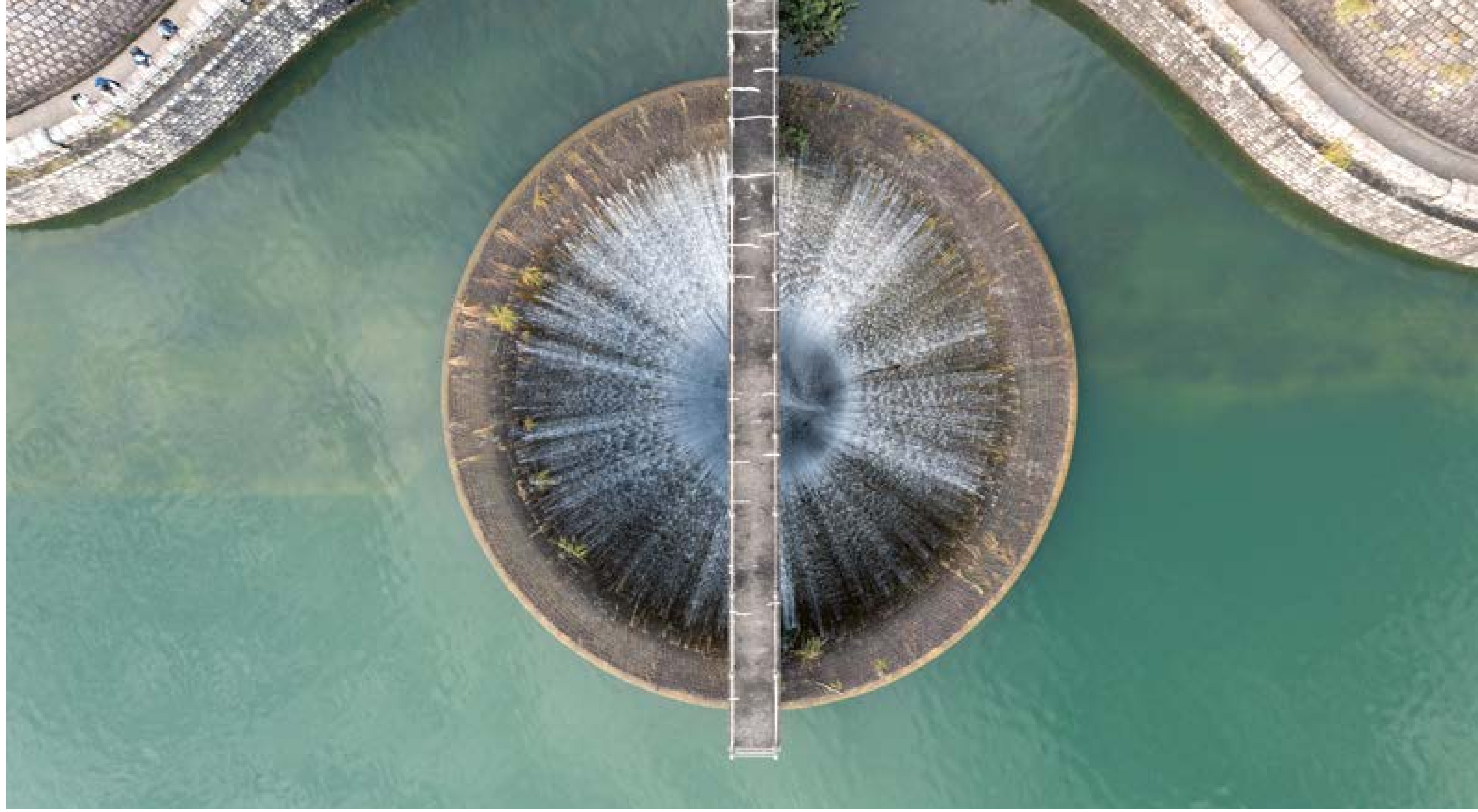
▲ Spillways of the subsidiary dam of Plover Cove Reservoir (left) and Tai Tam Tuk Reservoir dam (right)

Overflow Facilities – A Bellmouth Overflow

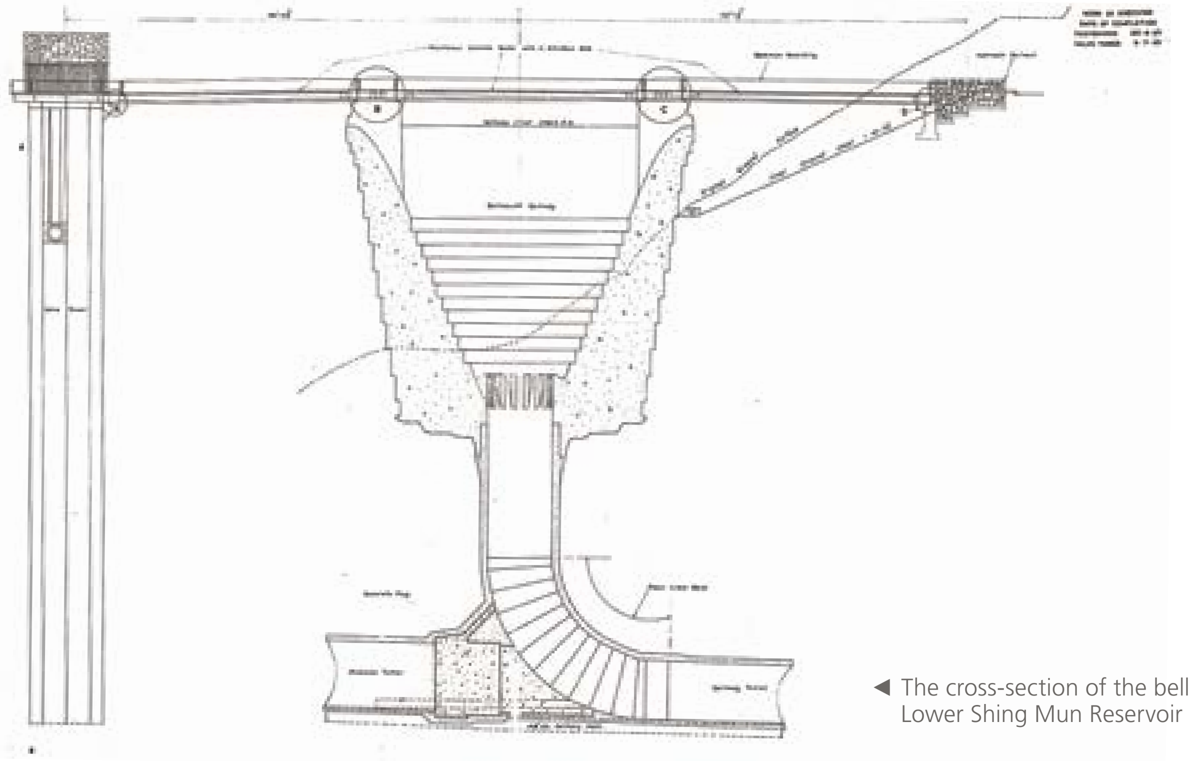
The large circular hollow structure, known as a 'bellmouth spillway', in the reservoir and connected to an underground drainage tunnel, is often a popular photographic attraction for the public. It drains excess water to a downstream area. For example, the Upper and Lower Shing Mun Reservoirs each have a bellmouth overflow with a height equivalent to the top water level. When the Upper Shing Mun Reservoir is full, the water will flow down to the Lower Shing Mun reservoir via the bellmouth spillway. When the Lower Shing Mun Reservoir is full, the water will then overflow through the spillway to the Shing Mun River at lower level and then out to Tolo Harbour.



▲ If the Lower Shing Mun Reservoir is full, raw water will be discharged into the Shing Mun River through the overflow.



▲ Aerial view of the bellmouth spillway at the Shing Mun Reservoir



◀ The cross-section of the bellmouth spillway of the Lower Shing Mun Reservoir

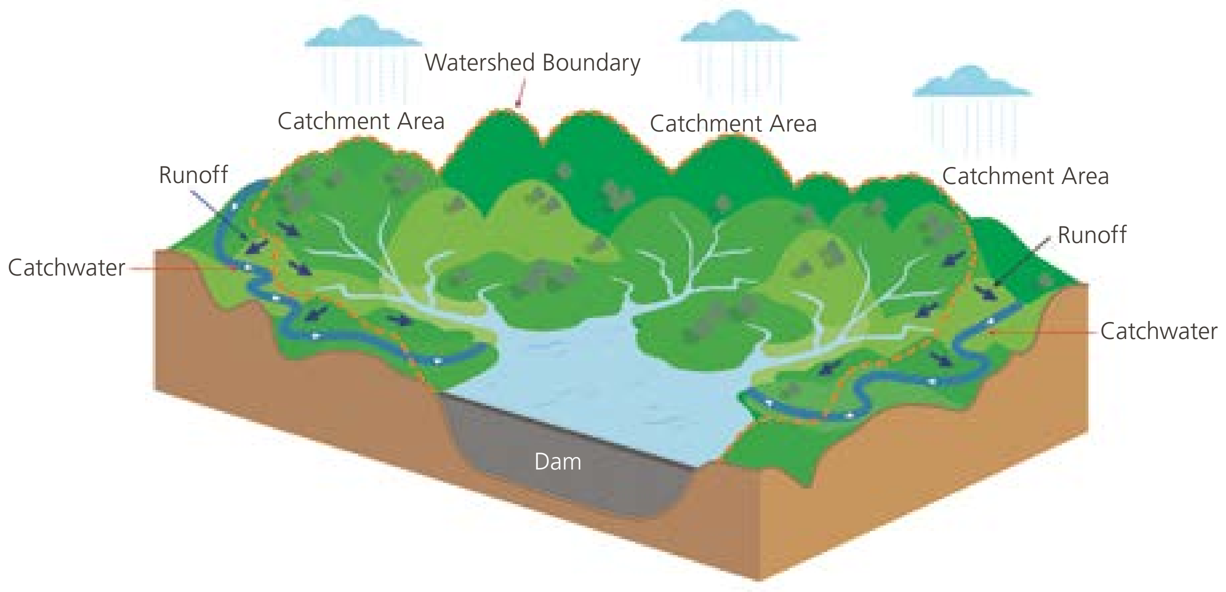
Gathering Grounds and Catchwaters

Reservoirs are built in gorges and valleys surrounded by mountains. A reservoir's catchment area is formed from the highest points of these mountain ridgelines. Meanwhile, some rainwater falls directly into the reservoirs and some flows via natural streams and rivers. In the absence of human intervention, there is a high chance of water loss as rainwater falls on the slopes or streams on the other side of the watershed, eventually ending up in urban storm drains or the sea. To collect rainwater more efficiently, the WSD also builds catchwaters on the opposite side of the watershed to redirect untreated water to reservoirs or water collection sites that would be otherwise lost.

In 1898, the British and Chinese sides signed the *Convention for the Extension of Hong Kong Territory* to further lease the New Territories. It led to the government's plan to build the Kowloon Reservoir in 1901. In 1902, 32 boundary stones were erected on the ridge line of the valley to the west of Beacon Hill and south of Needle Hill to mark the extent of the natural catchment area, to improve the collection of rainwater. Messrs Denison, Ram & Gibbs, the Hong Kong architectural and engineering consultants, recommended adding a catchwater system. In March 1904, $40,000 was successfully sought from the Legislative Council for the project.

There are currently 45 catchwater systems, with a total length of 120 kilometres around the territory as built over 40 to 100 years ago, 57 km were built before World War II, supporting various reservoirs/groups of reservoirs. They were constructed as waterways that cut into the natural hillsides before World War II. Therefore, the majority of these catchwaters are linked to man-made slopes. Catchwaters are either open channels or enclosed tunnels, which can suddenly fill with rainwater during flash floods. It is advised that people should not enter catchwaters as quickly rising water levels can be dangerous.

◀ Boundary Stone No. 10 at Kowloon Reservoir



▲ The catchwater is built to collect rainwater from outside the watershed that does not flow into the reservoir via the natural stream.

In addition, to prevent contamination of raw water in gathering grounds, the Waterworks Ordinance, Cap. 102, stipulates that no person shall enter, bath or wash in water forming part of "waterworks". This includes the gathering ground, which is defined in the legislation as "any surface of land in or by which rain or other water is collected and from which water is, or is intended to be, drawn for the purposes of a supply". Interestingly, the catchment area referred to in the legislation includes not only the geographical natural catchment area, but also the man-made development of the whole water gathering system, i.e. the engineering design plus the whole system of catchwater in the natural catchment area.

Rome was not built in a day. The development of such large water gathering systems in Hong Kong has taken over a century, and continues to serve and nourish the city today. From the first days of the Water and Drainage Department of the former Public Works Department, to the present-day WSD, these government departments have effectively maintained uninterrupted operation of the entire water supply system for over a century, providing an adequate water supply to the general public today - a formidable task indeed.

Stunning Landscapes due to Excellent Ecosystems

▲ Lau Shui Heung Irrigation Reservoir

Hong Kong is renowned for its spectacular scenery, often inspired by its various reservoirs and water gathering grounds. These are a combination of natural scenery and man-made structures, which receive continuous regular maintenance and improvements to ensure that Hong Kong - a city also brimming with skyscrapers - maintains a good environment while also acting as a natural purification system for local raw water. These reservoirs represent a significant collection of the city's cultural assets and have been a historical legacy for more than a century.

The water gathering grounds in Hong Kong cover about 300 square kilometres, i.e. about one-third of Hong Kong's total area. Most of these areas fall within country parks and are regulated and protected under the Waterworks Ordinance and the Country Parks Ordinance. These two sets of laws ensure that the reservoirs, catchwaters and adjacent surface runoff within the gathering grounds are not allowed to be contaminated, in order to protect the natural environment and the biodiversity in the country parks. To foster a harmonious coexistence between people and nature, most reservoirs and the adjacent countryside are easily accessible from urban areas with famous hiking trails, making them popular destinations for the public.

High Ecological Value of Natural Habitats in Catchment Areas

The importance of safeguarding reservoirs from contaminants is generally well understood. However, streams and catchwaters are also important parts of water gathering grounds, and to prevent contamination, people should not enter these waters.

Rivers and streams are ideal habitats for a variety of wildlife and plants. Plants growing alongside rivers offer nourishment for the river life, to shield sunlight, as well as to regulate water temperature and purify the water. It is common to find freshwater fish such as the pond loach and goby in Hong Kong's rivers and streams, and the amphibious Hong Kong Newt has also been recorded in Tai Shing Stream.

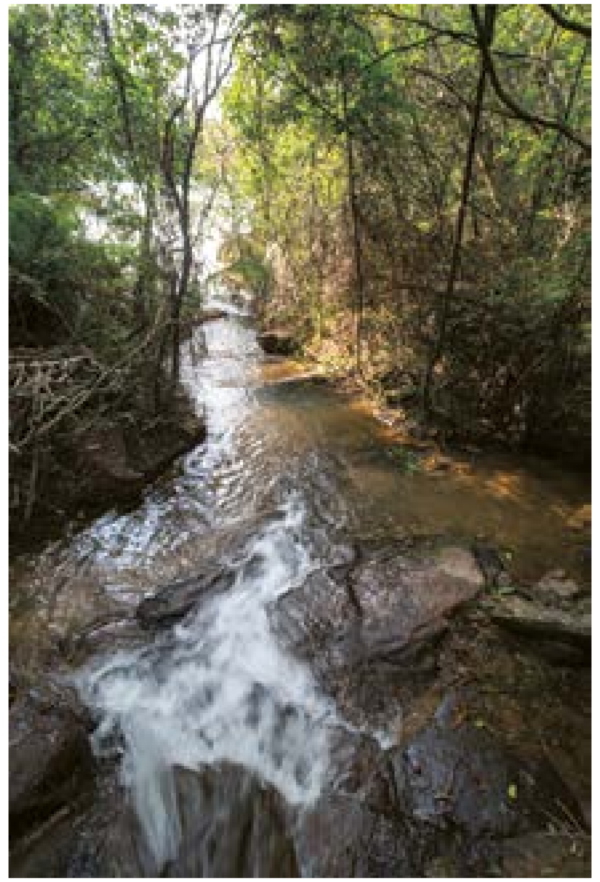
The city's "Top-Nine Major Streams" are among Hong Kong's top hiking attractions. It is important to note that Tai Shing Stream, Ping Nam Stream, Lin Fa Stream, Ng Tung Stream and Wang Chung Stream are all located within water gathering grounds, whereas Sheung Luk Stream, Wong Lung Stream, Ngong Sham Stream and Shui Lo Cho Stream are partly located in the gathering grounds. The public should be aware and should not enter those areas for bathing or washing.

#Fun Fact

Tips for Treasuring Water

We can all take action to protect our water resources. We must recognise the importance of our beautiful water gathering grounds and reservoirs by not contaminating the water. We should also take away our own rubbish and not wash or bathe in rivers.

▲ Hong Kong Newts prefer to live in streams with clear water



▲ A stream flowing into Kowloon Reservoir

Water Tunnel Habitat for a Variety of Mammals

Bats are the largest group of native mammals in Hong Kong. According to the Agriculture, Fisheries and Conservation Department (AFCD), there are 55 species of mammals recorded in Hong Kong, of which 25 are bats. Ten of the bat species are widely distributed in water tunnels or abandoned mine caverns, indicating that water tunnels provide a suitable habitat for bats. Bats can play a balancing role in the ecosystem; take insect-eating bats for example, they can eat dozens to hundreds of insects every hour. Large bat colonies can consume tons of insects in a single night, including crop-eating beetles and moths. Alternatively, fruit bats which feed mainly on fruits and the nectar of flowers, can help to spread pollen and seeds. Bananas and mangoes both flower at night and rely on bats to pollinate their flowers.

Further Enhancing Biodiversity

The WSD not only relies on the public to safeguard the habitat of the city's reservoirs and gathering grounds, but also by participating in an eco-friendly initiative: *Hong Kong's first city-level Biodiversity Strategy and Action Plan 2016-2021*, initiated by the former Environment Bureau (currently the Environment and Ecology Bureau). In collaboration with other government departments, the WSD aims to enhance the conservation of streams and catchwaters by improving maintenance procedures to reduce its impact on the ecosystem.

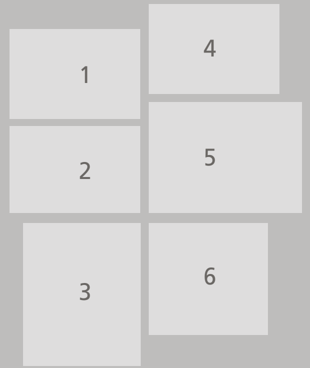
Supported by the AFCD, the WSD has piloted a number of wildlife-friendly measures in catchwater areas, such as installing animal escape routes and using ecological friendly materials in its improvement works. For example, additional stairways and non-slip materials have been applied to stone walls on both sides of the catchwater on Lantau Island.

▲ The ecologically-beneficial floating islands are home to a variety of plants, including water chestnut, soft rush, awl club-rush, ginger lily, and water clover and spreading dayflower.

▲ A pilot scheme placing ecological floating islands in Hung Shui Hang Irrigation Reservoir helps to enhance biodiversity.

The WSD has also worked with various green groups, including on a pilot scheme to divert part of the collected rainwater to the downstream Tung Chung River on Lantau Island. The scheme supports ecological studies and the recovery of downstream freshwater habitats. Also, a number of biodiversity pilot projects have been launched in irrigation reservoirs, including the trial use of ecological floating islands and an ecological survey in the Hung Shui Hang Irrigation Reservoir. It is envisioned that by planting a variety of aquatic plants on the floating island, various small insects and birds will be attracted to inhabit the platform. As a result, the reservoir's biodiversity will improve, as well as improving the physical landscape.

▲ Steps were added to the stone wall of the catchwater. Animals that have fallen into the catchwater by accident can now easily climb out on their own.



1. The Kowloon Reservoir is located in the Kam Shan Country Park. The area is commonly referred to as "Monkey Hill." Monkeys are frequently seen and the public should not feed them.
2. The habitat around the reservoirs nurtures biodiversity. This photograph features the Brown Fish Owl, which is a large species of owl and a native resident bird.
3. The Verditer Flycatcher, a rare Hong Kong winter visitor, was photographed at Shing Mun Reservoir in winter.
4. This photograph of a Red-faced Skimmer was taken around the Hok Tau Irrigation Reservoir.
5. A Pale Awlet can be seen in the summer, they are mostly active in the early morning and late afternoon.
6. The Chinese Sparrowhawk, a common passage migrant, was photographed on an early spring morning at Tsing Tam Irrigation Reservoir.

Reservoir Management Matters

Reservoirs are the most important storage facilities for raw water. Reservoirs and water gathering grounds are both subject to regulation under Hong Kong's Waterworks Ordinance and the Country Parks Ordinance. Managing reservoirs is crucial for managing water resources and serves as the primary protective safeguard for the quality of drinking water. It is therefore crucial to also allocate adequate resources to ensure proper maintenance of all water facility components.

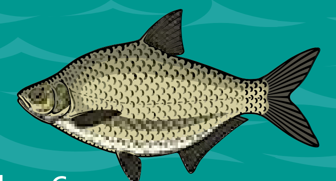
▼ Lau Shui Heung Irrigation Reservoir

Challenges to a Reservoir's Ecological Environment

The majority of Hong Kong's reservoirs are situated in the upper parts of river valleys. Rivers are diverted with dams built to create artificial fresh water ecosystems. Water levels in reservoirs naturally increase with rain and again decrease when the water is transferred to various water treatment works. These rapid and significant changes in water levels make it challenging for aquatic plants and animals to adapt to their habitat. As a result, it is difficult for a reservoir to become a fully mature and stable ecosystem. Sometimes, nutrients may accumulate when water circulation is slow. During hot weather with its intense sunlight in summer time, the growth of algae on the water surface can be triggered. This can reduce the clarity of the raw water and cause odour and taste issues, ultimately inducing pressure to subsequent water treatment procedures.

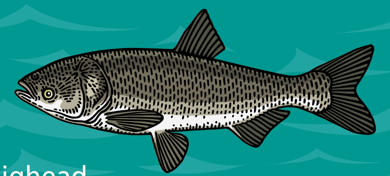
A Natural Reservoir Scavenger

Plover Cove Reservoir, Tai Lam Chung Reservoir, Shing Mun Reservoir and Kowloon Reservoir have previously been found to be particularly prone to algal proliferation. For this reason, since the 1980s the WSD began to explore fish stocking for the natural ecological regulation of reservoirs. Natural ecological regulation uses the feeding habits of different fish species to remove algae in reservoirs, thereby maintaining the quality of the raw water. The WSD regularly releases fish fry, such as silver carp, bighead and mud carp, into these reservoirs. Each fish species plays a different role in different locations to control algal proliferation.



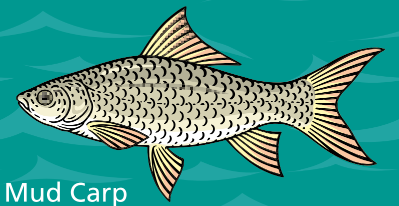
Silver Carp

Silver carp mainly live just below the water surface. Their fine gill rakers filter out phytoplankton as food and are particularly effective in suppressing algae growth.



Bighead

Bighead is an omnivorous fish that stays in the upper and middle layers of water, feeding on phytoplankton and other zooplankton.



Mud Carp

Mud carp lives in the middle and bottom of the water and feeds on organic detritus.

#Fun Fact

Fishing in Reservoirs

Seventeen reservoirs and nine irrigation reservoirs in Hong Kong have been open to the public for fishing during non-spawning seasons. Due to growing public interest in fishing activities, the WSD launched a pilot scheme to relax the fishing period in some reservoirs, beginning on 1 April 2021, so anglers holding valid fishing licences can fish in the Plover Cove Reservoir and Tai Tam Group of Reservoirs throughout the year.

The WSD employed an expert consultant to assess the impact of this relaxation during the pilot scheme. The assessment indicated that relaxing the restriction on the fishing period showed no appreciable impact on the reservoir environment and water quality, nor affected the species and quantities of fish inside each reservoir. After reviewing the expert consultant's advice that the reliability and safety of the water supply would not be affected, the WSD decided to relax the fishing period. Since 21 April 2022, anglers holding valid fishing licences can enjoy fishing in all Hong Kong reservoirs throughout the year. Anglers wishing to fish in local reservoirs shall apply for a licence from the WSD. Applicants must be over 13 years of age to apply for the licence at a fee of HK$33, valid for three years.

Anglers should observe the terms and conditions of the fishing licence when fishing in the reservoir as fish and their habitat are vital to the reservoir ecosystem and raw water quality.

Further information about applying for a fishing licence:

Fishermen in the Reservoir

The Artisans (fishing), also known as "reservoir fishermen," are the front-line staff who manage the reservoirs. Prior to joining the WSD, they had experience in the fishing industry and are adept at working on boats. Together with the Launch Master, they form the reservoir crew team and regularly conduct gill-net surveys at various monitoring points. Unlike ordinary fishermen, the fish they catch are not for consumption, but for recording basic information, such as species, size and quantity. The monitoring of changes in the fish population and species of fish maintains the ecological balance of reservoirs.

The crew team is also responsible for taking water samples from reservoirs. Due to the large surface area and capacity of reservoirs, there is an uneven distribution in reservoir water quality depending on various factors, such as the duration of sunshine, wind direction and rainfall, etc. The crew team must collect water samples at different monitoring points and depths for laboratory analysis, so as to monitor the reservoir water quality.

The crew team works in the reservoirs every day regardless of the weather. Reservoirs, however, are not always calm with clear water, and during unstable weather, large surface waves might form. During heavy fog, distances become difficult to judge and the crew team relies on their fishermen's experience. A thorough understanding of a reservoir, including known danger areas and which locations should be avoided has been recorded over the years.

“The experience of our frontline staff is important," says Launch Master YIP Chi-on, adding that the water level in reservoirs changes from time to time. "When the chemist is setting the water quality monitoring route for the unmanned surface vessel (USV), the crew team will provide advice. For example, there may be reefs at the bottom of the reservoir in some locations, and this information will help to adjust the USV routes during the times of low water-level.”

1 Reservoir crew team

2. Reservoir fishermen conduct gill-netting

3 Reservoir fishermen releasing fish fry into a reservoir

4 Reservoir fishermen regularly take water samples from a reservoir

Monitoring Water Quality by Unmanned Surface Vessels

The WSD’s Water Science Division introduced the USV system in 2011 to further enhance and to keep abreast the monitoring of water quality in reservoirs. The first USV was converted from a remote-controlled commercially available recreational boat. The WSD staff installed water suction pumps and sample bottles on board to automatically collect water samples. The second and third generations of USVs were gradually equipped with water quality analysis and global positioning devices. The fourth generation USV system currently in use at the Plover Cove Reservoir was jointly developed by the WSD and its supplier. The USV system now uses four vessels for parallel monitoring of surface water quality. The USVs automatically follow a pre-set route in the reservoir following signals received from the base station. Water quality data will then be sent back to the base station computer for real-time analysis. The WSD has installed a solar panel system on the exterior of the USV storage house at Plover Cove Reservoir. This generates electricity for use by the USVs and reduces carbon emissions.

Compared to water quality monitoring using conventional vessels, USVs can access narrow or shallow parts of reservoirs due to their small size. They allow coverage of more monitoring points at the same time, making them more efficient. In case of water quality emergencies, the easily transportable USVs can be deployed to other reservoirs. Nevertheless, the traditional manual collection of water samples cannot be fully replaced by USVs and the two methods efficiently complement each other. In fact, many related tasks, such as assisting in the set-up and retrieving of USVs, have become new responsibilities for the crew team; meanwhile, the application of new technologies also brings new challenges.

1 Water quality monitoring equipment is on board to measure water quality parameters in real time

2 Reservoir fishermen measure the light penetration of the water body in a reservoir with a Secchi disk

3 The first generation USV was converted from a remote-controlled boat

4 The fourth generation USV

5 Data collected from USVs will be sent to the base station computer

▲ Electrical Engineer SIU Ka-shun says that the application of floating solar power systems in reservoirs requires water safety considerations.

Floating Solar Power Systems

The WSD has been implementing various energy conservation measures to combat the impact of climate change. As well as enhancing energy efficiency in its operations, the WSD is looking into using renewable energy for its water supply facilities. In recent years, floating solar farms have been rapidly developed worldwide. In 2017, the WSD took the lead in installing two floating solar power systems at the Shek Pik Reservoir and Plover Cove Reservoir as a pilot project to demonstrate their feasibility and evaluate their performance.

A floating solar power system is a type of power generation system consisting of a floating platform and solar photovoltaic (PV) panels installed on a water surface. Compared with conventional solar power systems, the floating solar system's design is an excellent choice for Hong Kong because it makes use of the water surface of the reservoirs without using limited land resources.

Floating solar farms can be used in different bodies of water, including the sea, rivers and even the pit lakes of abandoned mines. SIU Ka-shun, the WSD's Electrical Engineer responsible for renewable energy explains: "When installing solar farms on Hong Kong reservoirs, it is crucial to consider the technical aspects and its impact on water safety and the ecosystem. The Hong Kong public places great importance on water safety, hence all materials used in the project must comply with international water safety standards. Hong Kong's reservoirs are also situated in country parks with a high ecological value. The WSD has made appropriate arrangements for the design, material selection and construction methods to minimise the impact on the environment. For instance, a modular design for easy component assembly has been adopted for floating platforms and anchorage systems to facilitate installation and to avoid the use of heavy machinery at construction sites. This reduces the risk of adverse impact to water quality during the assembly operations."

Water samples are regularly taken from different locations in reservoirs for testing. After installation of the floating solar power system, the test results indicate no water quality abnormalities. The solar PV panels are intentionally placed to avoid direct sun exposure. This helps to reduce water evaporation and improve the raw water quality by inhibiting the growth of algae in ponds.

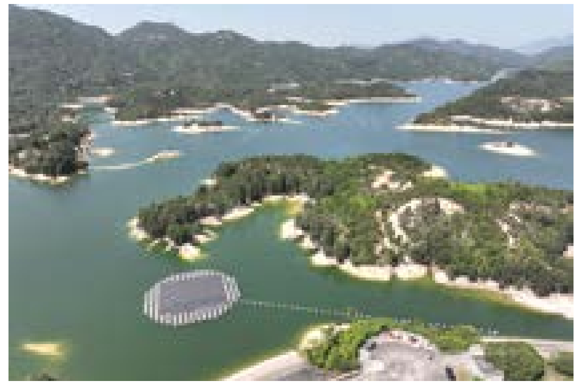
The two pilot floating solar power systems, each consisting of 352 panels, are mounted on a floating platform. The WSD has adopted different ideas in the system design to implement the floating solar system to blend into the environment. Further consideration about the visual appearance of the installations was given for the third floating solar power system installed at the Tai Lam Chung Reservoir in 2022. SIU explains, "As the name of Plover Cove Reservoir is 'Boat' Bay in Chinese, we have designed the system in the shape of a boat. The Tai Lam Chung Reservoir, commonly known as 'Thousand Islands Lake', features a circular design to blend in with the surrounding island cluster. We have studied and compared data from both designs while evaluating the fluctuating nature of the system depending on water levels. We still need to ensure that the solar system's performance is not affected by their visual design."

Floating solar power systems in reservoirs are usually installed near waterworks facilities. They generate electricity and send it through cables to nearby raw water pumping stations or air compressor houses. The large empty space around the reservoir increases the exposure of the panels to sunshine, additionally the water's cooling effect on the panels facilitates more efficient power generation. Currently, each system can generate up to 120,000 kilowatt-hour of electricity per year, which is equivalent to a reduction of 84 tonnes of carbon emissions.

These pioneer projects offer solid reference data to support Hong Kong's ongoing efforts to cultivate renewable energy use and prepare for the implementation of larger floating solar power systems.

▲ The floating solar power system at the Plover Cove Reservoir has solar PV panels shaped like a boat.

▲ The floating solar power system at the Shek Pik Reservoir



▲ The floating solar power system at the Tai Lam Chung Reservoir has a circular design.

Current and cumulative output of solar panel power systems:

Conserving Waterworks Heritage for the Future

▲ Former Chief Engineer Ir CHAN Tze-ho and Senior Engineer Ir WONG Hei-nok of the WSD

Ancient Rome's 2,000-year-old water supply system is one of the world's great architectural wonders. Did human civilization enable the construction of such great water supply systems, or vice versa? Although Hong Kong's first public waterworks projects were hampered by financial constraints, the construction of the city's second reservoir, the Tai Tam Reservoir[1], benefited from a variety of favourable factors. Significantly, Hong Kong's urban development began at the height of the European industrial revolution and this project was at the forefront of international engineering technology. Similarly, the city's future large-scale waterworks projects gained from subsequent engineering and technological developments. Despite Hong Kong's fast-paced urban development, many of the city's original waterworks facilities have stood the test of time and are still in excellent operational use today.

Ir CHAN Tze-ho explained that, "Since we work in the WSD, we know the waterworks and systems very well and greatly admire the heritage buildings and structures. We see not only the grandeur of their design, but also the origins of the entire water supply system. There is always a reason for designing a project in such a way. This is what makes it so informative for us when looking back over the history of the waterworks' monuments and the history of the projects when researching the traces and drawings left behind."

Former Chief Engineer Ir CHAN Tze-ho and current Senior Engineer Ir WONG Hei-nok of the WSD cover two generations of expertise overseeing the waterworks' historical facilities and monuments. Both engineers have been involved in a number of studies to facilitate the historical grading of waterworks facilities since 2000. During their research they learned more about the waterworks history and have become increasingly motivated to share their experience and knowledge in their day-to-day maintenance work.

The 42 Waterworks Monuments

Ir CHAN remembers that when he was posted to the WSD Design Division over 20 years ago, he frequently went to the Drawing Office to look for historic drawings prepared by his predecessors. "Back then, digitalization was not widespread and finding information was not so easy. Notwithstanding, it was fascinating to have access to handwritten drafts from a century ago, as they portrayed a vivid picture of the city's water supply history," he recalls. He later joined WSD's editorial team publishing a special publication commemorating 150 years of water supply in Hong Kong. This allowed him to further explore the history of Hong Kong's waterworks. In 2009, Mrs Carrie LAM CHENG Yuet-ngor the then Secretary for Development and the Antiquities Authority, requested the WSD to explore conserving historic waterworks facilities. At that time, Ir CHAN became the principal researcher in preparation for the heritage assessment and grading of the waterworks facilities. During this assessment, the WSD provided information on 41 waterworks structures to the Antiquities and Monuments Office and the Antiquities Advisory Board.

As of June 2022, there are 132 declared monuments in Hong Kong. Seven of these are declared waterworks monuments, including 42 historic structures across six reservoir systems and 46 historic buildings rated Grades 1 to 3. The waterworks monuments represent the largest coherent grouping of heritage structures amongst all the declared monuments and historic buildings in Hong Kong. Together with the country parks in which they are situated, they constitute an exemplary component of Hong Kong's cultural landscape. The WSD's heritage is widely recognised by the general public for its unique combination of natural environment reflecting the history of urban development and the ingenuity of artificial engineering structures. This array of heritage reservoirs declared as monuments were all built before World War II and include: Pok Fu Lam Reservoir, the Tai Tam Group of Reservoirs, Wong Nai Chung Reservoir, Aberdeen Reservoir, Kowloon Reservoir and Shing Mun Reservoir.

These declared monuments of historic reservoir systems comprise 13 masonry bridges or aqueducts with bridging facilities, involving large spanning structures mostly built of granite, reflecting Hong Kong's geological composition. Whilst the overall design is mostly functional and utilitarian, the masonry walls, columns and arched structures, in particular, demonstrate a subtle influence of the popular neoclassical architectural style prevalent in the late 19th and early 20th century. Adding to their timeless elegance, these reservoirs are surrounded by forests of tall shady trees, often situated far from other urban buildings and occupying vast green areas with unobstructed views.

The Tai Tam Group of Reservoirs with 21 historic structures accounts for half of the total number of declared waterworks monuments, making this reservoir possess the highest number of declared heritage buildings. In total, they form a five-kilometre long heritage trail that is a two-hour walk around Tai Tam Upper Reservoir, Tai Tam Byewash Reservoir, Tai Tam Intermediate Reservoir and Tai Tam Tuk Reservoir. The Tai Tam Reservoir project set a precedent in public financing for infrastructure at the time, as the scale of the original project was increased to over HK$1 million. The project also pioneered the use of a drilling rig to build Hong Kong's first water transfer tunnel. The project also introduced a local concrete engineering method that enabled the construction of the largest concrete dam in the British colonies at that time. This project greatly contributed to the increased local production of cement, and changed the city's established construction methods over the following years[2].

Five Key Features of Waterworks Heritage

After years of research, Ir CHAN identified that, "There are five key features of waterworks heritage structures. They need to be: 'site-specific', 'use local materials', have a 'mixture of aesthetics and function', have 'good documentation', as well as being 'bold and innovative'."

"Site-specific" refers to the design of reservoirs or related facilities to suit the geographical surroundings. For example, the Kowloon Reservoir system was built after the lease of the New Territories was granted to cater for the scarcity of fresh water on Hong Kong Island and in Kowloon. Despite being named the Kowloon Group of Reservoirs, they are actually located in the New Territories. The four reservoirs were built according to the topography of the hills, making good use of gravitational flow. Two water treatment works, Shek Lei Pui Water Treatment Works (SLPWTW) and Tai Po Road Water Treatment Works (TPRWTW), are located not far away, forming a clear and visible water supply network.

Practical considerations during the design of each project govern the use of the most suitable materials. This means using different components

1 The Tai Tam reservoirs, which includes the Tai Tam Upper Reservoir, Tai Tam Byewash Reservoir, Tai Tam Intermediate Reservoir and Tai Tam Tuk Reservoir, was constructed in phases between 1888 and 1917.

2 Ma Guangyao. (2011). *The Story of the Opening of Tai Tam Reservoir - A Turning Point in the History of Engineering in Hong Kong.* Hong Kong: Joint Publishing (Hong Kong) Ltd. 169 - 202.

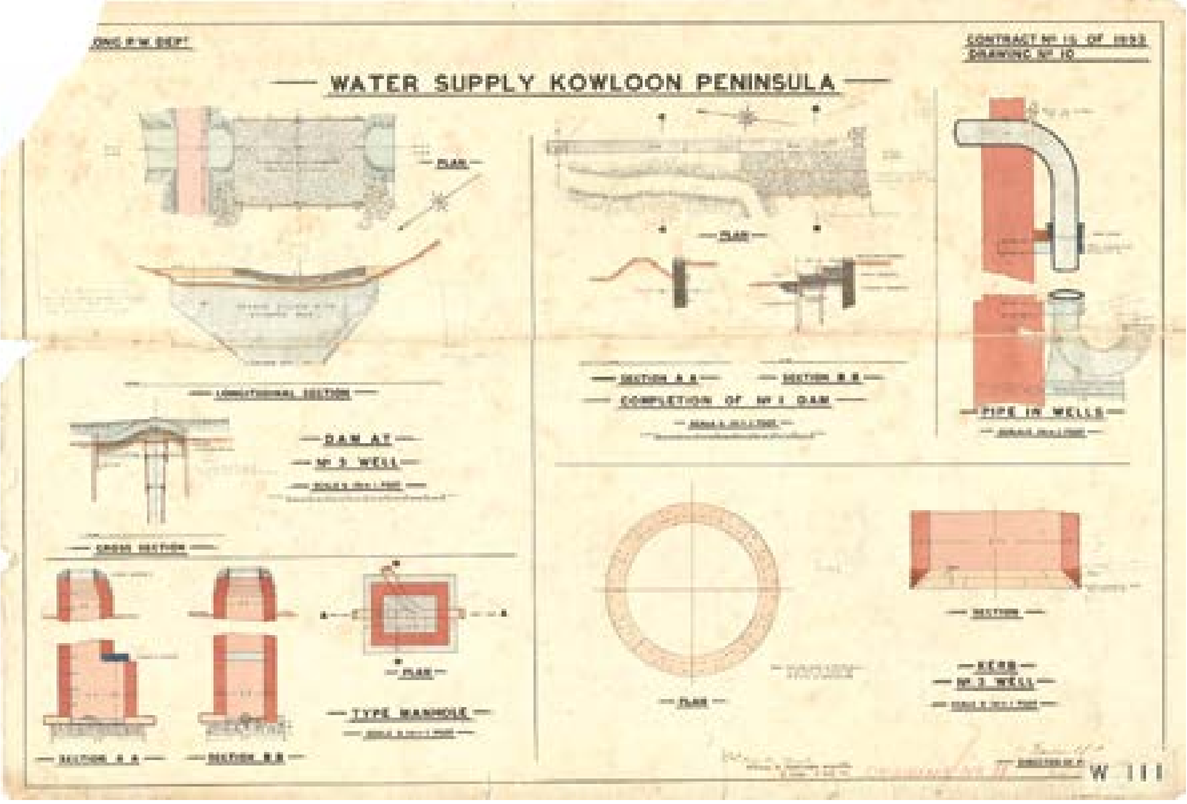
to construct a facility. The Ex-Sham Shui Po Service Reservoir at Mission Hill is a rare example of a service reservoir that combines a variety of materials, using granite, red bricks and concrete. Ir CHAN explains that the architecture is dependent on its specific use of material, "Inside the interior of the reservoir, stone has been used for columns because they have a greater load-bearing capacity. Red bricks are used to create curved arches, while concrete is used for large spans. In many cases, raw materials, particularly granite, were sourced on-site at the waterworks."

Waterworks heritage structures are often aesthetically and functionally pleasing. The methods and styles of construction used show their popularity at the time and the great thought that went into their design. According to Ir CHAN, "Early waterworks projects were bold and innovative, employing the most up-to-date and cutting-edge technologies. For instance, rapid gravity filtration was adopted at the SLPWTW despite there being only two comparable facilities in the United Kingdom before its introduction in Hong Kong." The idea of creating reservoirs in the sea, another example, was a world first at the time.

Exploring the Past Through Research

Many of the city's waterworks facilities are still in use today, which is good news for heritage conservationists and history enthusiasts. Their preservation are assisted with the many original drawings that have been preserved intact due to the facilities' need for continuing maintenance. This is not necessarily the case for other historic structures, especially those built before World War II, as much documentation was lost during the war. Ir CHAN and Ir WONG have established a history research group with like-minded colleagues to search for missing water supply heritage structures which they research and look for in their free time.

"We usually learn about an old project's design from documents and drawings", explains Ir WONG, "Then we set out to plan the route and estimate the approximate location of the missing structure. When we arrive at the site, we observe the terrain and search for possible alignments along the water supply system. We are like detectives." After examining old drawings, Ir WONG recalled their experience of searching for the original bridge no. 26 that was missing along the Pok Fu Lam Conduit. "The site conditions did not match the location stated in drawings, so by understanding the engineering design, we reckoned that the alignment had probably been altered during construction. We eventually discovered the old bridge hidden in grass at a lower level. We were thrilled!"



▲ The preserved drawing of the Kowloon Water Supply project, completed in 1895.

Historic Waterworks Facilities Still Serving the Public

"When we investigate historic structures, we often find that old buildings have been significantly altered for practical reasons," Ir CHAN explains. "For example, the roof of the decommissioned valve house at Wong Nai Chung Reservoir was originally designed with a pitched Chinese-tiled roof, but because of water leakage, the maintenance staff quickly replaced it with a flat concrete roof." This modification understandably solved the urgent problem of water leakage at the expense of aesthetic considerations.

Ir WONG, who is currently responsible for reservoir safety, says the WSD regularly maintained facilities. "Heritage conservation standards now ensure that maintenance work on our 42 monuments listed waterworks facilities are undertaken properly."

Our Heritage for Future Generations

Before retirement, Ir CHAN had been in charge of the maintenance of the Ma On Shan Water Treatment Works. He recalled discovering in 2014 an endangered and precious incense tree on the hillside, close to the Works' boundary fence. "The tree was in poor condition and hence special arrangements were made to transplant it to a better location. The daily works and decisions made by team are of crucial to preserve our heritage for future generations."

In a similar vein, Ir WONG added that drawings are crucial documents that give evidence of the historical value of heritage structures and buildings. "The WSD liaises with the Government Records Service to restore, classify and archive old drawings and documents. Hopefully, in the future, an online exhibition will be launched to make these valuable historical materials more accessible to the public."

▲ The boulders along Bowen Road show traces of past stone splitting.

▲ Traces of chiseled stone are still visible today.

▲ The Dongjiang water pipeline

Dongjiang – Relief from Drought

Nowadays, we may consider a round-the-clock water supply as ordinary. However, water rationing had been common in Hong Kong since the late 19^{th} century and particularly during the post-war economic boom years. In those days, the Waterworks Office (the predecessor of the WSD) would only supply water for a full 24-hour day during the three or four days of festive occasions, such as Chinese New Year, New Year's Eve and New Year's Day.[1] On 1 June 1982, the last restriction on water supply was lifted, bringing an end to years of intermittent water supply. The major reason for restrictions finally ending was the introduction of water supplied from the Dongjiang.

Dongjiang is the nearest natural river to Hong Kong and has an abundant amount of water. It originates from Anyuan, Xunwu and Dingnan Counties in Jiangxi Province and joins at the Hehe Dam in Longchuan County, Guangdong Province, known as Dongjiang as a whole. The Dongjiang River relies heavily on rainfall with a high annual average flow of nearly 30 billion cubic metres (bcm)[2]. Since 1965, Dongjiang water has been a water source for Hong Kong. In 2022, Hong Kong imported 810 million cubic metres (mcm) of Dongjiang water, accounting for about 80% of the city's fresh water supply.

1 Wu, Ba-ling (ed.) (1962). 'A Year in the Public Service of Hong Kong', *Hong Kong Yearbook*. Hong Kong: Overseas Chinese Daily Limited. 109 pp. https://mmis.hkpl.gov.hk//c/portal/cover?c=QF757YsWv5%2BakvA8rFW5Eu08M%2F8DHtP2
2 Ho, Pui-yin (2001). *Water for a Barren Rock. 150 Years of Water Supply in Hong Kong*. Hong Kong: The Commercial Press (Hong Kong) Ltd. 216 pp.

The Dongjiang-Shenzhen Water Supply Process

The Dongjiang is the nearest river to Hong Kong with an abundant supply, however diverting its water is a huge project as it is located more than 50 kilometres (km) away from the city. To enable water transportation to Hong Kong, the final proposal for the Dongjiang-Shenzhen Water Supply Scheme was to transform the Shima River into an engineered channel and reverse its original south to north flow at the initial sections of the river. The channel crosses six mountains and is elevated by a multi-stage pumping station, ascending from 2 metres to 46 metres above sea level, prior to its transmission into the Yantian Reservoir. From this point, the Dongjiang water flows into the Shenzhen Reservoir (see diagram on the right: Dongjiang-Shenzhen Water Supply System - Closed Aqueduct (Longitudinal Section)). Before the completion of the Dongjiang-Shenzhen Water Supply Improvement Works in 2003, Dongjiang water had to travel through an 83 km aqueduct before it could reach Hong Kong.

A Turning Point for the Supply of Dongjiang Water to Hong Kong

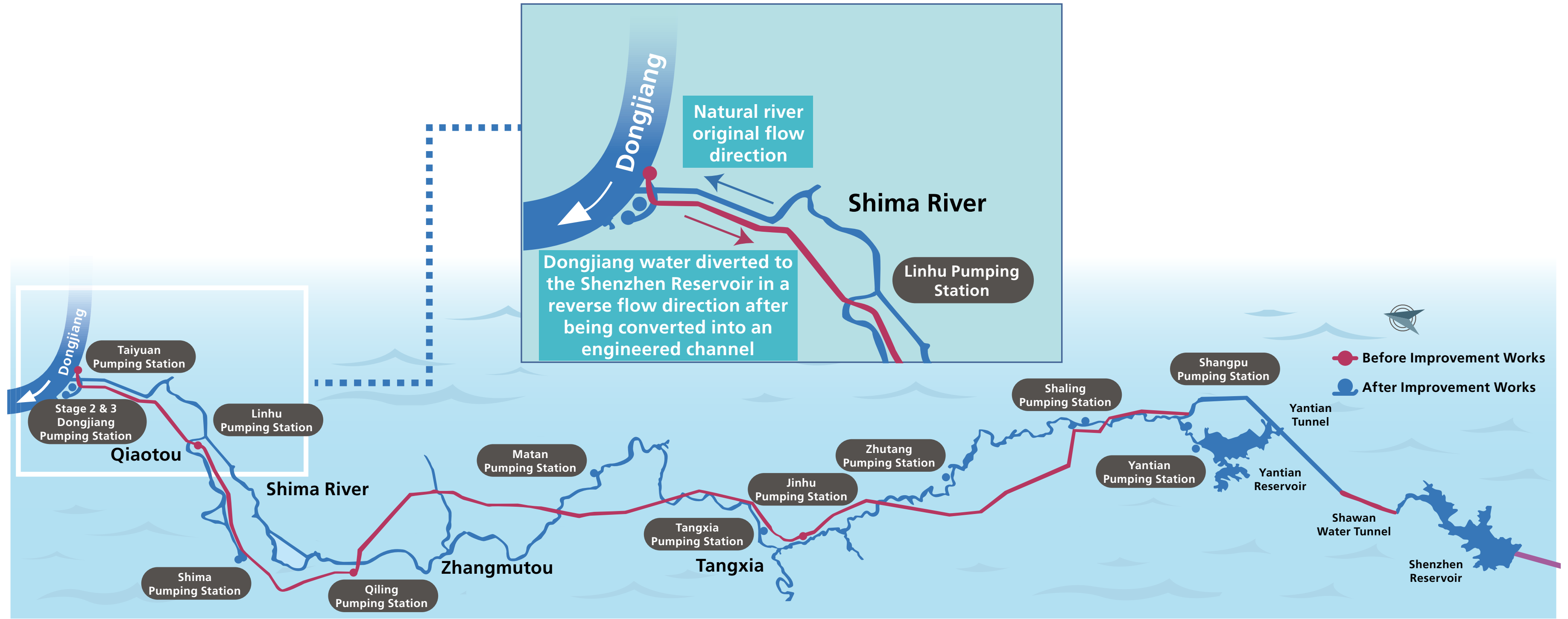
The supply of Dongjiang water can be traced back to 1963. In that year, the population of Hong Kong had jumped to 3.42 million[3]. There were 14 completed reservoirs with work on the Lower Shing Mun Reservoir in full swing and the construction of the Plover Cove Reservoir had commenced. The year's rainy season had been sparse, with an annual rainfall of only 901.1 millimetres (mm)[4], well below the annual average of 2,235 mm[5] .

Hong Kong's public hygiene issues had increasingly gotten worse due to the city's dense population and the prolonged water supply restrictions in hot weather. In fact, Hong Kong was declared a cholera epidemic zone several times between 1961 and 1963, with the 1963 epidemic lasting 177 days and occurring earlier than the previous two years with the number of patients increasing significantly to 114[6].

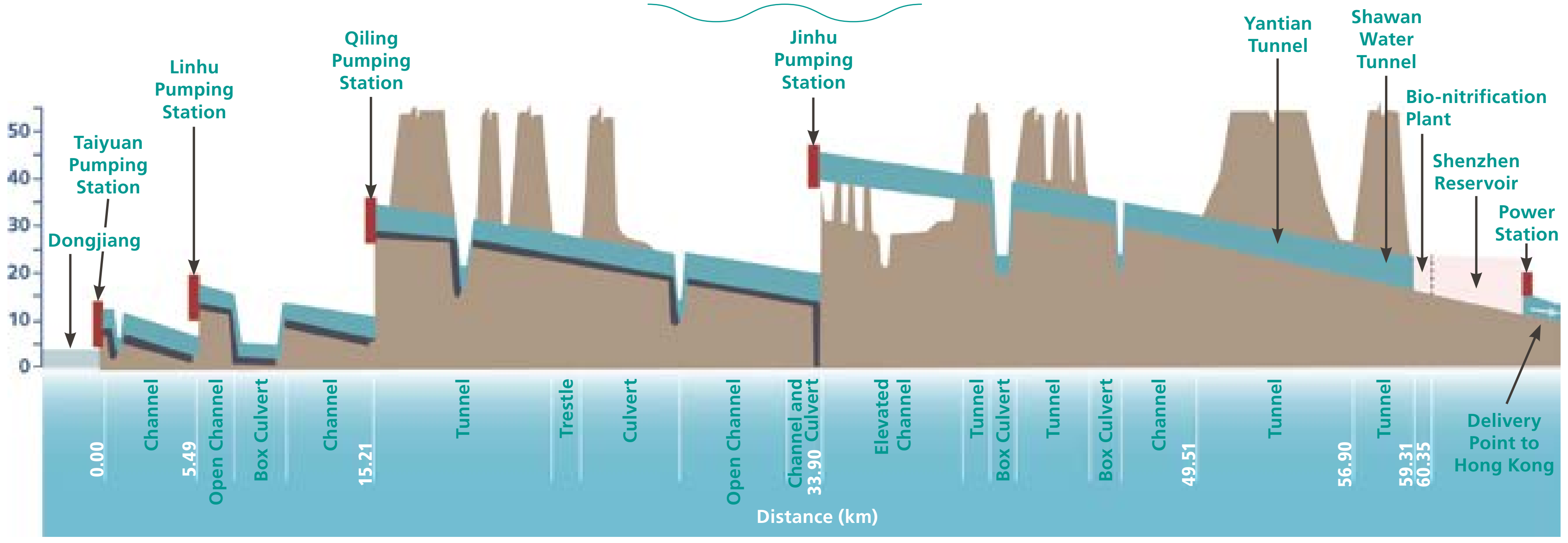
In addition to the epidemic, water shortage also had a serious impact on people's daily lives and on all sectors of the economy. As a result of the drought, many farms in the New Territories lost their harvest, fishing ponds dried up, swine and chicken fever were rampant, causing heavy losses to the agriculture and fishery industries. Factories were forced to shut down, reduce production or postpone deliveries. Retailers, restaurants as well as service industries had to shorten their business hours. Business turnover also declined significantly due to a decline in consumer sentiment. At that time, some members of the industrial and commercial sectors estimated that economic losses caused by water rationing was over $100 million[7].

3 Census and Statistics Department (1963). <Population by Sex and Age Group>. Retrieved from https://www.censtatd.gov.hk/en/web_table.html?id=1A
4 Hong Kong Observatory (1963). <Extract of Annual Data>. Retrieved from https://www.hko.gov.hk/en/cis/yearlyExtract.htm
5 Ho, Pui-yin (2001). *Water for a Barren Rock. 150 Years of Water Supply in Hong Kong*. Hong Kong: The Commercial Press (Hong Kong) Ltd. 182 pp.
6 Wu, Ba-ling (ed.) (1964). 'A Year of Health Care in Hong Kong', *Hong Kong Yearbook*. Hong Kong: Overseas Chinese Daily Limited. 111 pp. Retrieved from https://mmis.hkpl.gov.hk/coverpage/-/coverpage/view?p_r_p_-1078056564_c=QF757YsWv5%2BakvA8rFW5ErMITwS48ZVI
7 <Industrial Losses Exceed $100 Million, Manufacturers Urge Government to Deliver Water>(6 June 1963), *Ta Kung Pao*. Retrieved from https://mmis.hkpl.gov.hk//c/portal/cover?c=QF757Y-sWv59H%2FuxqfBwEJPIEzaE0VMxD

Dongjiang-Shenzhen Water Supply Scheme Schematic Layout Plan



Dongjiang-Shenzhen Water Supply Scheme - Closed Aqueduct (Longitudinal Section)



Evolving from a "Water Supply from The Shenzhen Reservoir" to the "Dongjiang-Shenzhen Water Supply Scheme"

In 1959, when the construction of the Shenzhen Reservoir was being planned on the mainland, the supply of fresh water to Hong Kong was already being considered. At the completion ceremony on 5 March 1960, TAO Zhu, the First Secretary of CPC Guangdong Provincial Committee expressed his concern about Hong Kong's water shortages and his willingness if necessary to supply water from the Shenzhen Reservoir to Hong Kong.[8] Local community leaders invited to attend the completion ceremony relayed Guangdong's willingness to contribute in alleviating the situation to the government.

After extensive negotiations, the government and Guangdong reached an agreement on 15 November 1960 to import about 22.7 mcm of fresh water annually from the Shenzhen Reservoir. The fresh water was delivered to the Tai Lam Chung Catchwater by laying water mains to connect to Hong Kong's water mains that located along the Chinese boundary.

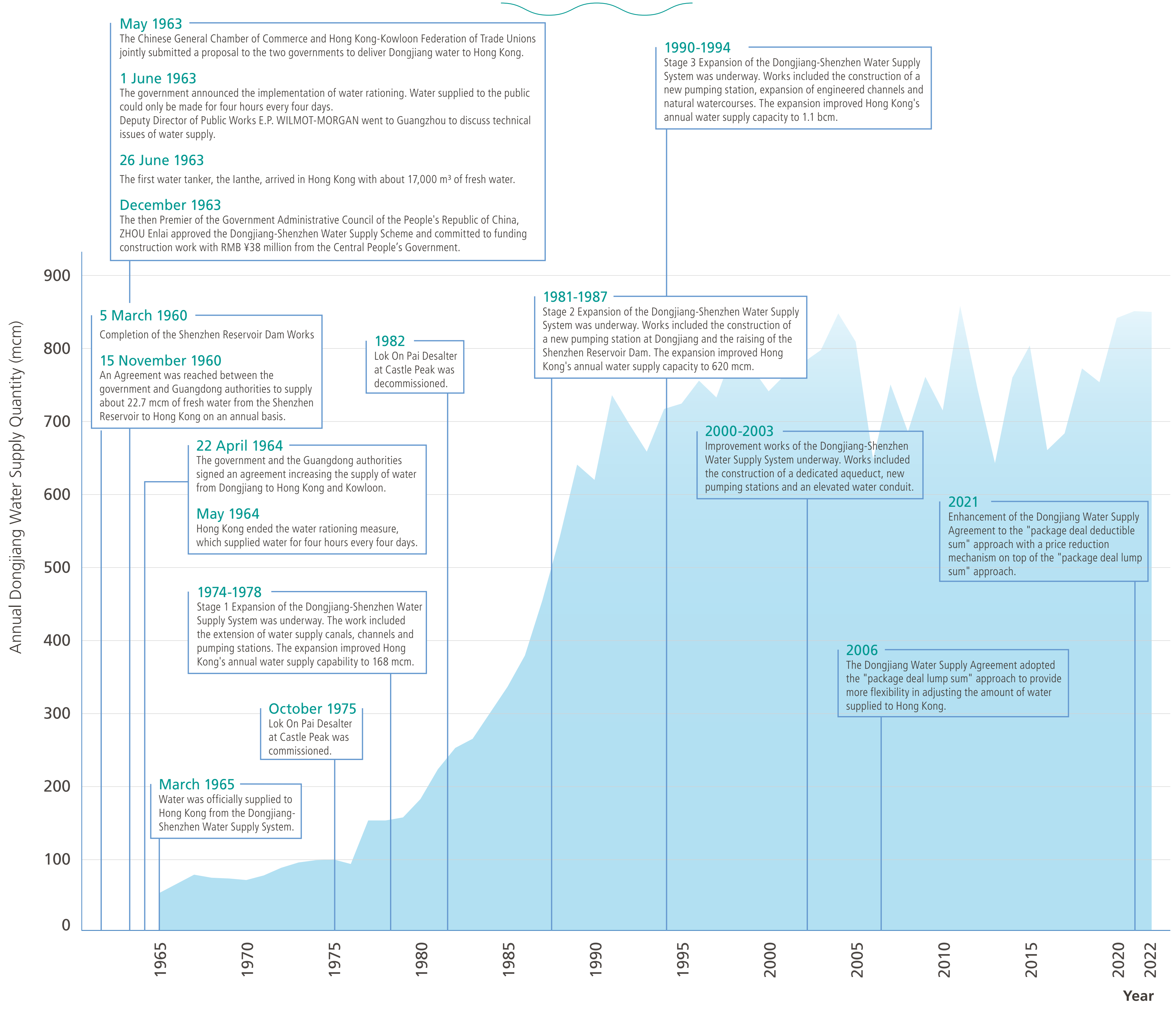
In 1963, at the height of the drought, the Chinese General Chamber of Commerce and the Hong Kong-Kowloon Federation of Trade Unions (predecessor of Hong Kong Federation of Trade Unions) jointly proposed to the governments of both sides that Dongjiang water be brought to Hong Kong. The Guangdong authorities responded positively to this proposal.

To alleviate the immediate water shortage, the mainland granted permission to Hong Kong to deploy tankers to extract fresh water from the Pearl River. Following the discussions between the two governments, a consensus was reached in the same year to build a Dongjiang-Shenzhen Water Supply Scheme which connected to the Shenzhen Reservoir. The Prime Minister, ZHOU Enlai approved the scheme and committed to fund the construction work with RMB ¥38 million from the Central People's Government.

The works commenced on 20 February 1964 and were completed in one year. In March 1965, the Dongjiang-Shenzhen Water Supply System began supplying water to Hong Kong, and has subsequently undergone three stages of expansion and comprehensive improvement works. In 1985, 319 mcm of Dongjiang water was imported to Hong Kong, exceeding half of local consumption for the first time.

8 'Tens of thousands of people celebrated the completion of the dam works of the Shenzhen Reservoir at a ceremony held yesterday' (6 March 1960). *Ta Kung Pao*. Page 1. Retrieved from https://mmis.hkpl.gov.hk//c/portal/cover?c=QF757YsWv59H%2FuxqfBwEJK%2BVvdiQPhSm

Dongjiang Water Supply and Related Important Events Timeline



Dongjiang Water Supply Route

Improving the Quality of Dongjiang Water

With rapid economic development and population growth along the route of the Dongjiang-Shenzhen Water Supply Scheme, including Dongguan and Shenzhen, a large amount of untreated sewage was being released into the Dongjiang-Shenzhen Water Supply System's watercourses. Beginning in the 1990s, the Guangdong authorities have carried out a number of water quality improvement projects to improve the quality of Dongjiang water, details below:

Dongjiang Water Intake

1 Relocation of the Intake Point Upstream (1998)

The original intake point for Dongjiang water was situated downstream where the Shima and Dongjiang rivers converge. In 1998, the intake point of Dongjiang water was relocated upstream to a location with better water quality. The Taiyuan Pumping Station was built to intake Dongjiang water for transfer to Hong Kong.

▲ Intake point at Taiyuan Pumping Station

2 A Dedicated Aqueduct (2000 - 2003)

The original Dongjiang-Shenzhen Water Supply System consisted of the Shima River and engineered water transfer channels. To reduce the chance of pollution entering Dongjiang water during its transfer to Hong Kong, the government of Guangdong Province started to construct a dedicated aqueduct in August 2000 to directly transfer Dongjiang water from the intake point at Taiyuan Pumping Station to the Shenzhen Reservoir. The entire aqueduct system spans about 59 km, including about 22 km of water transfer tunnel and about 37 km using a dedicated aqueduct. It formed an independent water transfer system, comprising pumping stations, elevated water conduits, tunnels, reservoirs and dedicated aqueducts. This infrastructure is entirely designed and constructed by the Guangdong authorities. A dedicated aqueduct was commissioned on 28 June 2003.

3 Shima River Sewage Diversion Works

Since the construction of the dedicated Dongjiang-Shenzhen aqueduct, the water supply system has been separated from the Shima River and the natural flow of the Shima River has been restored. However, the area around the river basin has increasingly become degraded due to the discharge of industrial effluent. To further safeguard the water quality of the Dongjiang river, Dongguan City implemented the Shima River Sewage Diversion Works in 2004. It included the construction of a rubber dam to intercept any effluent from the Shima River so it flows into an eastbound canal and avoids contaminating the Dongjiang water sources.

4 Dongjiang Water Resource Protection Works at the Shima River Mouth, Stage 1

In 2017, the first phase of the Dongjiang Water Resource Protection Works at the Shima River Mouth was launched. The main construction works included a new controlling gate to replace the rubber dam at the entrance of the Shima River.

Improvement Works at Shenzhen Reservoir

The Shenzhen Reservoir is the regulating reservoir in the entire Dongjiang-Shenzhen Water Supply System which adjusts the water supplies to both Shenzhen and Hong Kong. Since 1995, the Shenzhen environmental protection authorities have intercepted sewage from the reservoir catchment area by initiating the Shenzhen Reservoir Catchment Area Sewage Interception Works.

5 Bio-nitrification Plant

The bio-nitrification plant located at the intake of the Shenzhen Reservoir was commissioned in 1999. It receives Dongjiang water from a dedicated aqueduct, removes ammonia and conducts further treatment before being stored in the Shenzhen Reservoir. It uses biological contact oxidation technology to degrade the pollutants in the water and achieves a 75% removal rate of ammonia after treatment.

6 Shawan River Sewage Interception Works

Located at the north of Shenzhen Reservoir, the Shawan River was initially one of the catchment rivers of the Shenzhen Reservoir before it was polluted by municipal wastewater. In 2003, the Shenzhen authorities completed the Shawan River Sewage Interception Works by constructing the Shawan River Gate Dam at the tail of the Shenzhen Reservoir. Sewage flowing into the Shawan River passes through an underground tunnel to the Luofang Wastewater Treatment Plant in Liantang for centralised treatment. This avoids contamination of the raw water in the reservoir.

7 Comprehensive Remediation Project for the Water Environment of the Shawan River Basin

The Comprehensive Remediation Project for the Water Environment of the Shawan River Basin commenced in late 2016 and was completed in 2020. This work protects Hong Kong's water quality by reducing the risk of pollution from the discharge of floodwater from the Shawan River, thereby protecting the water quality of the Shenzhen Reservoir. As the project has progressed, the results of WSD's monitoring between 2019 to 2022 at the Muk Wu Pumping Station which receives Dongjiang water, indicate that the short-term surge in faecal coliform levels in Dongjiang water supplied to Hong Kong, due to the flooding of the Shawan River into the Shenzhen Reservoir has been significantly reduced.

After Dongjiang Water Reaches Hong Kong

The first station of Dongjiang water reaching Hong Kong is the Muk Wu Raw Water Pumping Station (MWRWPS) located on the south bank of the Shenzhen River at Lo Wu. It is an important facility constructed to support the supply of Dongjiang water. The primary function of the MWRWPS is to facilitate the daily distribution of Dongjiang raw water to the water treatment works at Ngau Tam Mei, Au Tau, Yau Kom Tau, Sheung Shui, Tai Po and Sha Tin.

The Muk Wu Raw Water Pumping Station has a 24-hour on-line monitoring system. It operates round the clock to monitor the quality of Dongjiang water supplied to Hong Kong. Samples of Dongjiang water are regularly taken at the MWRWPS for detailed analysis to ensure that the quality of Dongjiang water supplied to Hong Kong complies with the required standards. The WSD will adjust the water treatment processes at water treatment works as necessary to ensure the quality of the treated water fulfills the Hong Kong Drinking Water Standards.

▲ Muk Wu Raw Water Pumping Station located at the other side of the river from Lo Wu, Shenzhen.

▲ The WSD staff collect water samples at regular intervals for testing to monitor the quality of raw water for a range of water quality parameters, including physical, chemical, bacteriological, biological and radiological.

To cope with the increase in the supply of Dongjiang water, the WSD built an additional pumping station at the MWRWPS in 1984[9]. The annual supply quantity of Dongjiang water to Hong Kong at that time was about 290 mcm. By 2021, the annual supply quantity had increased to 810 mcm. Consequently, the MWRWPS was expanded from one to two pumping stations. For instance, Muk Wu Pumping Station No. 3 houses twelve large pumps that are two-storey high. They operate round the clock to pump raw water from the aqueduct to the water mains and to the water treatment works via the three major aqueduct supply systems (Western, Central and Eastern routes) to the water treatment works. The MWRWPS staff confirm daily with the Shenzhen authorities the amount of Dongjiang water supplied and monitor the pumping station 24 hours a day to ensure its smooth operation.

The Dongjiang water mains network in Hong Kong spans approximately 71 km, with the largest pipe measuring 2.4 metres in diameter. Regular maintenance of the Dongjiang water mains is crucial to ensure a stable water supply to Hong Kong. The water supply to Hong Kong from Guangdong Province is suspended in December every year. During this period, the raw water stored at various impounding reservoirs such as Plover Cove Reservoir and High Island Reservoir would be used, while the Tai Po Tau Pumping Station is responsible for pumping and distributing Dongjiang water.

The WSD carries out major repairs and maintenance on the Hong Kong section of the Dongjiang water supply network during the suspension period. This work includes inspecting and maintaining the structures that support the pipelines, removing sediment from the water mains and drainage channels, and repairing the internal lining of the water mains. In order to guarantee the resumption of the Dongjiang water supply in January of the following year, all inspection and maintenance

▲ The raw water is transferred from the MWRWPS to downstream water treatment works and impounding reservoirs via pipelines. These pipelines, over two metres in diameter, are of a rarely seen above-ground type.

▲ The pump is two-storey high, with the motor on the top driving the impeller of the rotary pump at the bottom to generate a centrifugal force, which drives the rotation of Dongjiang raw water for transportation.

▲ The motor pushes the balance shaft to drive the pump and transfers the raw water to impounding reservoirs or water treatment works.

▲ The MWRWPS is equipped with a buffer tank (also known as a surge vessel) connected to the Dongjiang raw water mains, with a 50/50 split between raw water and compressed air. This device is usually located in water mains that have many bends, so as to alleviate the problem of rapid pressure increases caused by water hammering. In the event of a mains burst causing a sudden drop in pressure, the raw water in the surge vessel is replenished to balance the water pressure in the pipe and protect the pump which is constantly running.

▲ The MWRWPS undergoes annual maintenance in December, during which it will be inspected in detail by engineering staff.

9 Muk Wu No. 1 Raw Water Pumping Station was in operation that year. Muk Wu No. 2 Raw Water Pumping Station and Muk Wu No. 3 Raw Water Pumping Station were opened in 1984 and 1995 respectively. Muk Wu No. 1 Raw Water Pumping Station is now decommissioned.

▲ The butterfly valve inside the Dongjiang water main controls the flow of water by a remote switch.

▲ Aerators are installed in the Dongjiang water supply mains. An air-blower is activated to inject a large amount of air to keep water flowing at the bottom of the incoming channel, thus reduce stagnant water areas.

▲ Muk Wu Raw Water Pumping Station during maintenance. The intake culvert is filled with water when in operation.

work had to be completed within 20 days. This significantly increased the difficulty of the task.

“Package Deal Lump Sum” and the “Package Deal Deductible Sum” Approaches

In 2020, the HKSAR Government signed a new agreement with the Department of Water Resources of Guangdong Province for the supply of Dongjiang water from 2021 to 2023. The new agreement enhances the previous "package deal lump sum" approach to be a "package deal deductible sum" approach. Under the former, a fixed annual payment was made to secure a guaranteed annual supply ceiling of 820 mcm per year. Whereas, under the latter arrangement, a price reduction mechanism will be added to the “package deal lump sum” approach. The reduction amount will be calculated by multiplying a unit rate to the difference between the annual supply ceiling and the actual amount of water supplied. Both sides have agreed that this approach will be adopted until at least up to 2029.

Future Prospects: The Pearl River Delta Water Resources Allocation Project

Dongjiang water is a vital water source that has long supported the development of the entire Pearl River Delta region. However, with the region’s economic and social development, the competition for water resources has become increasingly fierce. The overall utilisation rate of Dongjiang has reached 38.3%, which is close to 40%, the international standard of the limit for reasonable exploitation of a river’s water. In the winter of 2021, the Dongjiang River basin was affected by drought and salt tides, which rendered serious impact to water supply.

A salt tide occurs when seawater intrudes into a river, making it impossible to use the fresh water in the river. This is particularly serious during astronomical tides when the seawater level rises significantly. If the weather remained dry and the river flow was inadequate, the seawater will flow up the river from the estuary, making the fresh water salty. This has a severe effect on water supply to water treatment works, water safety, and agricultural and industrial production.

To support the development of the Greater Bay Area, it is imperative to explore new water sources. According to the water conservancy department of Guangdong Province, the average annual net flow of the Xijiang River's main stream is 216.3 bcm, nine times that of Dongjiang, but its overall utilisation rate is only 1.3%. The government of Guangdong Province therefore commenced the Pearl River Delta Water Resources Allocation Project (commonly known as the “West to East Water Diversion Project'') in 2019. The project involves the construction of a 113 km large-scale pipeline to divert water from the Foshan section of the Xijiang River to Guangzhou, Shenzhen and Dongguan. The development will alleviate the situation of only having a single water supply in the eastern part of the Greater Bay Area. It also solves the water supply problem of Guangzhou, Shenzhen and Dongguan, and provides an emergency backup water source for Hong Kong.

Use of Flushing Water

Each person on average drinks about two litres of fresh water per day. The legal specifications in Hong Kong for toilet flushing is 7.5 to 15 litres of water per flush. So, with an average of six or seven toilet visits per day, flushing requires up to 105 litres of water per person. Currently, about 85% of Hong Kong's population was covered by seawater supply network. In 2021/22, the average daily amount of seawater used for flushing was 876,000 cubic metres (m³), equivalent to 30% of the average daily consumption of potable water.

If the WSD had not taken the bold decision to introduce seawater flushing 50 years ago, Hong Kong may have faced even greater pressure on its water supply. At the time, this decision saw Hong Kong as one of the few places in the world to pioneer seawater flushing technology.

Sanitation issues can be resulted if there are insufficient water resources. In the mid-19th century, as the city of Victoria slowly grew, the issue of toilets and sanitation illustrated the cultural and lifestyle differences between officials and the general public, and between China and the west.

The Introduction of Flush Toilets to Hong Kong

In the 19th century, a number of doctors reported on Hong Kong's sanitation conditions. Criticism was made over such issues as: sewage discharge and its treatment, and the use of earth privies. Sir John Pope HENNESSY, Hong Kong's Governor held a different viewpoint from these doctors on whether the water closet or the earth privy was more suitable for the city's Chinese community. He quoted Dr. John DUDGEON, a consultant physician in Peking, who believed that the Chinese made good use of human waste as fertiliser for farming by using the earth privy. Although smelly, it did not cause disease, whereas the European water closet was a hotbed of disease[1].

The practice of collecting manure (night soil) for farming had gradually changed as Hong Kong had increasingly moved towards commercial trade. In those days, outbreaks of disease and epidemics amongst British soldiers and European merchants pressured the government to improve the environment, amenities and update the building regulations.

In 1882, Sir Osbert CHADWICK, a consulting engineer appointed by the Colonial Secretary, published *Mr. Chadwick's reports on the sanitary condition of Hong Kong* (commonly known as "Mr. Chadwick's Report"). It investigated the connection between infrastructure, building and sanitation in Hong Kong. In the early years, water closets were only found in European houses, whereas the Chinese community relied on wooden buckets for disposing human waste. These buckets were manually transported and emptied. Most public toilets in the community were privately owned and intended to collect human waste for sale as fertiliser[2]. Given the profitability of this trade, there was little incentive for the government to spend public funds on its management.

Toilet Reform in the 20th Century

CHADWICK also reviewed disease data, waste collection frequency and methods amongst different social classes and between districts, the bacteria incubation period in human waste, and differences in bacteria retention between materials used in private and public toilets. The report highlighted in detail the underlying issues and provided justification for the development of water closets and improvement of the sewage system, particularly in densely populated places such as military barracks and hospitals.

The year after Mr Chadwick's Report was published, the government set-up the Sanitary Board (the predecessor of the Urban Council[3]) to supervise the city's sanitation. However, constrained by older building specifications, the installation of water closets in restaurants and teahouses was not regulated until the early 1940s, and at the beginning was resisted by the restaurant industry. There was also a chronic shortage of fresh water supply and most flushing toilets in the early days were connected to untreated fresh water sources such as wells, streams and rainwater.

In 1954, the government amended the law to prohibit the use of tap water for toilet flushing with offenders liable to a fine of HK$500. At the time, there were shortages of tap water, well water and stream water. The Urban Council was concerned that the lack of water for flushing made the water closet system inferior to the previous arrangements, and that environmental pollution would increase.

1 Governor's Report on Blue Book (1880). *Administrative Reports for the Year 1880.* (12). https://digitalrepository.lib.hku.hk/catalog/bz60jz89v#?c=&m=&s=&cv=11&xy-wh=106%2C1714%2C1759%2C748

2 O. Chadwick (1882). *Mr. Chadwick's reports on the sanitary condition of Hong Kong; with appendices and plans.* London: Printed by George E.B. Eyre and William Spottiswoode, for Her Majesty's Stationery Office. 18-20. https://wellcomecollection.org/works/mpnmmdbz

3 The Urban Council was Hong Kong's municipal authority from 1883 to 1999, and was initially responsible for food and health, and after 1985, also for culture and recreation on Hong Kong Island and in Kowloon.

Seawater as a Water Resource

Following the Shek Kip Mei fire, the construction of large-scale public housing was initiated by the government in the mid-1950s. This provided an opportunity to also introduce the water closet and district sewerage systems. In 1957, seawater flushing systems were piloted in the Shek Kip Mei Resettlement Estate and Lei Cheng Uk Resettlement Estate. The earliest resettlement blocks had communal trench latrines, which were later replaced with individual flush toilets in each flat.

In 1959, the government enacted Cap. 123I Buildings (Standards of Sanitary Fitments, Plumbing, Drainage Works and Latrines) Regulations. Section 19 of the Regulations requires new private buildings to be equipped with flushing sewage facilities, including flushing systems, sewerage, flush toilets and other fittings. Since then, water closets have been essential for the public, and the seawater flushing network has expanded over time. In 1965, further legislation was introduced for new or redeveloped buildings to be equipped with pipes suitable for seawater flushing systems. Consequently, separated supply system for fresh water and flushing water was established in Hong Kong.

The Seawater Flushing Supply System in Hong Kong

Hong Kong is surrounded by sea on three sides, making it suitable to develop a comprehensive seawater flushing supply system. This has led to the establishment of a seawater flushing supply system independent of the city's fresh water supply system. As seawater is at a low height level, the requirements for water quality and treatment methods for flushing water are different, making the distribution methods for seawater different from that of fresh water. For details, please refer to the article "The Principles Behind Hong Kong's Unique Drinking Water Distribution Systems" in Chapter 3.

At present, there are 35 pumping stations and 55 service reservoirs in the seawater flushing system in Hong Kong, with a total storage capacity of nearly 260,000 m³, and about 1,600 kilometres[4] of seawater pipes. The pipes employed are primarily composed of cement-lined ductile iron pipes, cement or epoxy-lined mild steel pipes, and plastic (polyethylene) pipes.

Hong Kong is now the only city in the world with such an extensive seawater supply network used for flushing. Its seawater supply network covers about 85% of the population at the end of 2022. In 2021/22, the consumption of seawater for flushing is 320 million cubic metres, which is 31% of fresh water consumption. The average cost of flushing seawater treated by the WSD is HK$4 per cubic metre, compared to HK$10 per cubic metre for fresh water, about 2.5 times costlier. The seawater flushing system, which has been expanding over the past half century, has achieved remarkable results in conserving and exploiting water resources. The separate diversion of flushing seawater and fresh water has also proved to be successful. In 2001, the WSD's seawater flushing projects were awarded the Chris Binnie Award by the Chartered Institution of Water and Environmental Management, recognising its achievements in sustainable water management with Hong Kong's seawater flushing serving as a model for the rest of the world.

Looking Ahead

In early 2021, the Tung Chung East Reclamation area had commenced to extend the coverage of seawater flushing with a salt water pumping station, a salt water service reservoir and associated pipelines. For the scattered populations in the central and northern inland areas of Hong Kong, far from the coast, fresh water flushing remains a more technically feasible and cost-effective option. The WSD is also exploring the use of "recycled water" (i.e. reclaimed water, treated grey water and harvested rainwater) from a centralised water supply system for flushing and other non-potable uses. For more details, please refer to the article "New Water Resources" in this chapter.


食物店衛生設備
衛生當局嚴令改善
～～規定食品製造地點 限令開設工人廁所～～
五行商會中人談酒樓建水廁問題

貨艇載貨開赴惠陽
在九針島海面被劫

▲ From the 1940s onwards, the government regulated restaurants to improve sanitary conditions, including the installation of water closets.
Source: *Hong Kong Business Daily*, 21 July 1941

4 Calculation to 31 March 2023

Planning a Sustainable Water Strategy for the Future

The introduction of Dongjiang water reduced Hong Kong's reliance on local rainwater as its primary water source. Since then, Hong Kong has had a reliable water supply. However, the increasing impact of climate change and the occurrence of more frequent droughts and floods increases the possibility of water scarcity around the world, including in Hong Kong. Since 2008, the HKSAR Government has implemented the Total Water Management Strategy (the Strategy) and has made long-term plans to develop a diversified and stable water supply model for the city.

The Assistant Director for Development, Ir Wilson MA Hon-wing, says the WSD had been improving its waterworks and water treatment technologies over the years. But in the long run, the challenges faced by Hong Kong cannot be ignored. "On the one hand, water demand will increase as the city's population and economy grows. However, the amount of local water gathered may decrease due to climate change. As for the Dongjiang water - which we have been relying on – the needs of cities in the Dongjiang basin are also high," adds Ir MA.

As the main water supplier of Hong Kong, the WSD needs to have a broad and forward-looking vision in its overall water planning. Total Water Management is a modern concept of holistic water resources management. In simple terms, it means tapping into all sources of water and reducing consumption. "At present, we are adopting a two-pronged strategy to contain the growth of fresh water demand, while building resilience in the fresh water supply by diversifying water resources. By promoting water conservation, managing water loss and expanding the use of lower grade water for non-potable uses, we hope to reduce average fresh water use per capita by 10% by 2030," says Ir MA.

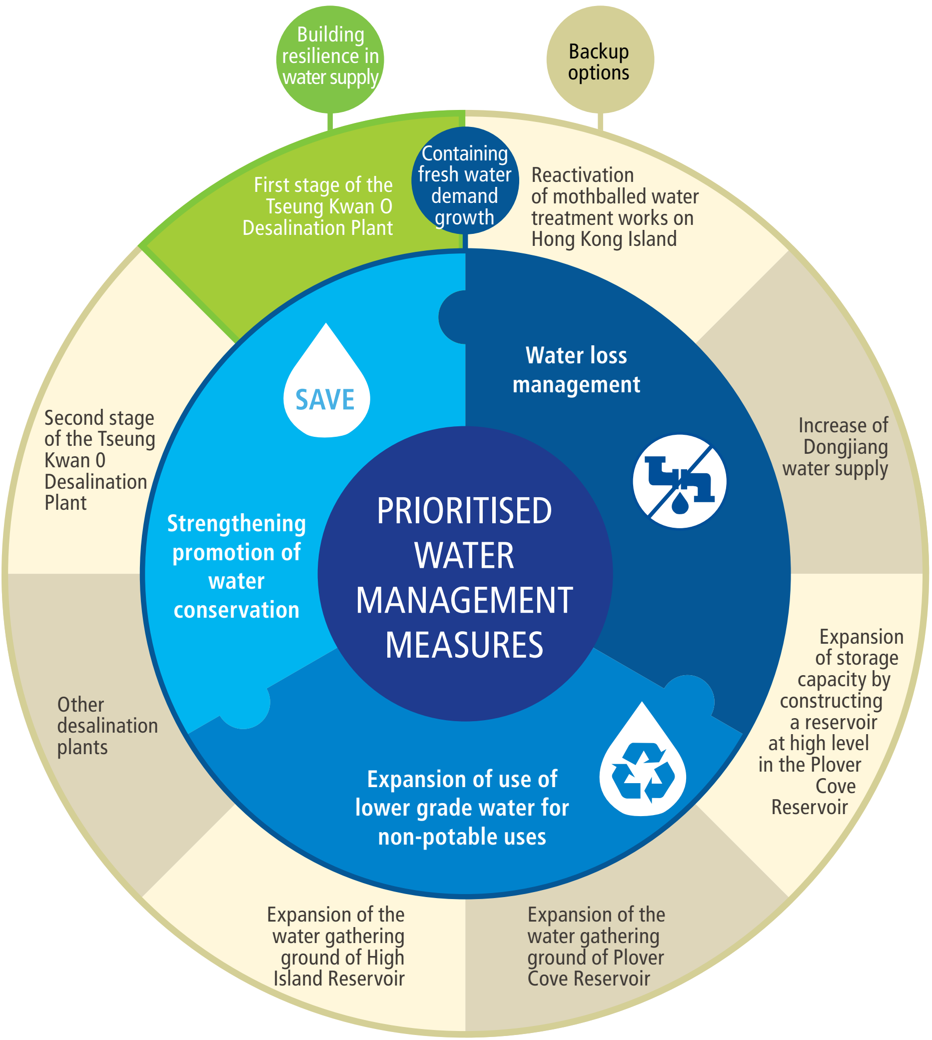
▶ Assistant Director of the WSD, Ir Wilson MA Hon-wing, said the WSD's strategy to cope with climate change is by having a holistic management of water resources.

Interpreting the Strategy 2019

The WSD has adopted the "Plan, Do, Check, Act" management model when planning and implementing its water supply policies to achieve its water saving targets, Ir MA explains, "We have to plan in advance. That is why we formulated the Strategy back in 2008. Then we implemented and enforced the measures step by step, which is the 'action' stage."

The WSD reviewed and updated the Strategy 10 years after its implementation, evaluating the effectiveness of various measures and establishing key performance indicators. "We assessed and prioritised the water management options in terms of their resiliency, economic factors and sustainability, and adjusted the measures to meet the challenges," says Ir MA. The review was completed in 2019. The updated Strategy (Strategy 2019) will adopt a two-pronged approach:

Prioritised Water Management Measures



Diversifying Water Resources

- After evaluating various water management measures, desalination was identified as the best option to enhance the resilience of the fresh water supply (see the article "Desalination as a Strategic Water Resource" in Chapter 2).

Containing the Demand for Fresh Water

- Increase the use of lower grade water for non-potable uses and reduce fresh water consumption (see the article "New Water Resources" in this Chapter)
- Water loss management (see the article "Smart Technology Management of Water Mains and Water Leakage" in Chapter 3)
- Strengthening the promotion of water saving (see the article "Initiating Water-Saving Habits at a Young Age" in Chapter 6)

Long-term Water Supply Strategy for New Major Developments

The WSD is currently working with government departments on water supply planning for a number of new major development projects, including the Northern Metropolis and Kau Yi Chau Artificial Islands. As these projects involve new land or re-planning of existing land, there will be an increase in long-term water demand. This presents bigger issues for Hong Kong's water resources as well as dealing with climate change.

In addressing these challenges, the WSD began a mid-term review of The Strategy in 2023, taking into account such factors as climate change, the long-term water supply needs of major development projects and the latest estimation of Hong Kong's long-term population. The review will help to formulate an appropriate water management strategy to ensure an ample water supply to fulfill Hong Kong's water demand. Apart from Dongjiang water, the WSD will continue to explore new water resources to meet increased demand, such as considering a wider adoption of desalination technology as one of the major sources of fresh water resources in future. For new development and inland areas, the WSD is encouraging the use of recycled water for toilet flushing and other non-potable uses where feasible, so as to reduce the demand for fresh water.

Development of the Total Water Management Strategy

2003	In the Policy Address, the HKSAR Government pledged to implement a Total Water Management programme to save water and protect water resources through education and promotional activities. A detailed pilot scheme was launched to study wastewater recycling and desalination technologies.
2008	The WSD published the Strategy. It emphasised containing the growth of water demand through promoting water conservation and exploiting new water resources.
2017 and 2018	As pledged in its policy agenda, the HKSAR Government aimed to reduce the average fresh water per capita consumption by 10% by 2030 at the earliest (using 2016 as the base year).
2019	WSD reviewed and updated the Strategy by formulating, evaluating and recommending strategic water management options. The Strategy 2019 was promulgated to ensure the sustainability of Hong Kong's water supply.
2023	WSD commences an interim review of the Strategy 2019.

Total Water Management Strategy

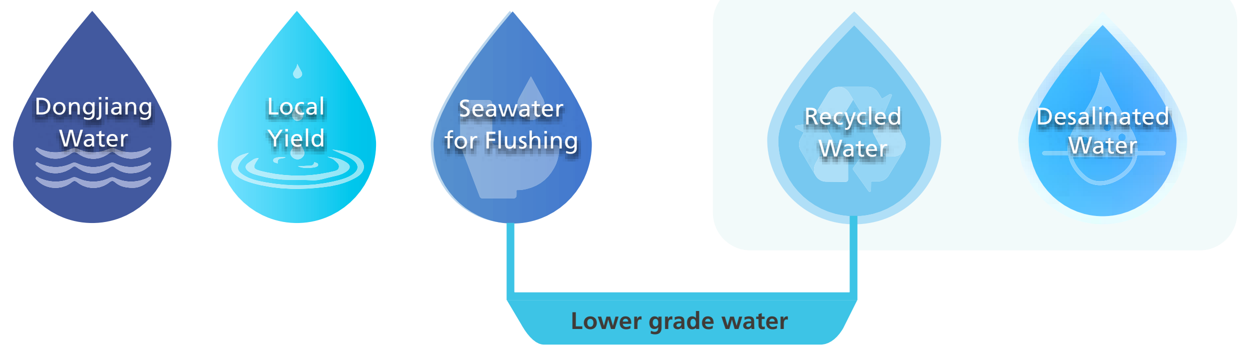
Total Water Management Strategy (2019)

Renewing the Water Supply Portfolio and Expanding Lower-Grade Water Use

Based on the updated Strategy, Hong Kong's forthcoming water supply portfolio will comprise new water resources that remain unaffected by climate change, including desalinated and recycled water, alongside the existing supply of local yield, Dongjiang water and seawater for flushing. The new water supply portfolio will ensure the stability of Hong Kong's water supply and support the sustainable development of the city.

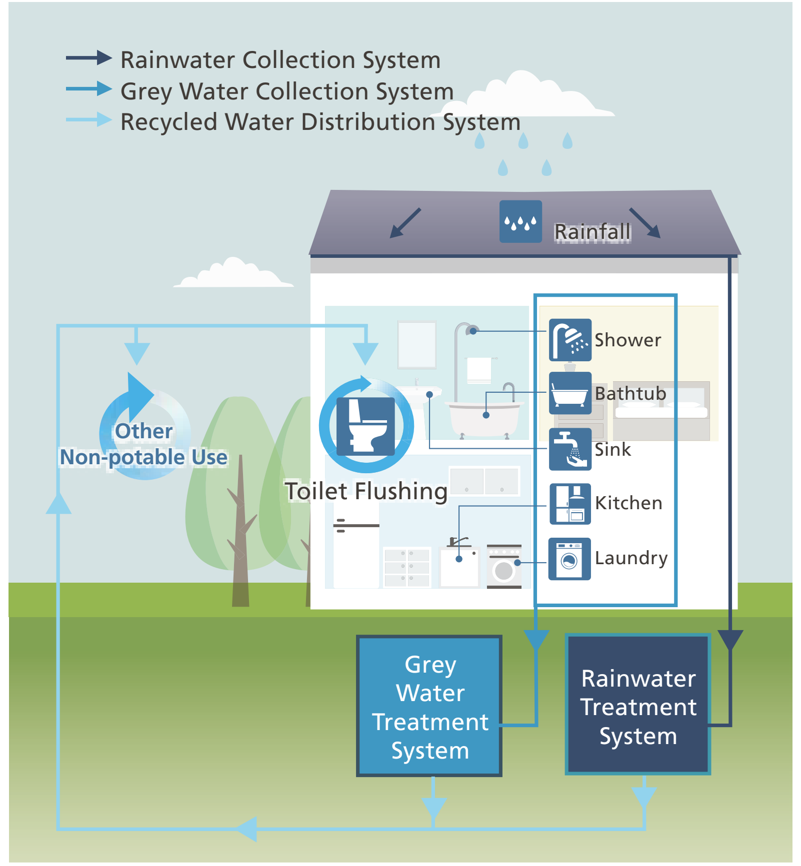
The long-term goal of Strategy 2019 is to increase the network coverage of using lower grade water for flushing from 85% to 90%. Lower grade water includes seawater and recycled water. The former has been widely used for toilet flushing since the late 1950s (please refer to the article "Use of Flushing Water" in this chapter). However, in some areas with a low population density, a longer distance from the coast and an unfavourable topography, transportation of seawater for flushing is more energy-consuming and less cost-effective. As a temporary measure, fresh water is therefore used for flushing.

Recycled water includes reclaimed water, treated grey water and harvested rainwater. As recycled water does not meet the Hong Kong Drinking Water Standards, it is intended for non-potable uses only. The use of recycled water not only reduces the consumption of fresh water, but also minimises the impact on the environment by reducing the treated effluent discharged into the receiving water.

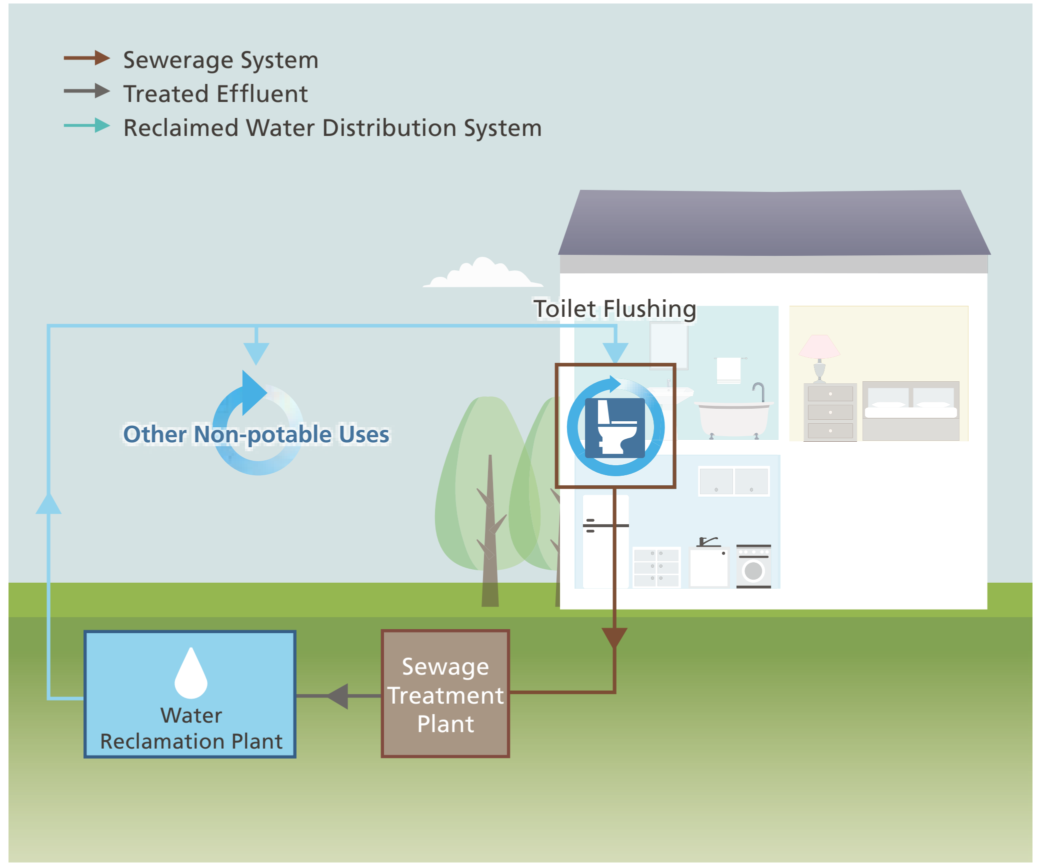


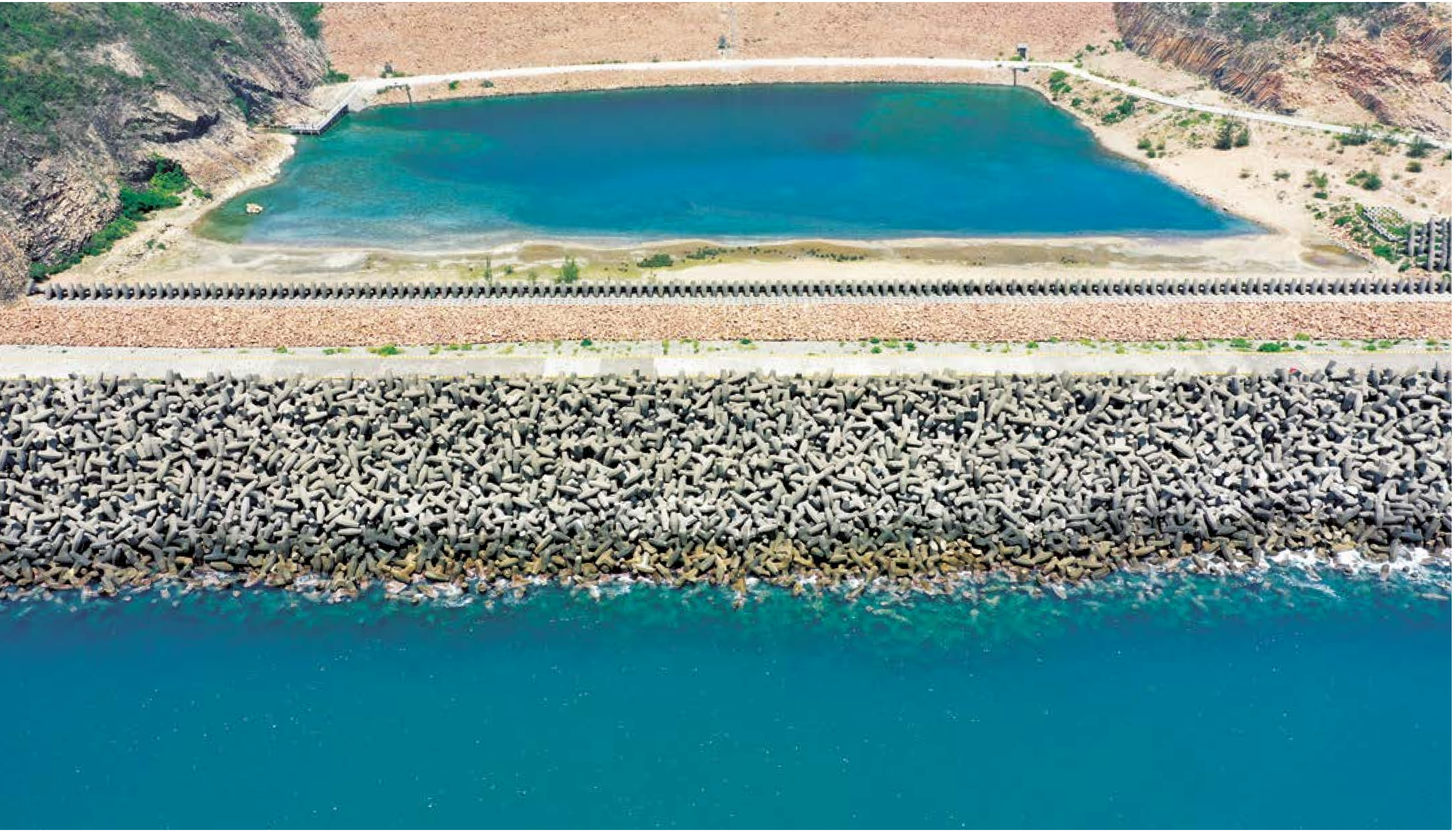
▲ Hong Kong's New Water Supply Portfolio

Gray Water Recycling and Rainwater Harvesting System



Water Reclamation Process





New Water Resources

The Strategy 2019 proposes to expand the use of lower grade water for non-potable uses. In addition to seawater, which has been primarily used for flushing for decades, recycled water will also become a new source of non-potable water in the future. The WSD has promoted the adoption of grey water reuse and rainwater harvesting facilities under suitable new government works projects in recent years, and formulated the technical specifications on grey water reuse and rainwater harvesting in 2015. By the end of 2022, grey water reuse or rainwater harvesting systems had been installed in about 130 new government building projects. The WSD makes use of the assessment tools in the Building Environmental Assessment Method Plus for New Buildings Version 2.0 issued by the Hong Kong Green Building Council to encourage private buildings to adopt grey water reuse and rainwater harvesting systems. The awarding of bonus credits encourages private buildings to adopt these systems.

Grey Water Treatment Plant for the Development of Anderson Road Quarry Site

Generally, sewage and grey water generated in buildings is conveyed to sewage treatment plants through an integrated pipeline system. In order to adopt a grey water recycling system, a dedicated collection pipe network should be installed in buildings for collecting raw grey water from baths, showers, wash basins and kitchen sinks etc., and conveyed to a grey water treatment plant. Consequently, this recycling system is more suitable for newly designed buildings in new development areas.

The first district-based grey water recycling system in Hong Kong is located in the Anderson Road Quarry (ARQ) site in Tai Sheung Tok, Sai Kung. This development site will provide about 12 hectares of residential land for housing development and will accommodate about 30,000 people. The ARQ site's elevation at about 200 metres above Hong Kong Principal Datum and its distant location of over 3,500 metres from the seashore hindered the conventional supply of seawater for flushing. The provision of seawater for flushing in such a large-scale development site would consume a significant amount of energy and carbon emissions to pump seawater and the laying of uphill pipelines. Grey water recycling is a practical solution to overcome these site-specific constraints and adheres with the concept of a green and smart city development.

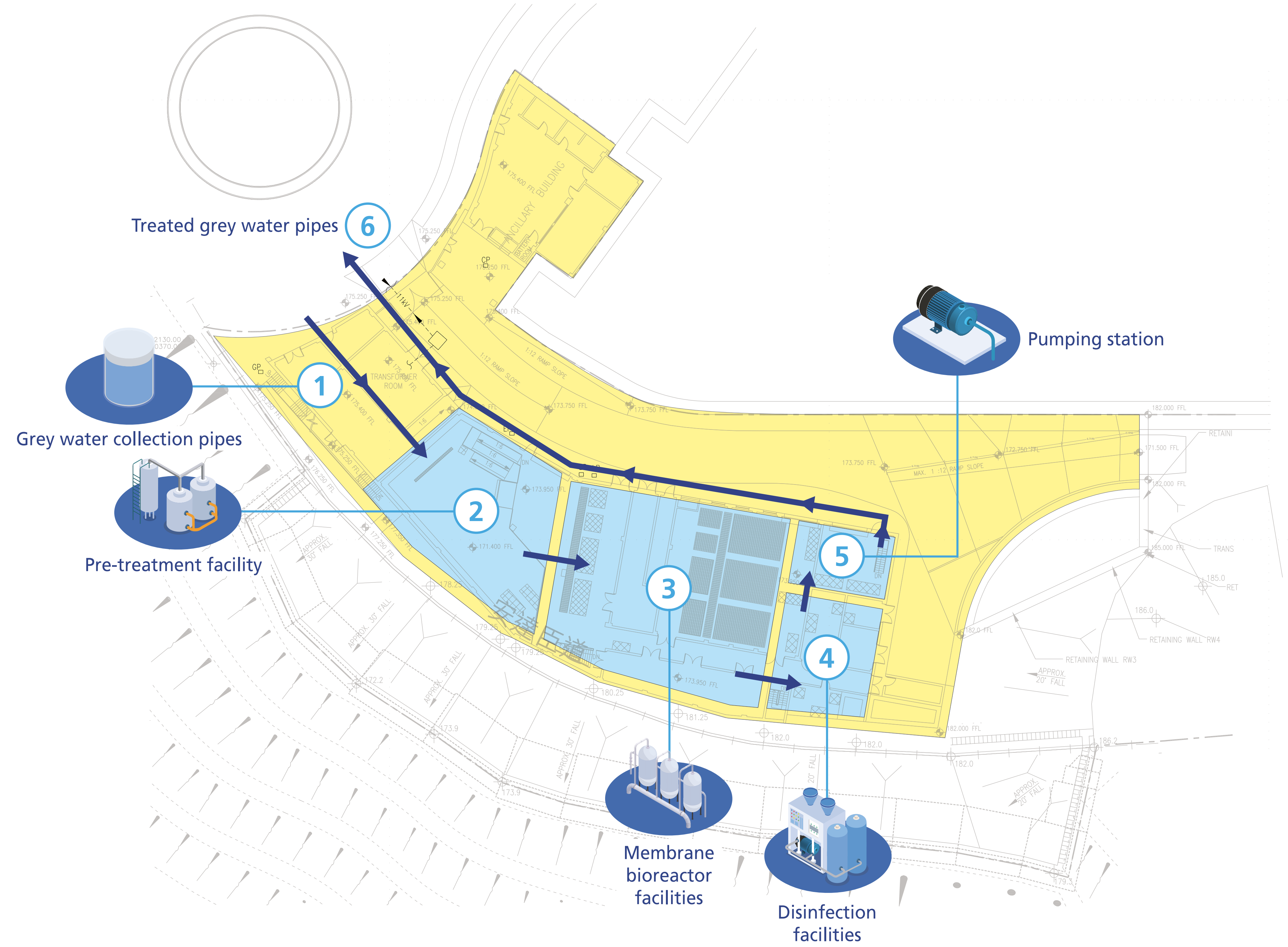
Like all resources, it is best to perform separation before recycling. Grey water and discharge from toilet bowls generated within the ARQ development area has to be treated separately. Thus, two separate systems for collecting grey water and soil are installed in individual buildings. The grey water will be conveyed to the nearby grey water treatment plant. The treated grey water will then be supplied for toilet flushing within the development area. As the capacity of the treatment plant has been designed to be 3,300 cubic metres (m³) per day, the flushing water is self-sufficient. Surplus treated grey water will be used for other non-potable purposes, such as landscape irrigation and street cleansing.

Construction of the grey water treatment plant at the ARQ site commenced in late 2020. The grey water recycling system is anticipated for commissioning in phases starting from 2024 to tie in with the continuing development of the ARQ and its population increase. As most of the treatment plant is built underground, its design merges with the surrounding environment and the community, and also serves as a natural noise barrier. It also features green architecture and landscaping, including a green façade, a rooftop green park for public enjoyment and solar panels.

The project is sustainable and cost effective, and fits in with the high density of Hong Kong's new development areas. The project was awarded the Institution of Civil Engineers (ICE) Award 2021 - Chris Binnie Award for Sustainable Water Management in recognition of WSD's excellent work in further improving the sustainable uses of water resources.

▲ Photomontage of the grey water treatment plant for the development of the Anderson Road Quarry Site

Schematic diagram of the operation of the grey water treatment plant at the Anderson Road Quarry site



Shek Wu Hui Water Reclamation Plant

The HKSAR Government started a pilot reclaimed water scheme as early as 2006. It set up an inter-departmental working group led by the WSD with the participation of the Drainage Services Department (DSD) and the Environmental Protection Department (EPD). Ngong Ping Sewage Treatment Works was its initial pilot site to treat and recycle the district's collected sewage for flushing. The HKSAR Government conducted a public consultation exercise in 2018 showing that public opinion on the supply of recycled water in Hong Kong was generally positive and supporting the use of recycled water for non-potable purposes. Consequently, the WSD is actively supplying reclaimed water in areas that currently rely on fresh water for flushing and in new development areas.

A significant increase in sewage flow is anticipated due to the population growth in the Kwu Tung North/Fanling North New Development Area. The DSD has commenced the reconstruction of the existing Shek Wu Hui Sewage Treatment Works in 2019 to increase the sewage treatment capacity from 93,000 m^3 to 190,000 m^3 per day and upgrade the sewage treatment level from a secondary to tertiary standard for conversion into a Shek Wu Hui Effluent Polishing Plant.

The WSD and the DSD have taken the opportunity of the reconstruction project and collaborated in promoting a large-scale reclaimed water project by constructing the Shek Wu Hui Water Reclamation Plant adjacent to the Shek Wu Hui Effluent Polishing Plant to produce reclaimed water at a lower cost. The treated sewage effluent, which has undergone tertiary treatment at the Shek Wu Hui Effluent Polishing Plant, will be sent to the Shek Wu Hui Water Reclamation Plant for processing. Sodium hypochlorite will be added to the treated sewage effluent to remove pathogenic bacteria. The treated water, i.e. reclaimed water, will still contain an appropriate amount of residual chlorine to ensure that it is free from bacterial contamination during its delivery to customers. As the reclaimed water is colourless and odourless, food colouring will be added as an additional precautionary measure before delivery to the service reservoir. Consumers will be able to distinguish reclaimed water from potable water with the naked eye.

▲ Photomontage of WSD's Shek Wu Hui Water Reclamation Plant

Shek Wu Hui Water Reclamation Plant, with a daily production capacity of 73,000 m^3 of reclaimed water, began construction in July 2021, and is expected to be completed in phases starting from the first quarter of 2024. Supply of reclaimed water will be made available in phases to the North East New Territories (including Sheung Shui, Fanling and Kwu Tung North/Fanling North New Development Areas) for non-potable uses such as toilet flushing. The whole project is expected to be completed by the end of 2026. This is the first time reclaimed water will be used for domestic flushing purposes on a large scale in Hong Kong.

Increasing Development Capacity for Future Water Supply

In line with the new development approach of "Bringing Forward Infrastructure Construction" and "Increasing Development Capacity", the WSD is now planning the water supply infrastructure for major new developments. As mentioned above, the WSD is developing new water resources to meet Hong Kong's long-term sustainable development needs. A new desalination plant (see the article "Desalination as a Strategic Water Resource" in Chapter 2) is being planned. It is also considering the deployment of supply infrastructure for reclaimed water and grey water treatment in new development areas, while planning and constructing a number of major water infrastructure projects, including service reservoirs, pumping stations and trunk mains laying. These proposed waterworks facilities will increase the city's water supply capacity and pave the way for future development.

Interactive Game

Please login by scanning with smartphone

*Participants must be Facebook or Instagram users

Facebook

Instagram

Q. Food Colouring is added to the treated effluent at the water reclamation plant to identify it for reuse. Guess which colour is added?

(After login to the interactive game platform, please use the phone scanner to select one of the following colours you think is correct. Water Save Dave will tell you the correct answer.)

Yellow

Green

Blue

Reclaimed water can be used for the above three non-potable purposes.

What is Hydrology?

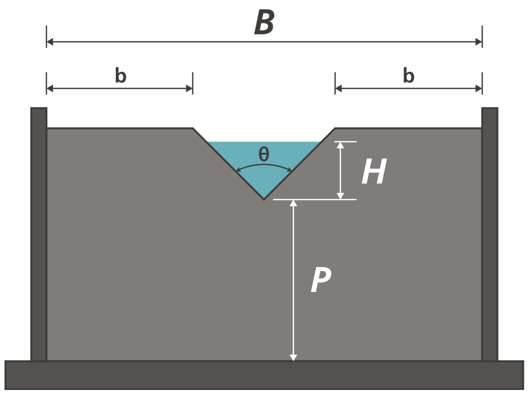
We have all probably heard of "astronomy", but there is also a discipline related to water called "hydrology." The Hydrology Unit of the WSD is responsible for carrying out estimates of stream and catchwater flows, reservoir overflows and the collection of local hydrological data to facilitate the analysis of the city's water resources.

The WSD's Hydrology Unit was initially established to identify representative natural streams and catchwaters within the water gathering grounds for the installation of hydrological monitoring stations. The hydrological monitoring stations are generally located in remote areas. Despite having a well-established road network, the Hydrology team encounters challenges in travelling to remote areas for inspection and maintenance duties. One can envision that the work was even more challenging in Hong Kong's early days.

There are currently about 20 hydrological monitoring stations located in the water gathering grounds of Hong Kong Island, Kowloon, the New Territories and the outlying islands. The Hydrology Unit has installed instruments at major impounding reservoirs to measure the water level and calculate each reservoir's overflow. The water gathering grounds in Hong Kong are extensive collection of hydrological data that can facilitate analysis of the local water resource situation and support formulation of relevant water resource policies.

Hydrological monitoring stations on major watercourses are typically installed with a water retaining pond and a small recorder cabin to store equipment. The water retaining ponds are usually constructed of concrete with a v-notch weir that serves as the outlet for effective measurement to the water levels of the pond and estimation of the stream flow. As the stream flows through the pond, an intake pipe within it diverts some of the water to a well in the adjacent recorder cabin; the height of the float in the well is used to measure the water levels of the pond and hence the stream flow is estimated. Data loggers and modem are placed within the recorder cabin and connected to the float so as to facilitate recording and transmitting water level data. Hydrological monitoring stations at the reservoirs have a similar configuration as those stations located at watercourses, except that they do not have a water retaining pond before the weir.

The figure on the right shows the v-notch weir of the pond of a hydrological monitoring station. When the water level of the pond is higher than the water level at the v-notch weir, the water level will be measured using the nearby water level indicator. The Hydrology team will also use tree cutting shears and shovels to regularly clear the weir and the water retaining pond to prevent accumulation of sediment and tree branches that may affect data collection.



B : Weir width

b : Width of the edge of the weir notch

H : Water level

P : Height below the weir notch

θ : Angle of weir top

▲ Illustration of the v-notch weir

▲ Waterworks staff clearing sediment adjacent the weir

▲ The hydrological monitoring stations

2

WATER TREATMENT

From Raw Water to Drinking Water

Water, in a liquid or solid form and mainly as seawater, covers over 70% of the globe's surface area. Water is also the most common solvent in the world, capable of dissolving many substances. As water flows, it dissolves different sorts of substances along its way. Rainwater falling onto a mountainside or into a reservoir has a shorter distance to travel and generally accumulates fewer substances. However, after reaching the sea, as the run-off distance is longer, more substances are collected by water as it is carried along. Since ancient times, due to the metabolic and chemical action of numerous marine organisms, seawater has harboured high chemical levels and accumulated elements. Scientists have discovered that seawater contains more than 90 substances and elements. Oxygen and hydrogen have the highest levels, as well as chlorine, sodium, sulphur, magnesium, calcium and potassium, etc.

Various treatment processes including filtration and disinfection are thus required for turning naturally collected raw water into potable water for human consumption, which involves the removal of a large number of visible and invisible substances. Drinking water standards are set to limit these substances below the permissible health levels. The Hong Kong Drinking Water Standards (HKDWS) have been developed with reference to World Health Organization recommendations and international practices. Furthermore, a set of drinking water standards suitable for local context has been established after being reviewed by water experts. The drinking water standards promulgated in April 2021 include 57 chemical parameters, 2 radiological parameters and 1 microbiological parameter. Each of these has an upper limit. The Government of the Hong Kong Special Administrative Region (HKSAR Government) also includes a series of aesthetic guidelines to ensure that the appearance, taste and odour of water are acceptable (see "Hong Kong's Drinking Water Standards" in Chapter 5 for details).

The previous chapter discusses Hong Kong's efforts and achievements over the last century in exploiting and harvesting its water resources. These efforts resulted in the creation of a reservoir system that has become a collection of iconic and elegant architectural structures, and the introduction of Dongjiang water has put an end to Hong Kong's century-long water supply issues. The raw water treatment or filtration presented in this chapter shows the growing demand for enhancing water quality, following the stabilisation of the water source supply. While water purification and filtration are concepts that have been developed by different societies since ancient times, the regulation of water quality is a more recent practice. The City of London in the United Kingdom was the first to enact legislation in 1852[1] and has become a precedent for many places to follow. In Hong Kong, the first Albany Filter Beds at Mid-Levels were completed in 1890 in conjunction with the construction of the city's second reservoir system, the Tai Tam Reservoirs.

▲ The principal mains of the Water Treatment works

1 King's Printer of Acts of Parliament. (n.d.). *An Act to make better Provision respecting the Supply of Water to the Metropolis*. https://www.legislation.gov.uk/ukpga/Vict/15-16/84/enacted

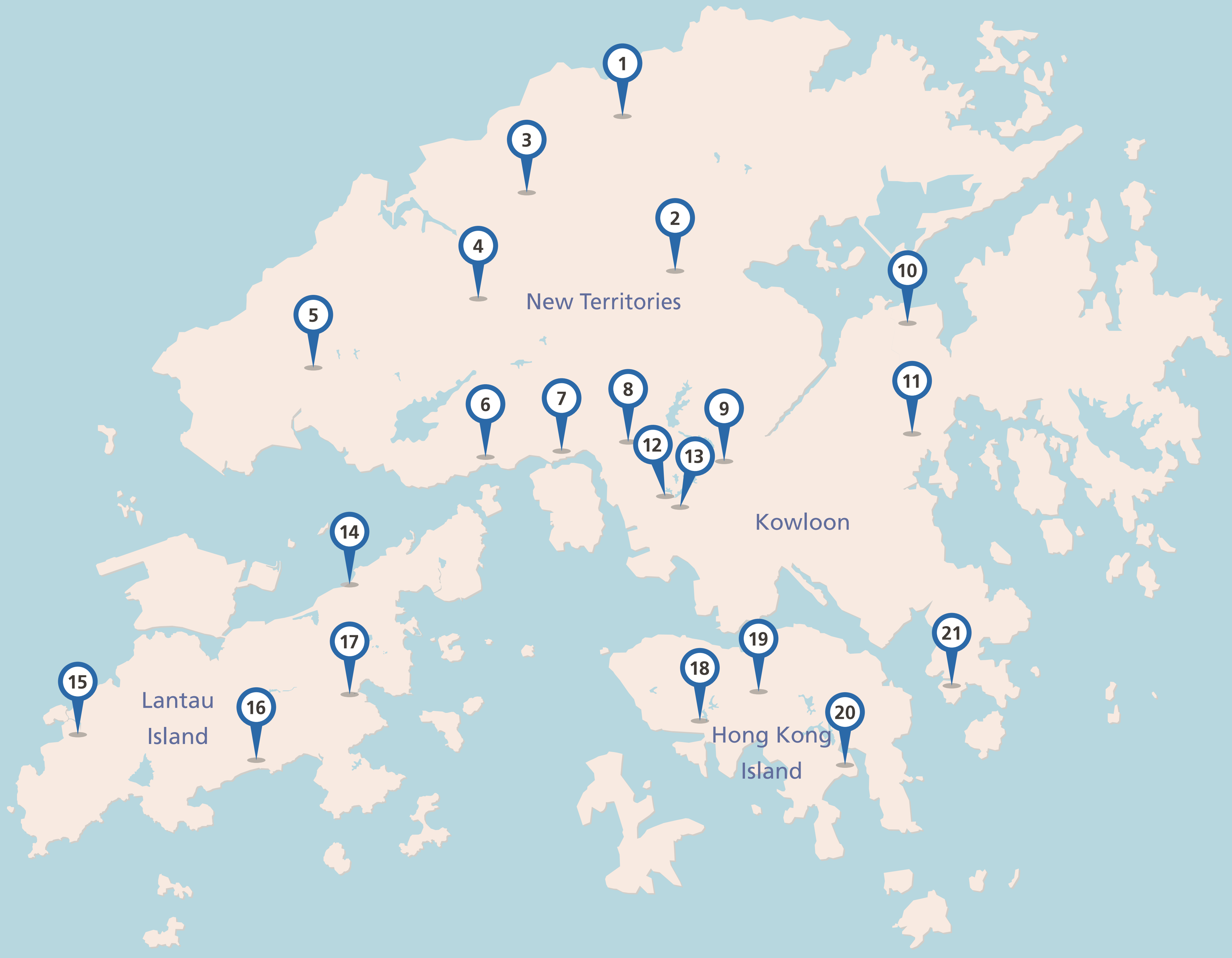
Location of Water Treatment Works in Hong Kong

There are currently 20 water treatment works in Hong Kong. In addition to treating raw water to comply with the HKDWS, these facilities are also subject to stringent water quality monitoring and control. Raw water originates from a wide range of outdoor areas and its quality varies with the surrounding environment. To meet that challenge, the treatment processes adopted at the water treatment works use different biological, physical and chemical processes, and have adopted recent technological developments for safeguarding the water quality of the public water supply.

In response to climate change and to create a wider range of local water resources, the Water Supplies Department has further explored the use of seawater and grey water by applying new filtration technologies and systems. This chapter, entitled "Water Treatment", outlines the evolution of water treatment technology in Hong Kong, including its scientific principles, with particular reference to new technologies adopted since the turn of the millennium.

List of Water Treatment Works in Hong Kong (as at 31 March 2022)

Year of Commissioning	Name	Raw Water Source(s) and status	Capacity (million cubic metres per day)
1928	Shek Lei Pui Water Treatment Works	Decommissioned	0.08
1948	Eastern Water Treatment Works	Decommissioned	0.05
1956	Tai Po Road Water Treatment Works	Kowloon Reservoir, Shek Lei Pui Reservoir, Kowloon Reception Reservoir, Kowloon Byewash Reservoir	0.03
1958	Tsuen Wan Water Treatment Works	Shing Mun Reservoir, Tai Lam Chung Reservoir	0.32
1960	Aberdeen Water Treatment Works	Decommissioned	0.02
1963	Silver Mine Bay Water Treatment Works	Tai Lam Chung Reservoir, Shek Pik Reservoir	0.16
1964	Sha Tin Water Treatment Works	Dongjiang Water, Plover Cove Reservoir, High Island Reservoir, Lower Shing Mun Reservoir	0.54
1970	Red Hill Water Treatment Works	Tai Tam Upper Reservoir, Tai Tam Byewash Reservoir, Tai Tam Intermediate Reservoir, Tai Tam Tuk Reservoir	0.02
1972	Tai O Water Treatment Works	Shek Pik Reservoir, Yi O Intake	0.002
1982	Tuen Mun Water Treatment Works	Tai Lam Chung Reservoir	0.37
1985	Sheung Shui Water Treatment Works	Dongjiang Water, Plover Cove Reservoir	0.20
1985	Yau Kom Tau Water Treatment Works	Dongjiang Water, Plover Cove Reservoir	0.25
1989	Pak Kong Water Treatment Works	Plover Cove Reservoir, High Island Reservoir	0.80
1989	Cheung Sha Water Treatment Works	Shek Pik Reservoir	0.006
1992	Au Tau Water Treatment Works	Dongjiang Water, Plover Cove Reservoir	0.33
1996	Sham Tseng Water Treatment Works	Tai Lam Chung Reservoir	0.037
1996	Siu Ho Wan Water Treatment Works	Tai Lam Chung Reservoir, Shek Pik Reservoir	0.15
1997	Ma On Shan Water Treatment Works	Plover Cove Reservoir	0.23
2000	Ngau Tam Mei Water Treatment Works	Dongjiang Water, Plover Cove Reservoir	0.23
2003	Tai Po Water Treatment Works	Dongjiang Water, Plover Cove Reservoir	0.80



1. Sheung Shui Water Treatment Works
2. Tai Po Water Treatment Works
3. Ngau Tam Mei Water Treatment Works
4. Au Tau Water Treatment Works
5. Tuen Mun Water Treatment Works
6. Sham Tseng Water Treatment Works
7. Yau Kom Tau Water Treatment Works
8. Tsuen Wan Water Treatment Works
9. Sha Tin Water Treatment Works
10. Ma On Shan Water Treatment Works
11. Pak Kong Water Treatment Works
12. Shek Lei Pui Water Treatment Works
13. Tai Po Road Water Treatment Works
14. Siu Ho Wan Water Treatment Works
15. Tai O Water Treatment Works
16. Cheung Sha Water Treatment Works
17. Silver Mine Bay Water Treatment Works
18. Aberdeen Water Treatment Works
19. Eastern Water Treatment Works
20. Red Hill Water Treatment Works
21. Tseung Kwan O Desalination Plant

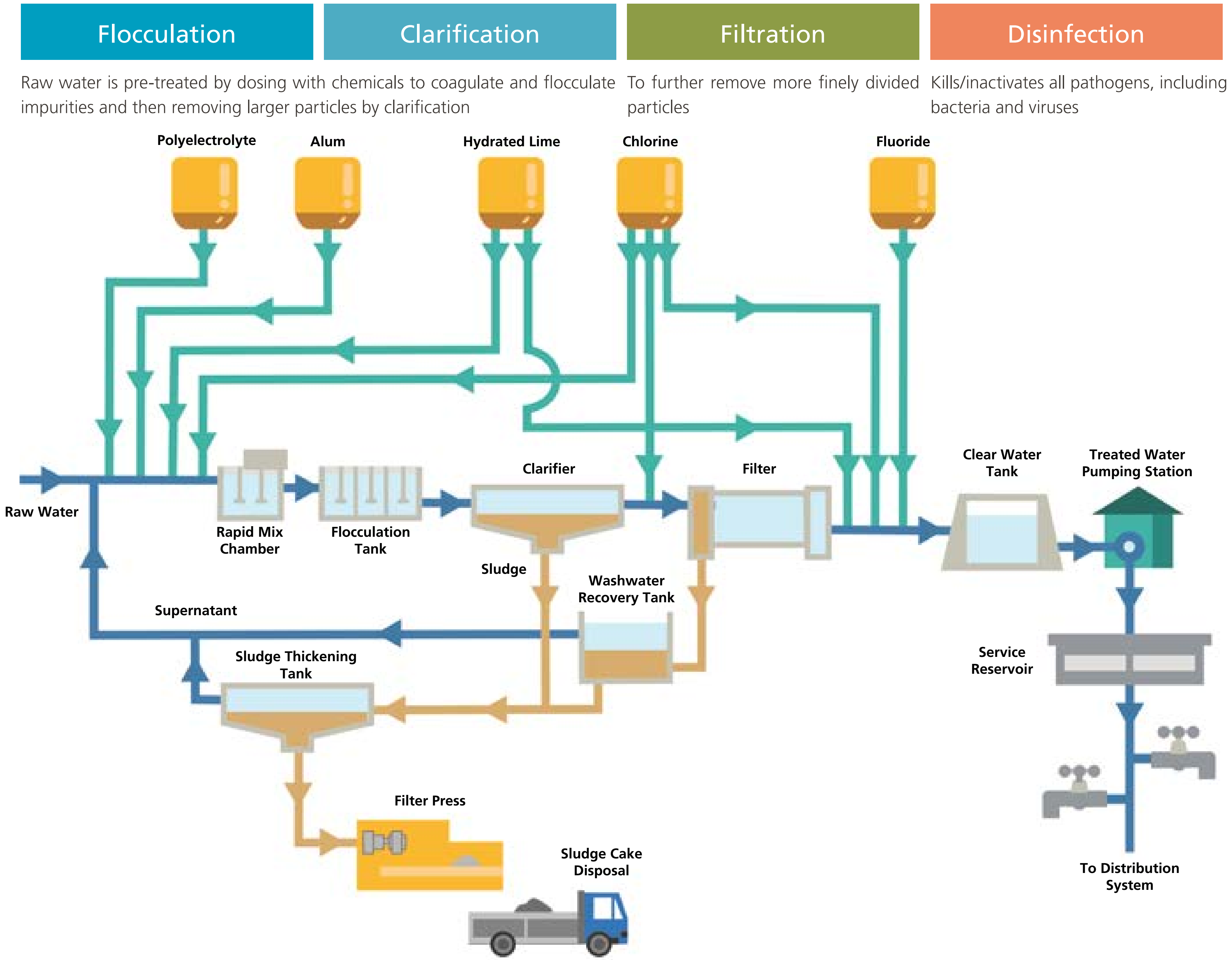
The Four Stages of Water Treatment

A series of purification processes - generally referred to as water filtration - makes raw water safe for drinking and consumption. Water filtration entails processes for removing or reducing suspended particles, metals, organic matter and microorganisms that are naturally present in the water, and of other unhealthy chemical contaminants.

Currently, there are 20 water treatment works in Hong Kong operated by the WSD and separated into the following four regions: Hong Kong Island and Outlying Islands, Kowloon, New Territories West and New Territories East. Using the city's raw water sources and reservoir systems, 4.7 million cubic metres (mcm) of raw water can be treated daily to meet the demands of the public. The water treatment works have been built at different times, with improvements and upgrades according to the city's water quality needs and the best technology available at the time. The water treatment process principally comprises the following four stages: flocculation, clarification, filtration and disinfection. This purification process removes impurities, ranging in size from large to small, in the raw water, and the dosing of chemicals, as appropriate. The water treatment works also has the important role of water quality monitoring and control. To meet the Hong Kong Drinking Water Standards, the monitoring of the quality of incoming raw water, the water quality and performance at each stage of the treatment process ensures that the treatment process is performing optimally (see the article "Hong Kong's Drinking Water Standards" in Chapter 5).

The diagram on the right shows a typical water treatment process that ensures treated water is clear, clean and free from pathogens to a standard safe for direct consumption.

The Four Stages of Water Treatment



Step 1 | Flocculation

The traditional method of water purification relied on gravity to draw down suspended solids - those with a higher density than water - to the bottom of a pond from which they could be removed. To speed up this sedimentation process, raw water is pre-treated with chemicals such as alum. This helps the fine suspended impurities to coagulate and flocculate into larger and denser particles through a process known as flocculation. Hydrated lime is also added to regulate the pH level of the raw water within the range of 6.4 and 7.2 to achieve the desired flocculation result.

▲ Alum

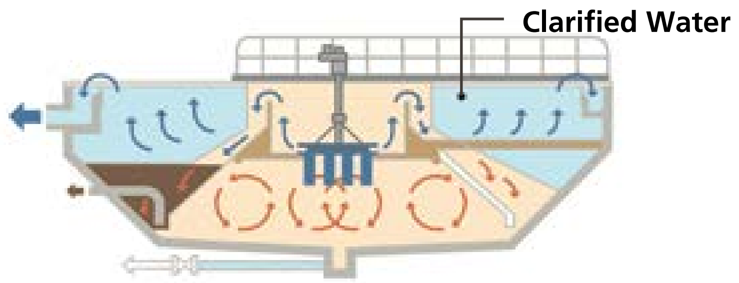
▲ Alum causes the suspended impurities in the raw water to coagulate and flocculate into larger particles.

Step 2 | Clarification

Clarification refers to the process of raw water being mixed with a coagulant and the suspended particles in the water coagulate into large floc particles which are then removed. Currently, four technologies are used in Hong Kong's typical water treatment works: solid contact clarification, high rate clarification, multi-deck sedimentation and dissolved air flotation.

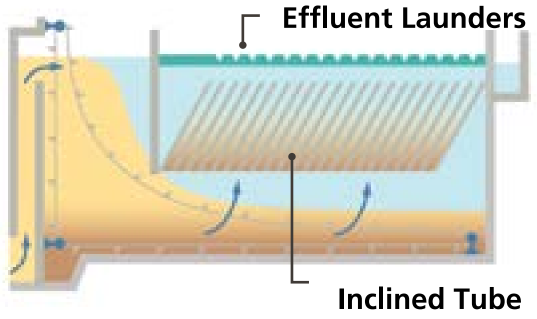
Solid Contact Clarification

Solid contact clarification is an older design consisting of mixing impurities together to form a stable and evenly distributed layer of suspended sludge blanket. As the flocculated raw water flows from the bottom to the top of the clarifier, the impurities coalesce with the suspended sludge blanket and the clarified water is collected on the top of the clarifier. A key feature of the Sha Tin Water Treatment Works is that these clarifiers are usually circular reinforced concrete tanks due to the need for a strong actuator to drive the flocculation cycle.



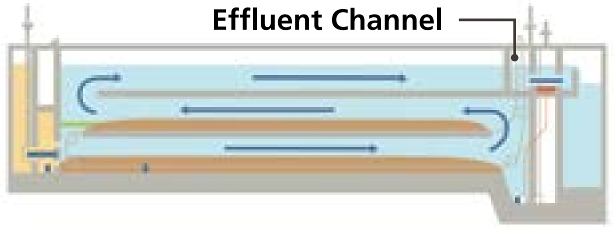
High Rate Lamella Sedimentation

The lamella clarifiers are installed with a row of inclined tubes. As the flocculated raw water flows upwards through the inclined tubes from the bottom of the tank, the impurities in the water settle on the bottom surface of the inclined tube. Once the impurities have reached a certain weight, they will sink to the bottom of the tank by gravity. The clarified water then rises to the effluent launders.



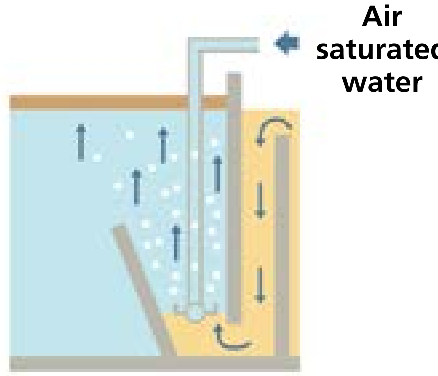
Multi-deck Sedimentation

The clarifier is constructed as a three-tray tank to conserve space and facilitate the sedimentation of flocs. The bottom and middle decks are each equipped with a scraper. Following flocculation, the water flows from the bottom to the top deck, with the larger flocs first settling in the bottom deck, followed by the second deck where the lighter particles settle, and so on. The raw water, after flocculation, settles three times before it flows through the top deck to the filter beds.



Dissolved Air Flotation

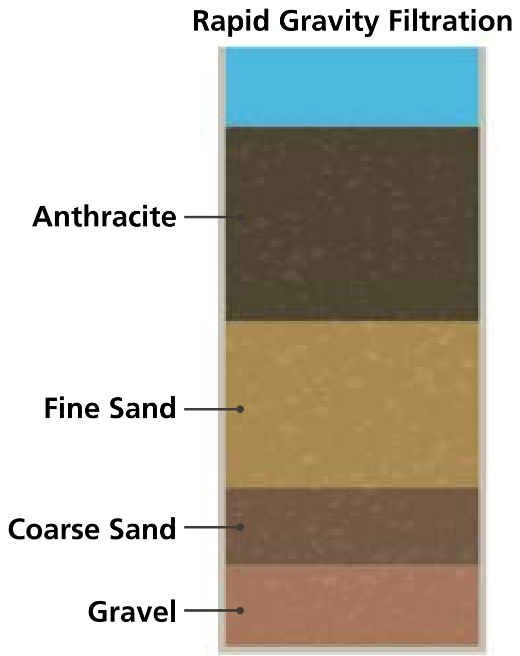
Dissolved air flotation is a rather new treatment technology for water clarification. In comparison with the conventional method of sedimentation for clarification, this new process brings suspended material to the surface quicker. It involves saturating the water with compressed air to generate numerous fine air bubbles that attach to the suspended material and lift it to the surface, forming a 'sludge blanket.' A movable scraper in the clarifier removes the 'sludge blanket' and the clarified water is transported to other water filtration facilities through pipes near the bottom of the tank. Dissolved air flotation is a faster method of purification than traditional clarification techniques and reduces the amount of chemicals used.



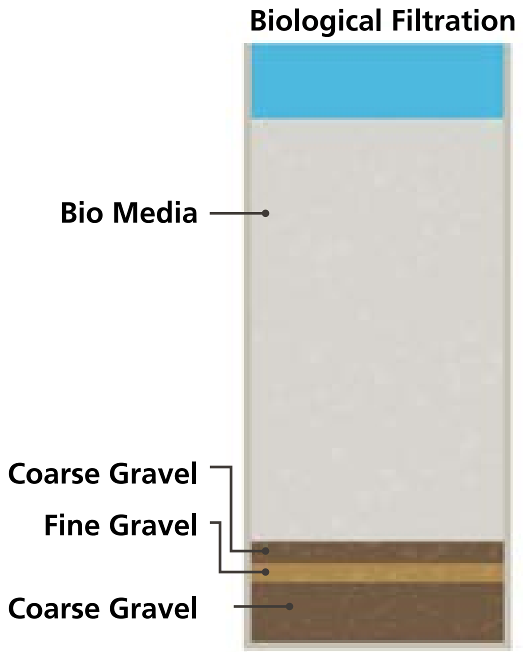
Step 3 | Filtration

After removing larger particles, water is further filtered to remove impurities through interception. Traditionally this is done by gravity, using a variety of filter media to capture the suspended particles in the raw water, while allowing water molecules to pass through. Two types of gravity filtration are currently used in Hong Kong - the main difference is the type of filtration media used, as explained below.

▲ Filter beds



▲ Use of anthracite, fine sand and other granular media to remove more finely divided suspended particles.



▲ Use of bio media and other media to remove more finely divided suspended particles, ammonia nitrogen and organic matters.

Step 4 | Disinfection

After the filtration of clarified water, any remaining bacteria and viruses are deprived of the protection of suspended particles, thus creating the conditions for subsequent disinfection. Chlorination is generally used as the most traditional and effective method of disinfection.

Chlorine Disinfection

In Hong Kong, chlorine is usually applied in two stages of the water treatment process: "pre-chlorination" and "post-chlorination". "Pre-chlorination" refers to the addition of chlorine to raw water or clarified water to oxidise and remove impurities in raw water and suppress the growth of algae. "Post-chlorination" is the addition of chlorine to disinfect filtered water and ensure that the treated water is free of pathogens from the time it leaves the treatment works until it is used.

▲ Before on-site chlorine gas generation became available, liquid chlorine was required to be stored at water treatment works.

▲ Full view of the control room

Water Quality Monitoring

Water samples are taken from raw water, flocculated water, clarified water, filtered water and treated water, and are monitored simultaneously and analysed following each step and throughout the water treatment process.

Water quality control at Hong Kong's water treatment works has implemented a three-tier water quality monitoring system. The first tier is the "Online Water Quality Monitoring System'', which uses various monitoring sensors to monitor different parameters round-the-clock such as pH, turbidity, residual chlorine and fluoride levels in the water automatically and continuously. The second tier is the "On-site Primary Control Test", where grabbed water samples are taken for operational water quality monitoring. This assists in adjusting the required chemical dosage and compares the accuracy against the first tier of online monitoring. The "Comprehensive Water Quality Monitoring" is the third tier, acquiring water samples regularly from every treatment stage and sent to the laboratory for comprehensive physical, chemical, bacteriological, biological, and radiological testing by laboratory staff to ensure compliance with water quality requirements.

▲ The control room of the water treatment works has various "clarify bowls", for easy inspection by operators analysing the condition of the water samples after the completion of each treatment process.

▲ A screen on the wall of the control room displaying the real-time water quality parameters of each process.

▲ Laboratory staff conducting tests on water samples.

State-of-the-Art
Water Treatment Technology

Amid worsening environmental pollution and demands for better water quality in recent years, water treatment has to address a wide range of considerations. The design of water treatment processes comes in different combinations and approaches according to changing situations. In fact, water treatment is an evolving science and the technologies used in the past represented the latest research and technological advances at the time.

The Albany Filter Beds was the first water treatment facility in Hong Kong, completed in 1889 and served by water supplied from Tai Tam Reservoir. This was the first reservoir built following Mr. Chadwick's Report on improving Hong Kong's sanitation in 1882. In addition to the dam, the Tai Tam waterworks project comprised an aqueduct, a service reservoir, and filter beds: a comprehensive water supply system in terms of quality and quantity.

Water Filtration First Acknowledged for Improvements in Hygiene

Sir Osbert CHADWICK, a British consulting engineer highlighted the significance of water treatment in his report. He considered that the use of sand filters was desirable for both old and new waterworks, "Though filtration has no appreciable chemical action on the substances in solution in water, still by removing suspended matter it is more than probable that most important improvement is effected[1]."

The Albany Filter Beds adopted the slow sand filtration method, which was invented by the British engineer James SIMPSON in 1829. Typically, the slow sand filtration bed is constructed from reinforced concrete and is overlaid with a filter medium containing three layers of fine sand, gravel and coarse gravel. This arrangement permits the raw water to pass slowly through the sand and gravel to the bottom of the tank, thereby purifying the water. This group of six filter beds, built into a hillside above Central, was recommended as a tourist attraction in *The Hong Kong Guide* of 1893 and frequently depicted on postcards of Hong Kong[2].

▲ Albany Filter Beds (reproduced by permission of the Government of the HKSAR from the collection of the Hong Kong Museum of History)

1 O. Chadwick (1882). *Mr. Chadwick's reports on the sanitary condition of Hong Kong; with appendices and plans*. London: Printed by George E.B. Eyre and William Spottiswoode, for Her Majesty's Stationery Office. 37. https://wellcomecollection.org/works/mpnmmdbz

2 Shepherd, Bruce (1982). *The Hong Kong Guide 1893*. Hong Kong: Oxford University Press. 94.

Water Filtration Principles Discovered After Implementation

At that time, it was widely believed that slow sand filtration was solely a physical filtration process, achieved by screening out the impurities. However, it was not until the late 19th century that studies revealed that water purification was mainly achieved through the activities of the gelatinous layer of living matter gradually deposited on the surface of the filtering medium. Therefore, in general the longer a filter is in use, the more efficient it becomes, provided that the surface layer does not become so dense that it interferes with the flow of water. These findings overturned the traditional practice of frequent cleaning of a filter bed[3].

With effective water filtration in place, it was unacceptable for water to become turbid after heavy rainfall. As a solution, the government constructed a slow sand filter bed near the city's first reservoir, Pok Fu Lam Reservoir. Similar facilities were gradually introduced to other parts of Hong Kong Island. Until 1925, that the Public Works Department first introduced rapid gravity filtration during the Bowen Road Filter Beds Conversion Project. Rapid gravity filtration is a technique that relies on physical screening to eliminate impurities and has the advantage of a rapid filtration speed and a smaller required land footprint. To complement rapid gravity filtration, chemicals such as alum and hydrated lime are added to the raw water prior to helping impurities to precipitate and to regulate the pH value. To facilitate this process, a chemical house is built next to these plants.

Water Filtration Rates Increased After Automated System Introduced

By 1928, there were already eight water treatment facilities in Hong Kong. The recently finished Shek Lei Pui Water Treatment Works was constructed as an additional water treatment facility to complement the Kowloon Group of Reservoirs, alongside the Kowloon Slow Sand Filtration Plant. It is located to the south of the Kowloon Reception Reservoir and backed by the service reservoir. As the area was not considered large enough for a slow sand filter, the Public Works Department decided to use rapid gravity filtration and imported an automatic filter sand backwashing facility from the United Kingdom. There were only two such units operating in London at the time. This method eliminated the need for manual backwashing and the work processing time was ten times faster[4]. It was the most advanced technology at that time, using hydro turbines rather than coal to power the facility, thereby eliminating the need for manual operations. The performance of the filtration process was found to be satisfactory. Government bacteriologist E.P. MINETT wrote in his operation report that Kowloon raw water was consistently superior to that on Hong Kong Island for unknown reasons. Kowloon filtered water underwent weekly chemical and bacteriological examination before chlorination and the results showed that the quality of filtered water from rapid gravity filters was of exceptionally good quality[5].

It is worth mentioning that the construction of the Shek Lei Pui Water Treatment Works was undertaken by Yee Lee & Co., co-founded by NG Wah and TAM Shiu-hong. The latter is well known for risking his life to assist burying the 72 Martyrs at Huanghuagang. Tam became a renowned architect in Hong Kong with many of his projects awarded bonuses for their good management, excellent workmanship and early completion.

There were eleven water treatment works in Hong Kong by 1949. This year, the Eastern Filters was commissioned. It filtered all raw water delivered through the Tai Tam Water Tunnel, replacing the pre-war sand filters at Bowen Road, Albany and Eastern. As a result, the Eastern Filter can filter eleven million gallons of water per day, which is four million gallons more than the combined capacity of the three old sand filters.

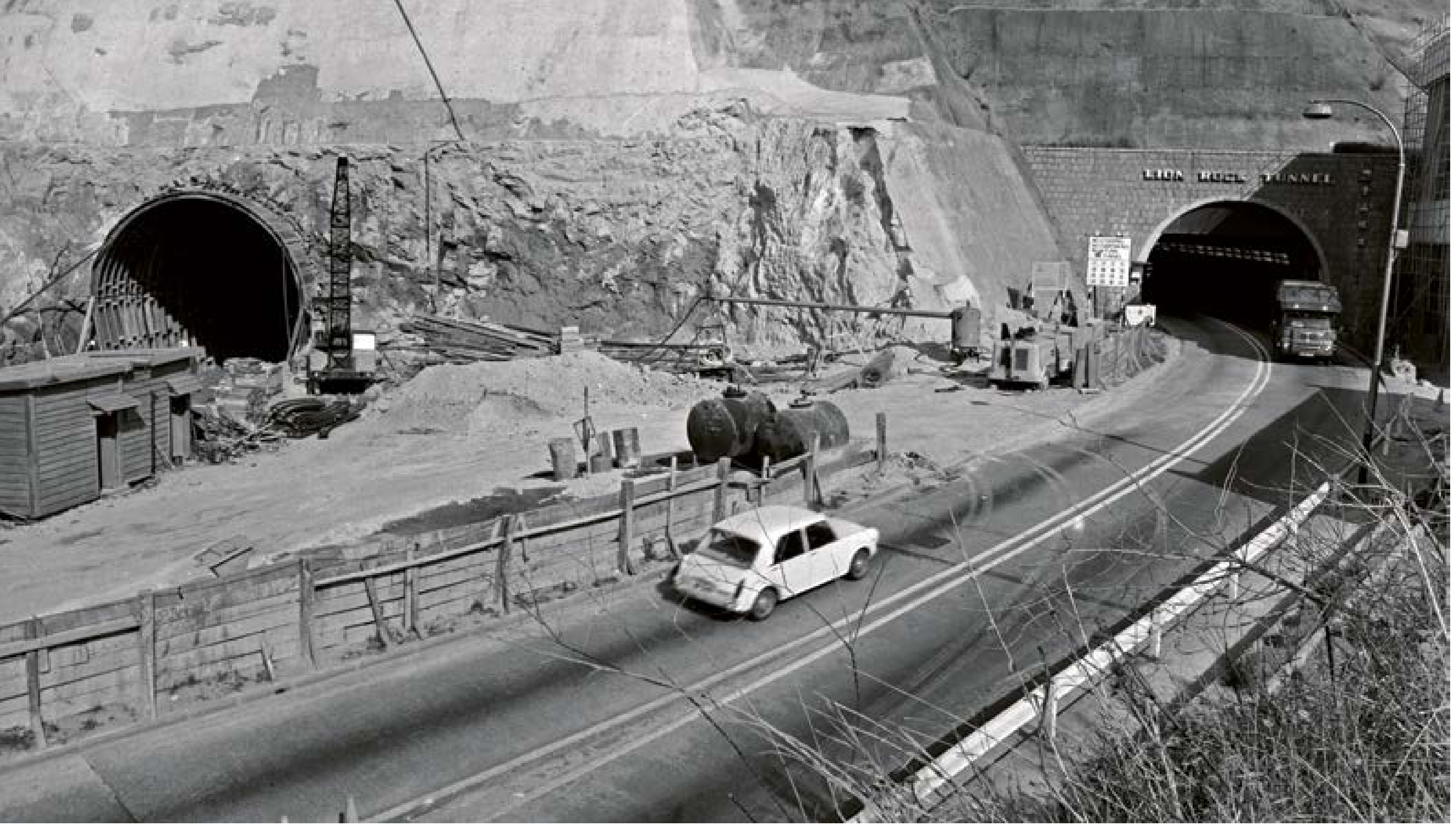
Water consumption had increased dramatically after the war and these new treatment facilities were extremely important to Hong Kong. The existing filter beds had become overloaded and filtering bottlenecks occurred when their capacity was exceeded. On many occasions, the city experienced limited hours of water supply due to the inadequacy of the filter beds, despite reservoirs being at capacity and often overflowing at the same time[6].

3 Francis A. Cooper (1896). *Report on the Water Supply of the City of Victoria and Hill District Hong Kong*, Public Works. *Sessional Papers for the Year 1896*. 14. https://digitalrepository.lib.hku.hk/catalog/dr274p440#?c=&m=&s=&cv=&xywh=-231%2C676%2C2359%2C1173

4 Tam, Shiu Hong. (1954). Memories of 50 Years of Building Works in Hong Kong. *Year Book of Hong Kong Construction Association*. Hong Kong: Hong Kong Construction Association. 50. Retrieved from https://sites.google.com/yahoo.com.hk/tamfamily/tam-shiu-hong-tbcahk-%E8%AD%9A%E8%82%87%E5%BA%B7%E8%88%87%E9%A6%99%E6%B8%AF%E5%BB%BA%E9%80%A0%E5%95%86%E6%9C%83/memoir-of-50-years-of-construction-history-in-hk?authuser=0

5 E.P.Minett. (1930). A review of the Water Supplies of Hong Kong. *Transactions of The Royal Society of Tropical Medicine and Hygiene*. 3-4.

6 Six points to be explained: Water ban remains unresolved as filtering capacity cannot cope with full-day water supply. (23 June 1950). *Wah Kiu Yat Po*. 5. Retrieved from https://mmis.hkpl.gov.hk/coverpage/-/coverpage/view?_coverpage_WAR_mmisportalportlet_actual_q=%28%20%28%20%2Bdc.identifier.bibno%3A%28NPWK19500623%29%20%29%29&_coverpage_WAR_mmisportalportlet_sort_field=score&p_r_p_-1078056564_c=QF757YsWv58JCjtBMMIqoivUNh%2BPDT4X&_coverpage_WAR_mmisportalportlet_o=0&_coverpage_WAR_mmisportalportlet_sort_order=desc



▲ The Lion Rock Tunnel linking Kowloon and New Territories East was made possible by the water transfer project.

Water Treatment Works as a Water Supply System Hub

In 1959, the government decided to build the Plover Cove Reservoir to secure a stable water supply for all of Hong Kong. Consequently, the water distribution system is vast and complex. The Sha Tin Water Treatment Works (STWTW) is the hub of the entire water supply system with a central control room to remotely monitor and control the operation of the Plover Cove Reservoir water supply system. At the time, it was the most modern water treatment works in Southeast Asia, occupying 800,000 square feet with the capacity to treat up to 727,000 cubic metres of water per day. Its main facilities encompassed filter beds, pumping stations, chemical houses and administrative offices. Its laboratory was equipped with the most advanced equipment. These facilities established a benchmark for water treatment works in operation at the time.

During the constructing of the STWTW, the (vehicular) Lion Rock Tunnel was also included in the same construction works. These seemingly disparate projects are in fact now part of the city's water supply network. The construction of the Lion Rock Tunnel was initially proposed by the Waterworks Office of the Public Works Department to transfer water from the STWTW to Kowloon. The plan was to cut through the mountain range separating Kowloon from the New Territories. In the early 1960s, when the government was keen to develop Sha Tin into a new town, it also took the opportunity to build a road tunnel alongside the water mains works, making it the first road tunnel in Hong Kong.

New Water Treatment Technologies after 2000

On-site Chlorine Generation

The water treatment works in Hong Kong use an average of six tonnes of chlorine per day. As there are no local suppliers of chlorine gas, it was imported in liquid form from the mainland. The chlorine is liquefied beforehand to make transportation over long distances more convenient.

Leveraging technological advances, chlorine generation has become increasingly sophisticated and reliable. As membrane electrolysis technology has improved in performance, the system to generate chlorine is now more efficient and compact in design. Since 2018, the WSD has in phases installed chlorine generation facilities at eleven major water treatment works. Chlorine is produced by electrolysis of brine with the electrodes separated by selective ion membranes. The system can safely and reliably produce chlorine on demand, eliminating the need for storage.

Chlorine generated in this process can also be converted into sodium hypochlorite solution through another simple chemical process. This is transported to other smaller water treatment works to replace liquid chlorine for disinfection. The transportation of sodium hypochlorite solution is safer than moving liquid chlorine.

▲ On-site chlorine generation

▲ The vacuum pressure swing absorption system at Tai Po Water Treatment Works extracting oxygen from the air.

Ozone Disinfection

Nowadays, it is preferable to reduce the amount of chemicals used in water treatment. Technological developments have made it possible to replace "pre-chlorination" with ozone. Ozone is a powerful oxidant and disinfectant that inhibits cell reproduction by oxidising bacterial and viral cell bodies, breaking down cell membranes and cell walls, and further destroying deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) in the nucleus of cells. After the oxidation reaction, ozone will be reduced to its oxygen form without producing any odour or residues.

As ozone is liable to decomposition and cannot be stored, it must be manufactured on site and used immediately. In 2000, Ngau Tam Mei Water Treatment Works was the first to introduce ozone disinfection technology into the treatment process, significantly reducing operation costs and the risk of gas leakage associated with chlorine use. This innovation saw the water treatment works receive the prestigious “Superior Achievement Award” from the American Academy of Environmental Engineers in 2001.

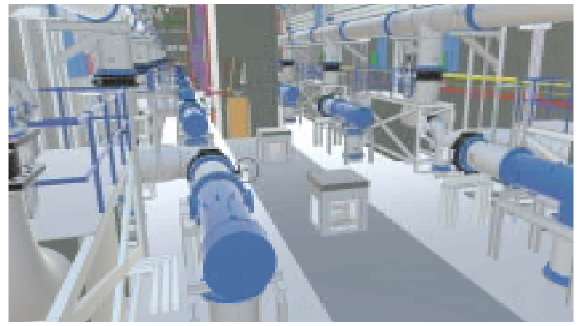
The use of ozone to replace "pre-chlorination" has reduced chlorine consumption by approximately 30%. However, ozone is liable to decomposition and cannot be effective in water for a long period of time. So, to prevent bacterial regrowth in the distribution network and maintain disinfection,

▲ The ozone generator at the Tai Po Water Treatment Works simulates the way ozone is produced in nature by lightning, using high voltage electricity to convert oxygen into oxygen molecules, which are then combined to form ozone.

"post-chlorination" remains in place to ensure that a certain amount of residual chlorine is retained throughout the water distribution system to maintain disinfection effectiveness.

Ultraviolet Light for Water Disinfection

After its commissioning in 2026, the South Works of STWTW will be one of the water treatment works using ultraviolet (UV) light for drinking water disinfection, which is more commonly used in wastewater treatment. In recent years it has also become widely used for treating drinking water. The aim of UV disinfection is to eliminate microorganisms instantly by destroying the structure of their nucleic acids, DNA and RNA, and killing their biological cells or suppressing their active form. Studies and tests find this treatment effective in eliminating pathogenic microorganisms, such as Cryptosporidium and Giardia, as well as other viruses.



▲ A three-dimensional depiction of the UV disinfection facilities at the South Works of the STWTW, using Building Information Modelling (BIM).

Biosensing Alert System with Dual Protection

Although advanced analytical instruments are capable of detecting chemical contaminants in water at microgram or even nanogram levels, the results of trace analysis generally require a longer time to be delivered. The WSD has developed and introduced a "Biosensing Alert System" featuring dual protection and validation capabilities to enhance water quality monitoring. Biosensing refers to organisms responding to changes in their surroundings. Therefore, tracking the specific reactions of individual organisms can be used for proactive monitoring. At present, the WSD has chosen zebrafish and *vibrio fischeri* as its water quality monitoring collaborators. Zebrafish can monitor the water quality round the clock, and *vibrio fischeri* can rapidly test the toxicity of water. When used together, frontline staff can identify and resolve water quality issues within an hour.

▲ The Sheung Shui Water Treatment Works is the first water treatment works to adopt the Biosensing Alert System. When a zebrafish behaves abnormally, the alert system will sound an alarm and automatically take water samples for testing. The bottom left corner of the picture shows the sampler.

▲ The high-speed camera records and analyses the movement of zebrafish 24 hours a day to monitor the quality of raw water.

Zebrafish

Zebrafish are genetically similar to humans by up to 70%. They are exceptionally sensitive to contaminants in water and are highly responsive, providing fast and accurate warning of water safety issues. During their "service", zebrafish are placed in a specially designed fish-tank. Raw water is continuously fed into the tank and a high-speed video camera is used to record and analyse the movement of the zebrafish 24 hours a day. If they show any abnormalities such as hypoactivity, suffocation or irritation, the system will alert the staff on duty. Water samples will be taken automatically for testing.

The zebrafish water quality monitoring system is the result of in-house research and development by the officers in the Water Science Division. The system integrates biological, computer, telecommunication and automation technologies. The video tracking of zebrafish is particularly challenging. Even simple things like lighting and the frequency of light-tube flickering, which are imperceptible to the naked eye, can be detected by a high-speed camera. Other hardware considerations, such as the thickness of the fish tank, material colour, water-flow control, and even air bubbles and reflections in the water can affect the clarity and accuracy of the recording tracking. After more than two years of experiment and refinement, the design of the fish-tank has already evolved to the eighth generation by the time the Biosensing Alert System was put into service.

The system won a Silver Award in the Civil Service Outstanding Service Award Scheme's Team Collaboration Award (Internal Service) and a Bronze Award in the Service Enhancement Award (Large Department Category) in 2013. It not only facilitates close monitoring of water quality, but also reduces the number of laboratory tests, resulting in a significant reduction in chemical and energy consumption. It is both cost-effective and in line with green science and environmental principles.

▲ The zebrafish are retired after one month of service.

Vibrio fischeri

Vibrio fischeri, commonly known as "light-emitting bacteria", emits blue-green light under normal water conditions. While, on the contrary, it may be less luminous or even non-luminous, researchers have used this property to develop a rapid detection system based on bioluminescence technology. When water samples contain harmful substances that inhibit *vibrio fischeri* from emitting light, the rapid toxicity testing system based on the bioluminescent technology is capable of screening over 1,000 harmful substances in water, such as formaldehyde and cyanide, in an hour. The test has the advantages of a short result time, low cost, high accuracy and sensitivity, and it has been approved by the United States Environmental Protection Agency and has been adopted by the Olympic Games, Asian Games and the United States Department of Defense to ensure water safety.

Desalination as a Strategic Water Resource

In response to the extreme impact of climate change on local yields, the WSD is developing desalination as a strategic water resource and has commenced construction of the first stage of the Tseung Kwan O Desalination Plant.

The principle of converting seawater into potable fresh water is the removal of salt and impurities. Despite not using rainwater or river water as the source, desalination is still considered to be a filtration technology. As seawater makes up 97.5% of the world's total water bodies, its utilisation means desalination is one of the few water resources that remains unaffected by climate change. To enhance the resilience of Hong Kong's water supply, the first stage of the Tseung Kwan O Desalination Plant will be commissioned in 2023.

As early as 1975, Hong Kong had built at that time the world's largest desalination plant at Lok On Pai. Run on petroleum, it employed the "Multi-Stage Flash Distillation" technology, using a distillation principle similar to those of a distilled coffee machine. However, the technology was very energy-consuming and expensive, eventually it was only used in times of low rainfall. In the 1980s, the global oil crisis led to a significant increase in the cost of desalination and the government suspended its service in 1982. Today, desalination technology has become more advanced. In addition to the conventional thermal method, the world's most advanced reverse osmosis (RO) technology will be used at the Tseung Kwan O Desalination Plant.

RO technology uses a special filter membrane to produce fresh water and compared to conventional thermal methods, RO uses less energy and has a higher fresh water recovery rate. For every tonne of fresh water produced, only 2.5 to 3.2 tonnes of seawater is required. The cost of desalination has been reduced due to the widespread use of new technologies. At present, the unit cost of producing drinking water at the Tseung Kwan O Desalination Plant is about HK$13 per cubic metre ($m^3$), which includes the initial construction costs, operation costs, water distribution, customer services expenses etc. This is comparable to the unit cost of the equivalent production overseas. However, it is still 30% higher than the cost of drinking water produced using Dongjiang water and from local yields.

Characteristics of the Semi-permeable Membrane

Although RO technology uses semi-permeable membranes to block impurities, and appears similar to filtration, it is more superior to conventional filtration methods. In general, filtration uses a porous medium that blocks large impurities, and allows water molecules and other water-soluble substances to pass through. For this reason, there is little difference in the chemical composition of raw water compared to filtered water.

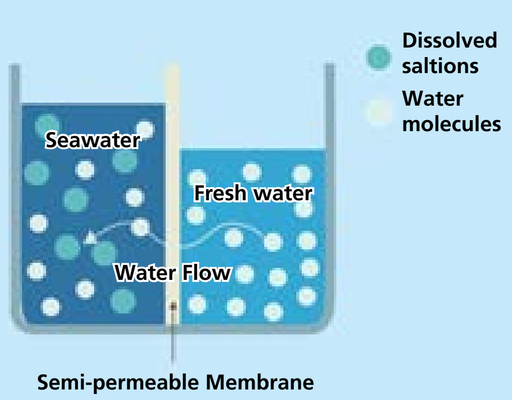
The semi-permeable membrane used in RO has extremely small pores with a diameter of just 0.1 nanometre (i.e. roughly one millionth the size of a hair). This allows only water molecules and trace mineral ions to pass through, thereby blocking salt, impurities and other harmful substances from seawater.

The Reverse Osmosis Principle

Membrane desalination applies the mechanism of interception using a semi-permeable membrane to remove impurities, but the principle at play is osmosis.

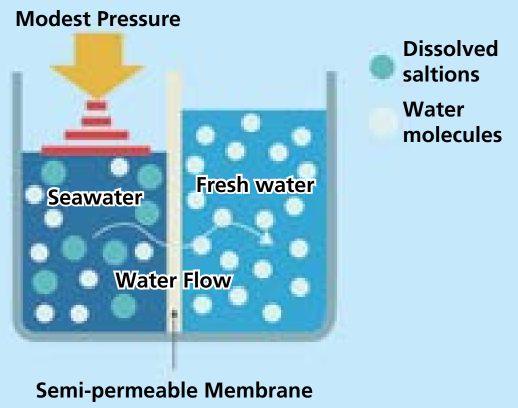
▲ Pressure vessels

The Osmosis Principle



When two liquids of different concentrations are separated by a semi-permeable membrane, water molecules flow from a less concentrated solution to a more concentrated solution until an equilibrium is reached. This phenomenon is known as osmosis.

The Reverse Osmosis Principle



RO involves reversing the flow of water by applying pressure on the more concentrated solution. As long as the pressure is greater than the osmotic pressure, water molecules are forced to flow through the semi-permeable membrane to the less concentrated solution, hence removing salt and impurities.

▲ Conceptual drawing of the Tseung Kwan O Desalination Plant

The Tseung Kwan O Desalination Plant

The Tseung Kwan O Desalination Plant is located in Tseung Kwan O Area 137, covering an area of eight hectares. The area is suitable in which to construct the desalination plant as it is adjacent to the WSD's existing water supply network and the water quality of nearby seawater is less affected by sediments in the Pearl River Delta. The first stage of the Tseung Kwan O Desalination Plant will be able to produce 135,000 m³ of fresh water per day. This will increase to 270,000 m³ per day after expansion, equivalent to 5% to 10% of Hong Kong's fresh water consumption.

As the Tseung Kwan O Desalination Plant is located close to Joss House Bay and Clearwater Bay Country Park, the design and construction of the plant incorporates sustainable environmental concepts to blend-in with the surrounding environment. Renewable energy such as solar energy and low-energy consumption processes, rainwater harvesting for irrigation and maximising a greening area to enhance energy efficiency have been adopted. The project has been rated as a Provisional Platinum Certified Project under the Building Environmental Assessment Method (BEAM) Plus for New Buildings.

Apart from making good use of the 1,832 photovoltaic (PV) panels installed on the roof of the desalination plant, the WSD is planning to build a large-scale PV farm at the South East New Territories Landfill near the Plant. It is expected to provide a renewable energy generation capacity of up to ten megawatts upon completion.

This desalination plant has been incorporated as a new source of water supply in the WSD's water supply strategy. It is an alternative for future water infrastructure planning, particularly in remote areas close to the waterfront. The WSD is currently planning the water supply strategy for the Kau Yi Chau Artificial Islands and will carefully examine the feasibility and operational benefits of desalination plants set up on the islands.

The Tseung Kwan O Desalination Plant is the first water treatment facility in Hong Kong adopting the new pre-treatment "ActiDAFF" technology. "ActiDAFF" combines Dissolved Air Flotation (DAF) technology and filtration in the same tank, with the former being placed on top of the filter bed so that processed water can flow through the filter underneath, thereby reduce the required floor space of the desalination plant. The treatment of the seawater removes larger particles and organic matter from the water, which helps to reduce membrane fouling, thus protect and extend its service life.

▲ Ir LAM Kwok-chuen, Senior Engineer, New Works Branch, says that large RO racks of the Tseung Kwan O Desalination Plant adopted the Design for Manufacture Assembly application.

Desalination Projects' New Technology and the Future

Ir LAM Kwok-chuen, Senior Engineer, New Works Branch is enthusiastic about the new plant: "As an engineer working for over 30 years, it is exciting to be involved in the construction of the Tseung Kwan O Desalination Plant. After all, it is a mega-project that applies many new technologies. Our colleagues and the entire consultant and contractor teams are highly engaged."

RO desalination technology is well-established overseas, but this is its first application for fresh water supply in Hong Kong. For WSD engineering team, "first time" means a process of learning, problem-solving, innovation and gaining experience.

The project has adopted the Design-Build-Operate (DBO) contract form, making the Tseung Kwan O Desalination Plant the first waterworks facility in Hong Kong to be operated by a contractor. "This arrangement is intended to bring in the experience and technology of overseas experts. WSD colleagues will work with the contractor as a team to operate the desalination plant. We hope that through cooperation and exchange, we will gain experience and promote the transfer of technology."

Despite the importance of experience, unexpected challenges and problems always arise. One such example is the COVID-19 pandemic outbreak during the first month of this 39-month construction project. "The contractor's team members are from Spain, Australia, the UK, etc and it takes time to apply for visas and work permits. Due to the tight construction programme, we had been looking at ways to efficiently integrate team members. With the push from the pandemic, it was pragmatic to undertake the design review of the desalination plant through electronic means, so the project adopted the Common Data Environment (CDE) as an electronic platform. All those involved in the project design review can modify the design on the same platform; this facilitates comparison and tracking of revisions, giving team members a thorough understanding of others' design philosophy and the reasons for revisions. It also reduces the risk of errors or omissions due to too many emails," said Ir LAM.

To speed-up progress of the project, the team has explored the use of Design for Manufacture Assembly (DfMA) during the design phase. This is a proactive design method that emphasises ease of manufacture and assembly effectiveness, to increase construction efficiency. "The Housing Department has long used prefabricated component construction, but waterworks structures are not as repetitive as public housing. Therefore, we explored whether DfMA could be adopted for electrical and mechanical works," stated Ir LAM.

The RO process for this desalination plant will be carried out in twelve large RO racks, of which eight are involved in the primary RO process and each contains 236 pressure vessels. The remaining four RO racks are involved in the secondary RO process, each containing 28 or 84 pressure vessels. Following the conventional construction sequence, 2,336 pressure vessels would have been delivered and assembled only after the civil works of the Reverse Osmosis Building had been completed. By using DfMA, the assembly of the pressure vessels was completed in advance at a factory on the mainland, and was transported to Hong Kong by barges. Each RO rack with 236 pressure vessels is nine metres high, eight metres long and nine metres deep, and weighs approximately 90 tonnes. To suit the assembly process, the construction approach of the Reverse Osmosis Building needed modification. The building's structural frame was constructed first to allow the accommodation of RO racks before the external wall panels were installed. Ir LAM said that such an arrangement allowed certain processes to be executed simultaneously, hence reduce the construction time and minimise the safety risks associated with working at height due to on-site assembly. "The WSD is receptive to innovative technology, particularly in promoting on-site safety and DfMA. The construction experience will be of great reference for future waterworks projects," said Ir LAM.

▲ The RO racks arriving at the site of the Tseung Kwan O Desalination Plant

▲ A giant crane lifts the 90-tonne RO racks onto temporary tracks during its installation prior to the completion of the building's structural frame

In-situ Reprovisioning of Sha Tin Water Treatment Works

The Sha Tin Water Treatment Works (STWTW), located at Hin Keng, is the largest water treatment works in Hong Kong. Commissioned in 1964, it underwent three expansions during the 1970s and 1980s. The treatment capacity reached one million cubic metres (mcm) per day at its peak. However, after operating for over 50 years the facilities are nearing the end of their service life, with a consequent decline in efficiency and a scarcity of replacement parts. In anticipation of rising water demand from new housing developments, the WSD began preparations for the reprovisioning of the STWTW in 2015. After completion of the new South Works on the same site by 2026, it will again be the largest water treatment works in Hong Kong.

The STWTW treats raw water from five different sources, including the Dongjiang, Plover Cove Reservoir, High Island Reservoir, Lower Shing Mun Reservoir and several catchment intakes. Water from these sources will be used depending on varying conditions, with the treatment process adjusted accordingly, making the operations of the STWTW challenging and complex. For instance, water would be relatively turbid during the rainy season, the treatment works will use an appropriate treatment process depending on the raw water quality. The treated water is widely distributed to Sha Tin, central Kowloon and parts of Hong Kong Island.

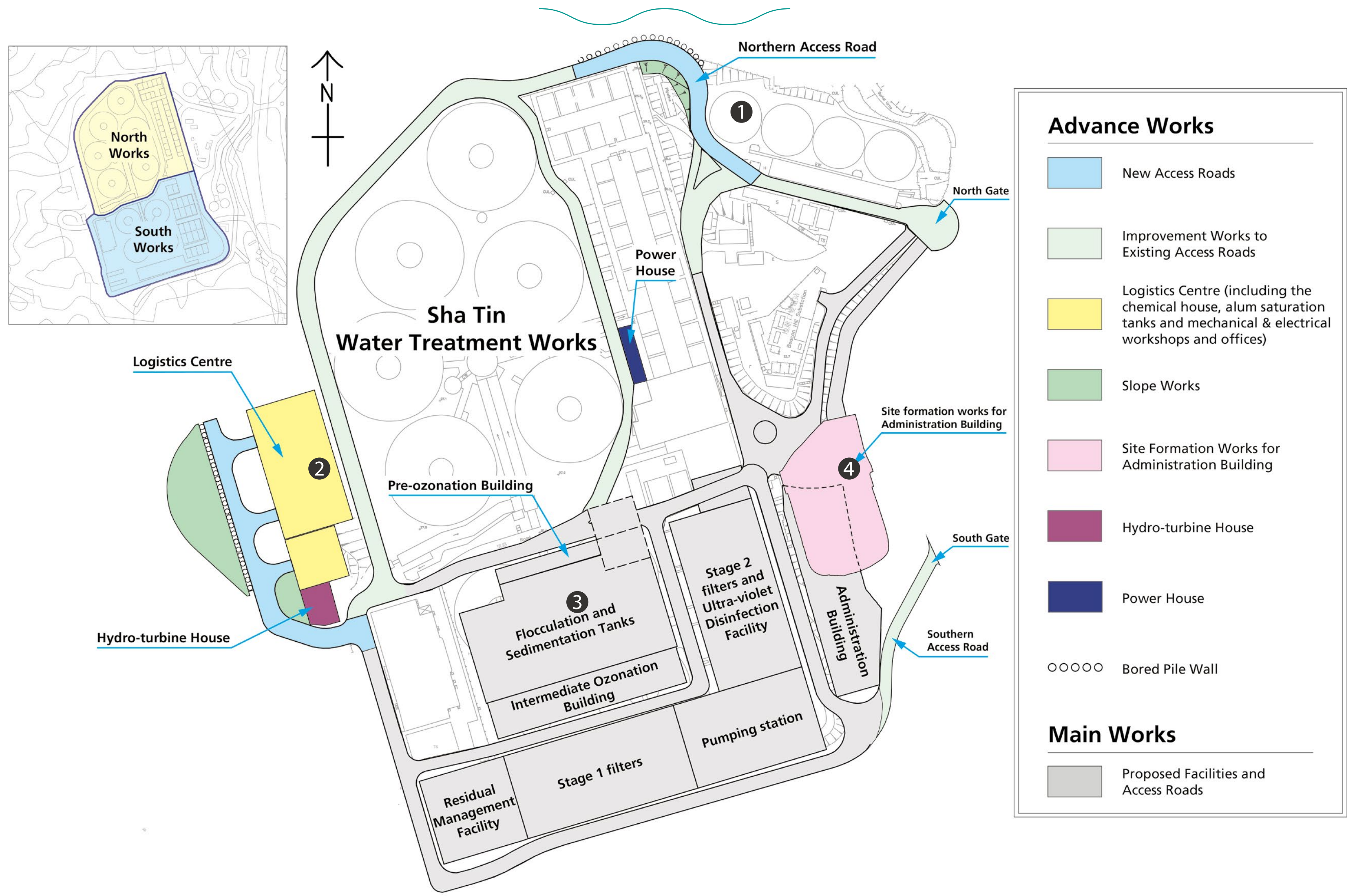
Design and Construction Challenges

The STWTW site is divided into two sections, the South Works and the North Works. Built first and commissioning in 1964, the South Works was accorded with priority for redevelopment. Taking into account the site area and the fully developed water supply network, reprovisioning of the South Works on its existing site is the most appropriate and effective redevelopment option. The entire project involves the planning and reprovisioning of all the facilities shared by the North and South Works, target daily treatment capacity of the South Works increased from its current 364,000 cubic metres (m^3) to 550,000 m^3, an increase of over 50%.

During the construction period, the North Works will keep operation to ensure adequate fresh water supply to the joint water supply zone. All construction and site works must be fully planned during the reprovisioning of the South Works. In particular, it is crucial to consider the constraints of the site's layout and continuing operational requirements, particularly when the original plant site has already been fully utilised. The design and construction arrangements must account for these factors:

▶ The STWTW (South Works) concept plan after in-situ reprovisioning

In-situ Reprovisioning of the Sha Tin Water Treatment Works (South Works) - Preliminary Works Plan



Ensuring Normal Operations for the North Works

❶The original access road to the STWTW passes through the South Works before reaching the North Works. To ensure the North Works continues to operate normally during the South Works' reprovisioning, a new road leading to the North Works will be built at the site's northeast corner.

❷Prior to the demolition of the chemical house at the southern end of the current site, a new logistics centre for the treatment works will be built and opened to maintain the North Works operations.

Local Adaptation Design and Waste Reduction

❸The new South Works' flocculation tank, sedimentation tank and ozone building are designed to fit within the original four circular clarifiers. The original circular clarifiers are located about ten metres below ground level, allowing the existing topography to be used and avoiding extensive excavation and unnecessary backfilling.

❹The original South Works' administration and laboratory building comprises four levels and a basement. It will be rebuilt within the three original wash water recovery tanks to reduce excavation when constructing the new basement.

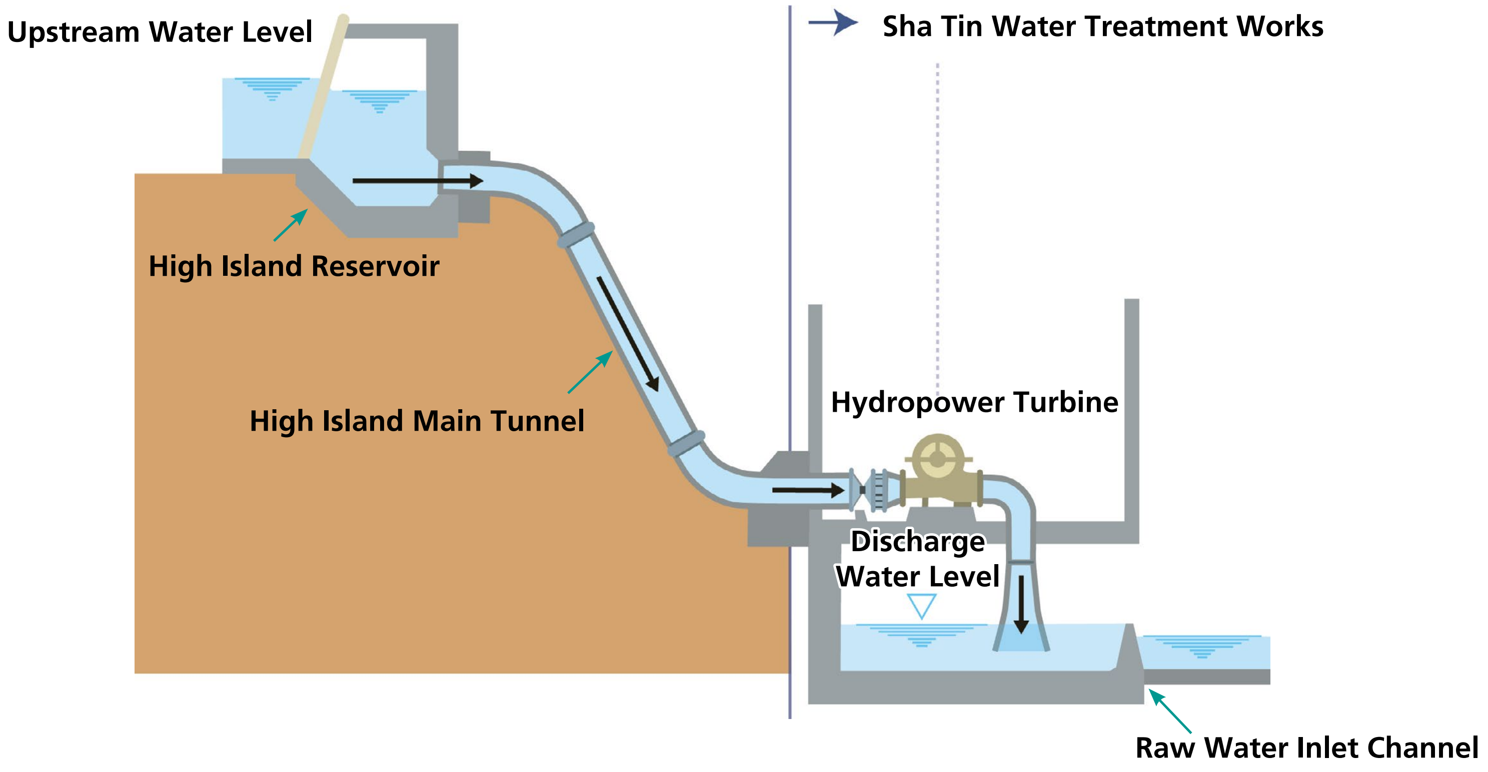
Innovation and Sustainable Development

Hydropower Generation

The STWTW is the second water treatment works in Hong Kong, after the Tuen Mun Water Treatment Works, to be equipped with a hydro-turbine for electricity generation. Due to the topographical level difference between High Island Reservoir and the STWTW, the hydropower station uses the raw water flowing down from High Island Reservoir to drive a generator, which converts surplus potential energy into electricity that can be fed into the power supply network of the water treatment works. This provides electricity for the plant's logistics centre, thus effectively use of renewable energy and reduce carbon emissions.

▲ The STWTW hydropower plant

Diagram of the principles of hydropower plant generation

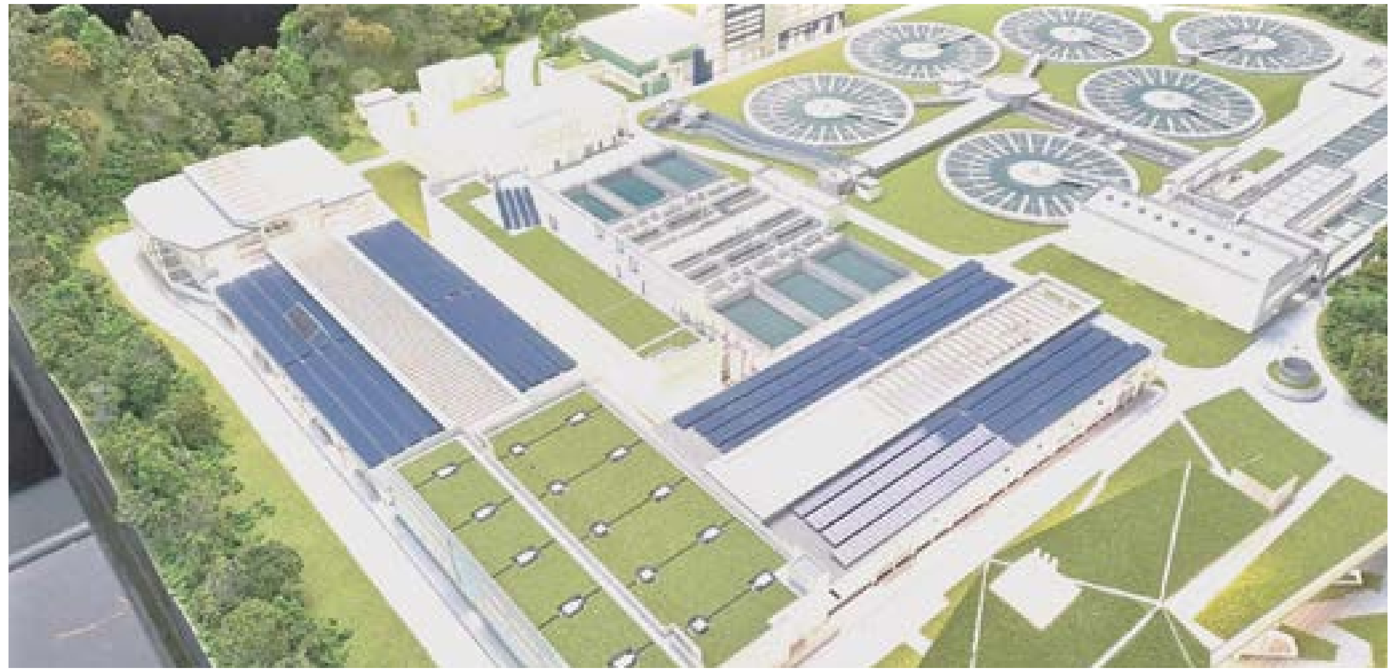


Solar Power System

Solar photovoltaic (PV) panels are installed at the ozone building's rooftop and on the roof of the filtration tank to generate electricity for the water treatment works facilities. The WSD will also explore the possibility of installing solar power systems to the rooftops of the remaining water treatment facilities to maximise energy efficiency.

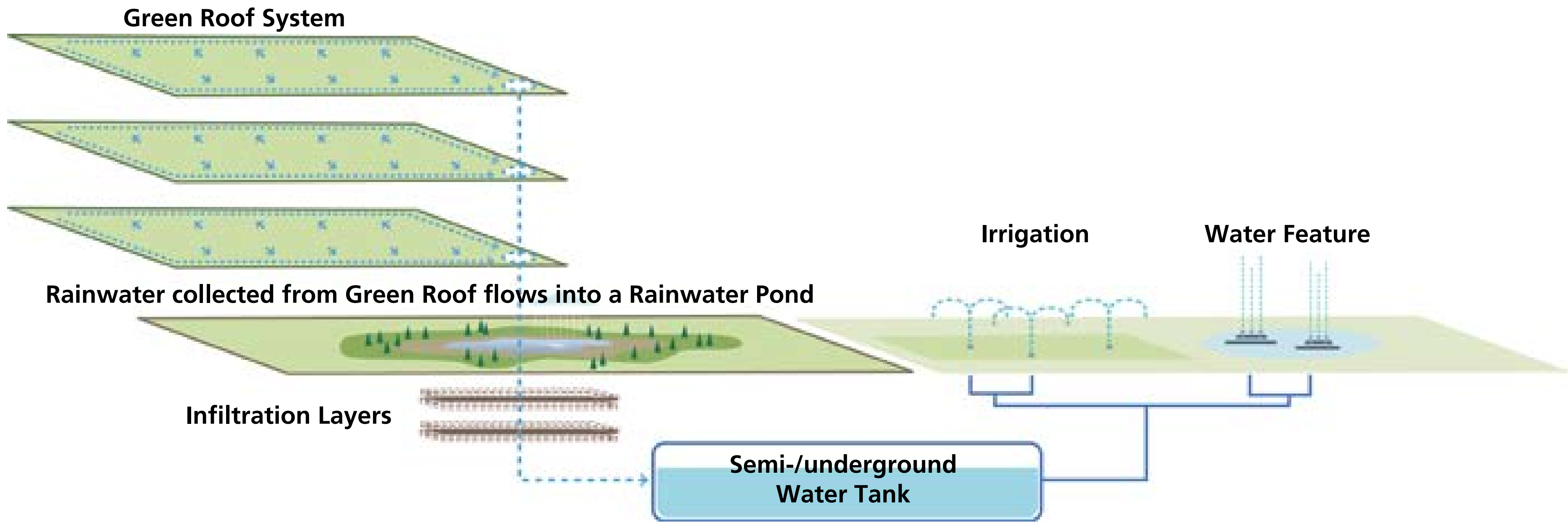
Green Roof and Rainwater Harvesting System

A rainwater harvesting system is installed in the water treatment works' administration building. The rainwater collected from these green roofs is filtered by activated carbon and disinfected by ultraviolet (UV) light stored in a water storage tank and used for irrigation and the site's water features. The tested water samples will be recovered through the recycling system, such that "zero effluent discharge" can be achieved for the entire water treatment process.



▲ Concept plan of solar power system

Diagram of the green roof and rainwater harvesting system



Old and New Water Treatment Technologies

The newly reprovisioned water treatment works will increase the efficiency and capacity of water treatment by replacing the current conventional 60 year-old technology with advanced water treatment processes and technology, which will use less land space and will enhance the reliability of water supply to meet the rising demand for fresh water and increasingly stringent water quality standards.

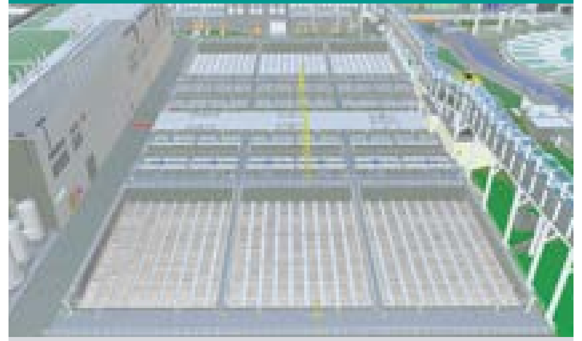
Clarification

Old

▲ Circular Solids Contact Clarifiers

The circular clarifiers are the signature feature of the STWTW. The South Works originally had four clarifiers, each was approximately 49 metres in diameter and 7.6 metres deep.

New



▲ High Rate Sedimentation Tanks

The new flocculation and sedimentation tanks utilise the advanced technology of high rate sedimentation to improve its efficiency. It significantly reduces the footprint of the treatment process unit. It will now treat 550,000 m^3 of raw water per day.

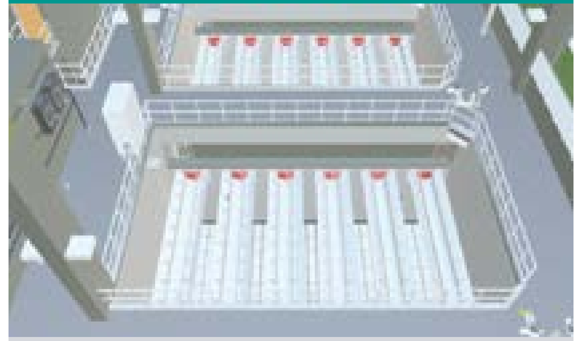
Filtration

Old

▲ Rapid Gravity Filters

The South Works has 22 rectangular rapid gravity filtration tanks, each with an area of 181.14 m^2 and a filtration rate of 8.365 metres per hour. The tanks are lined with two types of filtration media, quartz sand and anthracite, to eliminate fine suspended particles residues in the clarified water.

New



▲ Two-Stage Filtration Tanks

The refurbished water treatment works will feature a two-stage filtration to provide biological and granular deep bed filters. This process includes biological removal of ammonia nitrogen, which helps to reduce the amount of chlorine applied. Physical interception is subsequently employed to remove residual particles and purifies the water after biological treatment.

Water Disinfection

Old

▲ Chlorine Dosing System

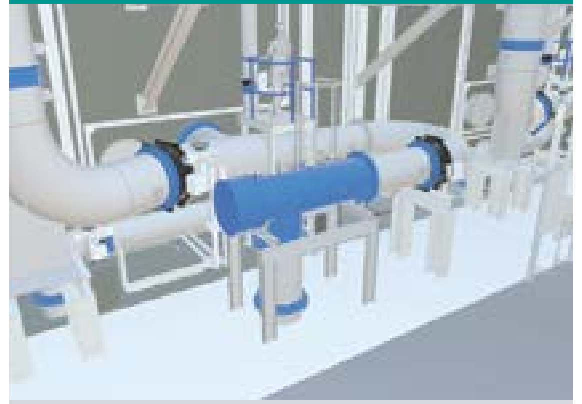
Chlorine is used for oxidation and disinfection at the South Works. The water treatment works has a chlorine storage room where chlorine drums containing liquid chlorine are stored. A chlorine evaporator raises the temperature of the liquid chlorine to a gaseous state and then delivers it to the water chlorination units.

New

▲ Ozone Disinfection

The ozone building will provide two-stage ozonation. Ozone is a potent disinfectant and oxidizer with a fast chemical reaction. It is effective in eliminating impurities that cause odour, and removing metals such as iron and manganese that cause a yellowish hue in the water. It also eradicates microorganisms and inhibits the growth of algae. Since ozone is produced on site, it is a safer alternative than transporting chlorine gas.

New



▲ UV Disinfection

The South Works of STWTW will be one of the water treatment plants using UV disinfection in water treatment processes. The UV disinfection facility is installed downstream of the filters. The filtration process can effectively kill 99.99% of pathogens, viruses and microorganisms, while reducing their activity and greatly enhancing the effectiveness of water filtration.

The Optimum Time to Start Reprovisioning

▲ Senior Engineer of the New Works Branch, Ir Horace NG Chou-keen, shares how he overcame the issues and challenges of reprovisioning the water treatment works on its original site

"Each individual team member is essential and valuable. Only by thoroughly applying every single person's knowledge, understanding and relevant experience can a task be fully accomplished - no matter the changing situations, considerable difficulties or unpredictable challenges that arise," Ir Horace NG Chou-keen, Senior Engineer of the New Works Branch, shares his experience of managing the STWTW reprovisioning project and the importance of a good work culture and ethics.

It was previously mentioned that the reprovisioning of STWTW is essential, and it was of utmost importance to ensure that the existing operation of the North Works and the associated water supply would be maintained. In fact, the planning for the reprovisioning of STWTW started some years earlier. It involved an overall review on the demand and supply of the entire joint water zone. This led to the earlier expansion of the Tai Po Water Treatment Works. When it came to the detailed design and construction stages for the new South Works, more robust and cautious considerations and assessment of the practical operations were required. This aims to achieve the seamless water supply transition from the existing North Works to the supply network of the South Works.

Ir NG explained that before demolition of the South Works structures, the common facilities of both the South and North Works must be isolated first. "As a comparison, the operation was simply like splitting the organs of conjoined twins. Among the shared facilities are five 1.5-metre diameter trunk water mains which are vital for transferring filtered water to the service reservoirs and water supply network. The STWTW serves a population of over two million people, so it is estimated that the supply of each trunk mains potentially affects the daily lives of households in a couple of hundreds thousands. This especially demonstrates how challenging and critical the scale of the diversion works would be implemented. The suspension, cutting and reconnection of water mains on such a large scale involves a series of comprehensive procedures, including: suspension of the STWTW pump operation, emptying the associated sections of water mains, cutting and welding of the new connecting pipe sections, and restarting of water pumps, etc. These procedures normally take several hours to complete.

The hours-long diversion operation at the site is only the tip of the iceberg, with the whole planning, preparation and coordination ahead of the diversion works being much more intensive. "To suspend the operation of the water treatment works for a few hours actually entails a series of detailed working procedures and a checklist to be followed the weeks before starting. We then had to coordinate with other water treatment works to temporarily increase their water supply, adjust the network of the water supply zones to cope with the situation, and fill up the potentially affected service reservoirs in advance to meet basic water supply demand during the shutdown. A fall-back was also arranged to temporarily supply water using water wagons if necessary. The entire deployment was so tight, even one mistake could lead to the failure of the whole operation with serious consequences," said Ir NG. With these considerations in mind and the careful implementation of each step by colleagues from different divisions, the focus quickly shifted to the final arrangements with frontline staff during the optimum work hours to minimise the impact to the public during the morning, afternoon and evening peak periods of water usage.

Ir NG recalled a potentially serious incident on Christmas Eve when the scheduled water suspension and diversion schedule were about to begin. While waiting for the operation to start and with dozens of staff from different divisions and engineering teams in place, the monitoring staff identified an abnormal drop in water pressure in the supply network. This was unexpected and immediately put stress on the entire plan and the capability of the work teams.

The problem implied a possible seepage or leakage in the water mains or connection points with a potential bursting risk. The original scheduled diversion scheme was immediately put on hold to implement the emergency plan to investigate the location of the suspected leak. This was achieved by comparing and analysing the pressure data while adjusting the water pump discharge, as well as the opening and closing of valves to trace and narrow down the potential location of the problematic section. It was followed by careful observation and excavation on site to confirm the location of the problem.

Ir NG outlines how they solved the issue, "We made use of the instant messaging group we had earlier set-up when planning the diversion works. Colleagues were then able to keep in close contact, as well as to disseminate the real-time information, such as water pressure, water levels, valve opening or closing conditions, and formulate action plan for different scenarios using the experience and knowledge of team members. You could feel the dedication of the whole team, all working closely to solve the problem and find the best solution of benefit to all. Suddenly, without any of us noticing, it was midnight on Christmas Eve! Collectively the group studied plans for every possible scenario and agreed that the repair, cutting and diversion works could still all be done if the leak could be identified before 2a.m. This would allow the work to be completed in one go and by the start of the morning peak demand period at around 6.30a.m."Although the leak was identified till at 3a.m., the main leakage was fortunately controllable. The team immediately stabilised the leaking pipe and maintained an adequate supply on the following day, while closely monitoring the situation and scheduling to complete the repair works on the following night when the water consumption is at its lowest. Despite a stressful night to locate and fix the leak, the spirit of the whole team remained high. During the Christmas holidays, the team continued reporting through the instant messaging group to ensure preparations remained on track.

Neighbours overlooking STWTW soon noticed the unusually brightly-lit water treatment works at night during the Christmas holidays and made telephone enquiries. Fortunately, the team were proud, but relaxed to advise that the necessary diversion works were successfully completed without disturbing everyone's Christmas celebrations.

Continuous Learning and Problem Solving Professionalism

There are 20 water treatment plants in Hong Kong and their useful life-span runs for more than 50 years. Opportunities to participate in the construction of new water treatment works are therefore rare. Ir NG, who majored in civil engineering at the university, had previously worked in the Highways Department and the Drainage Services Department before joining the WSD. Although there are similarities in the management of engineering projects between different departments, there are also significant differences in the required professional knowledge. For example, pipe networks look similar, however the discharge of drainage and sewage is mainly designed to fall by gravity without pressurisation, whereas the supply of treated water is achieved with pressure. Furthermore, the filtration and treatment of sewage and drinking water are very different in terms of purposes, technologies deployed and the processes and chemicals involved. As for the construction of roads, bridges and tunnels, these obviously require professional knowledge distinctly different from water services.

Ir NG joked that his water treatment knowledge still remained at the theory level, similar to university study without much practice. So, for his new role, he worked sleepless nights familiarising himself with project details by studying office files, emails, past records, documents, design calculations and standards, operation and maintenance manuals, and any relevant source of knowledge after first joining the department. He also took every opportunity to share and discuss with colleagues from other divisions and teams and through working meetings to grasp useful work knowledge and information.

Ir NG explains that having soft skills in project management is important and that, "In this era of artificial intelligence, when technology and machinery are gradually replacing many human tasks, the value of humans often lies in the ability to respond and perform, even under ever-changing and emergency situations by making decisive decisions using optimum solutions." He emphasised that, "The key to do this surely lies in a thorough understanding of the underlying theories, principles and content of each task. It is only when one has the relevant knowledge and actively learns from the experience of people in different positions that a task can be truly and well delivered; in particular, to achieve our fundamental mission of serving the public. You need to have the professionalism, attitude and ethics to do the right thing in engineering, if not all professions. I believe that when you work whole-heartedly and honestly without making shortcuts or bargaining, your colleagues and working partners, such as consultants and contractors, will show the same respect on projects and together try to achieve something great."

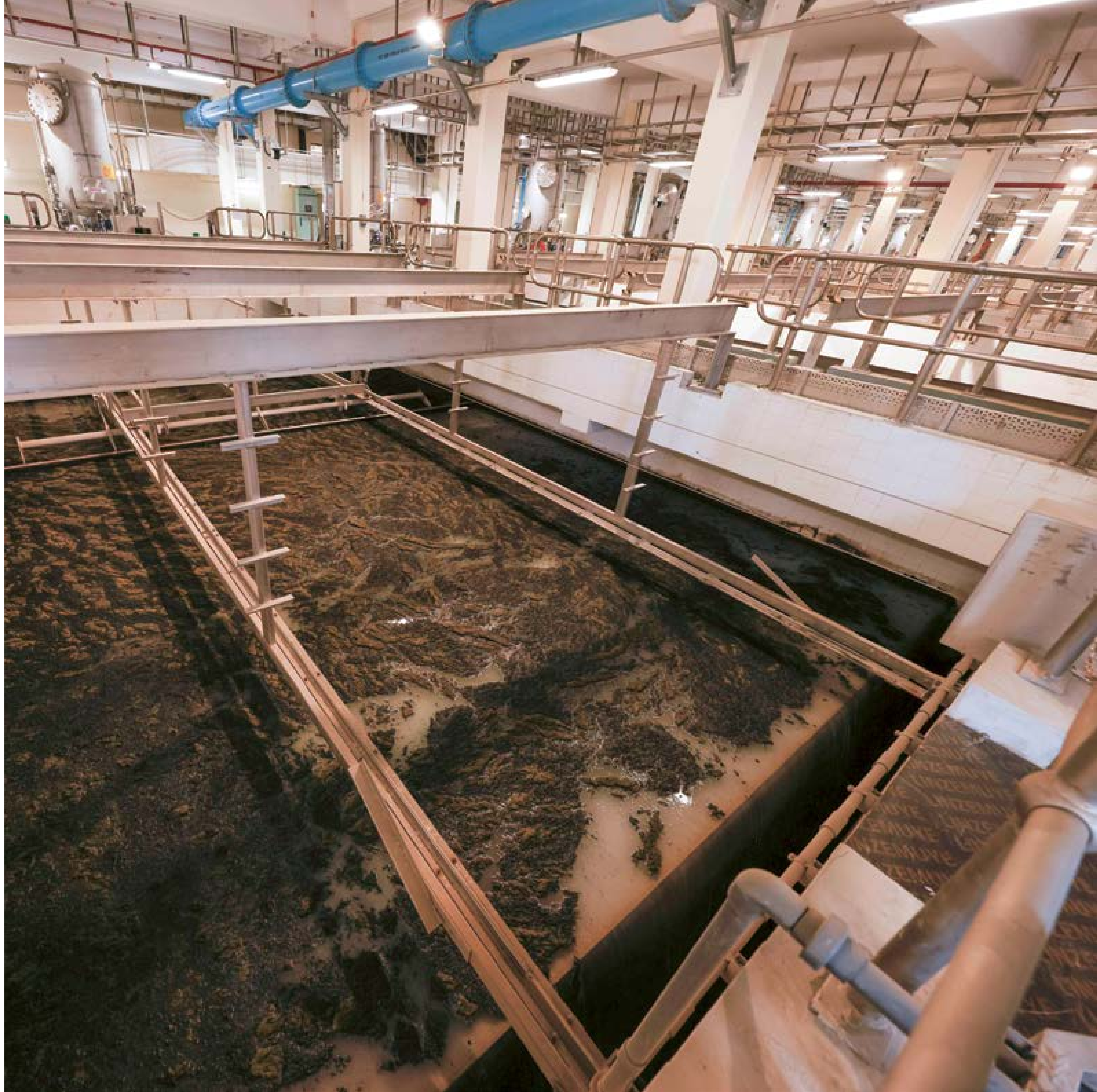
▲ New facilities for the wash water equalisation tanks, flocculation and sedimentation tank, as well as the ozone building, will be built on the site of the demolished chemical house.

The Expansion of Green Water Treatment Works - Tai Po Water Treatment Works

As the water treatment works operate continuously 24-hour a day, it is necessary to make well-thought-out plans for all new construction works to avoid any interruption to the usual water supply. The Sha Tin Water Treatment Works (STWTW) mentioned previously was specifically reprovisioned in-situ to reduce the impact of its expansion. Also, to ensure a continuous flow of fresh water supply during the suspension of the South Works of STWTW, the expansion works of Tai Po Water Treatment Works (TPWTW) commenced in 2013 to increase its output capacity from an average of 400,000 cubic metres (m^3) per day to 800,000 m^3 per day to meet growing water demand in Tai Po, Central and Western Kowloon, and the Central and Western District of Hong Kong Island.

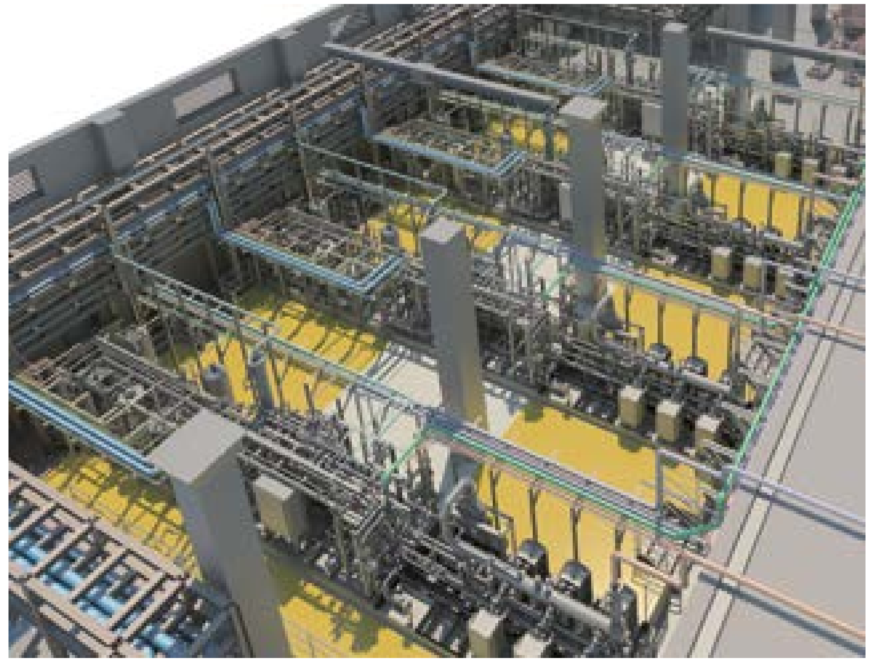
The expansion of TPWTW doubles its volume of treated water. However, the available site areas were very limited with hilly terrain. Careful planning and execution of the design and construction processes of the facilities are therefore required. Traditionally, water treatment plants in Hong Kong are single-storey buildings. However, due to the site's geographical constraints, TPWTW has adopted a multi-level building design to accommodate treatment facilities with a smaller footprint. An advanced dissolved air flotation technology has been chosen because the traditional sedimentation method requires a larger footprint and has a longer water treatment time. Dissolved air flotation is a clarification method that pumps compressed air into the water for producing a large quantity of micro air bubbles that adhere to suspended matter in water, creating a layer of sludge blanket. This layer is then removed by an automated sludge-scraper and by using this process, the water treatment rate is accelerated, allowing more raw water to be treated in a smaller plant. The introduction of this space-efficient design and new technology allows the facility to be reduced in size by 32% from the 20.5 hectares estimated at the investigation stage to its current 14 hectares. The project won the International Water Association Project Innovation Award in 2006.

At the time of completion of expansion, the TPWTW had the first large-scale on-site chlorine generation facility in Hong Kong. It was also the first occasion that the project team performed a hazard and operability analysis assessment using Building Information Modelling (BIM). This exercise made it possible to review and identify any issues at the design stage. Compared to conventional 2-D drawings, 3-D drawings allow for the visualisation of equipment and its surrounding space, whilst also helping simulate anomalies, reduce speculation and enhance project efficiency.



► TPWTW uses dissolved air flotation to remove impurities from the water

The expansion of the TPWTW also signifies the WSD's commitment to sustainable development while upgrading the water supply facilities in Hong Kong. Sustainable solutions were developed during the process, making it the first water treatment facility to attain the Final Platinum rating under the Building Environmental Assessment Method (BEAM) Plus. BEAM Plus is a Hong Kong-based certification for promoting green buildings in Hong Kong. It establishes a comprehensive set of performance criteria for a wide range of sustainability issues relating to the planning, design, construction, management, operation and maintenance of a building. The assessment results are recognised and certified by the Hong Kong Green Building Council.



▲ BIM is used to produce a 3-D plan for on-site chlorine gas generation at TPWTW

▲ The iconic vertical green wall in TPWTW

▲ Solar panels on the rooftop of the Dissolved Air Flotation Building

A number of unique elements have been incorporated into the expansion of TPWTW, with environmental protection solutions such as greening, energy and water conservation for both old and new buildings, including the following:

Zero Effluent Discharge

Effluent generated during the treatment process, such as the backwash water, water samples that have been tested for water quality, and rainwater harvested from the roof of the new building, can be used for irrigation and flushing purposes after appropriate treatment. Based on the average rainfall in 2015/16 and the estimated water consumption of the water treatment works, the amount of effluent collected from the TPWTW could provide 40,000 m³ of recycled water for the treatment works. TPWTW also collects water from filtration through a sludge press, which further reduces water loss and achieves a raw water conversion efficiency of 99.7%. With its outstanding performance in water use, TPWTW received full marks in all eight of the water scoring categories.

Optimising the Use of Sludge from Water Treatment Works

The sludge generated during the treatment process has its water removed and is turned into sludge cake for disposal at landfills. After the expansion, the volume of sludge generated at TPWTW has doubled. To optimise the use of the sludge, the project team commissioned universities to conduct feasibility studies on the reuse of the sludge. The study found that the sludge contains certain nutrients and can improve the pH value of soil, thus helping to improve soil quality. The sludge generated from the treatment works, together with the remaining 0.3% of raw water, has been used for greening and planting within the treatment works.

Renewable Energy Technology

The TPWTW has installed 693 solar panels, each measuring about 1.6 m². These can generate about 260,000 kilowatts of electricity annually, which is sufficient to provide about 3% of the daily energy demands for the operation of the water treatment works.

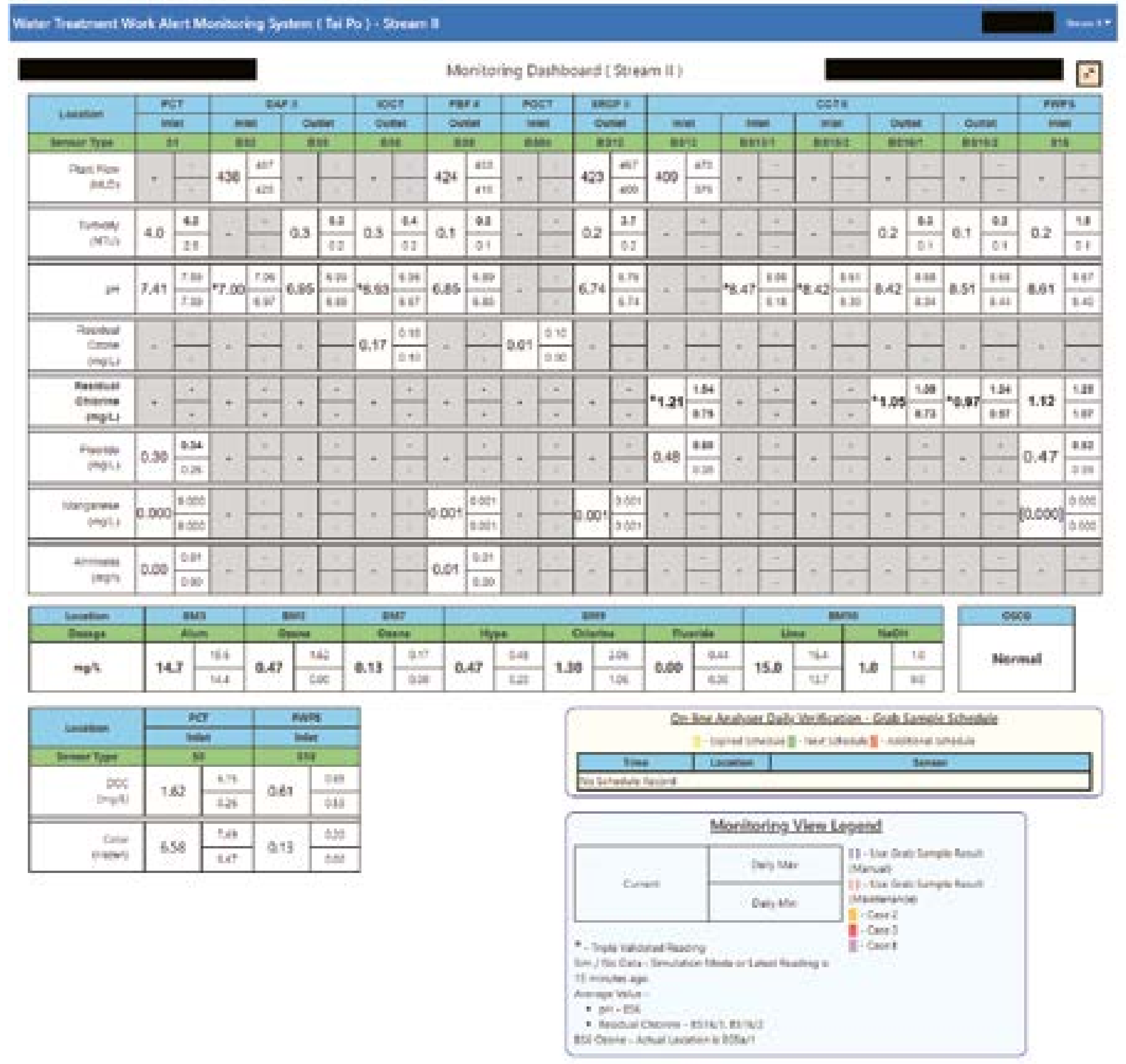
Research and Development of Automated Water Treatment Monitoring

Application of information technology is a global trend. While water treatment is a complicated process, its increasing complexity warrants consideration of automated technology to enhance efficiency, long-term stability and sustainability. Experienced chemists possess professional judgement in water quality monitoring, so, in recent years, the Water Science Division of the WSD has been endeavouring to build from chemists' knowledge and experience to gradually develop scientific and technological systems for automating more processes. This will give the water quality control process greater intelligence, and enable swifter and smarter decision-making and responses.

Water treatment works treat raw water to meet quality requirements at different stages and finally produce drinking water that is in full compliance with the Hong Kong Drinking Water Standards before supplying to the customers. The water treatment process involves monitoring of nearly 100 parameters. Currently, the water treatment works use electronic sensors to collect the required monitoring data and these are all simultaneously transmitted to the control room for overview by waterworks staff with real-time information on screens. The system is designed to set different levels of upper and lower limit indicators for each parameter. When the parameter value exceeds any limit, different alarms from the system will be triggered to alert waterworks staff for follow-up action. Apart from electronic water quality sensors, water samples are also tested manually at regular intervals to verify the accuracy of the online water quality data.

System Advancement and Automation

Given the multitude of parameters and variables involved at different treatment stages, coupled with the need to adjust chemical dosages to process water quality, the Water Science Division has spent three years to develop its own "Integrated Treatment Information & Tele-Alert System (INTEL)", which incorporates various Internet of Things (IoT) technologies and automation techniques, including Optical Character Recognition (OCR) technology, which simplifies the manual data entry process by waterworks staff when reviewing data. This not only reduces human error, but also automatically collects and consolidates data for simultaneous verification. In the event of water quality changes, the system will immediately alert personnel with the latest information electronically, allowing remote access to data at any time for timely responses. Given the vast physical area and limited manpower in water treatment works facilities, the development of information technology to enable remote control and automation of the system ushers in a new era of waterworks operation.



▲ Real-time data on all the parameters will be displayed in the "Integrated Treatment Information & Tele-Alert System" (INTEL)

Senior Waterworks Chemist, TANG Ki-lai, who was involved in the development of the new system, explains that there are numerous monitoring parameters and data in the operation of water treatment works. Traditional monitoring systems rely on the duty staff to screen and analyse the data. When an alert is raised, staff workload will be stretched, and if it turns out to be a false alarm, manpower will be wasted. He explains, "In fact, the exceedance of parameters is a general trigger. In particular, the extent and duration of parameters exceeding the requirements, their occurrence at different stages, and the underlying reasons, all impact treated water quality differently, necessitating varied response measures and intensities." Consequently, the water monitoring team began researching ways to improve the system by introducing Artificial Intelligence (AI) technology. Gradually, they transferred the chemists' practical experience into hierarchical and computer-recognised instructions, thus enriching the system's analytical and responsive capabilities.

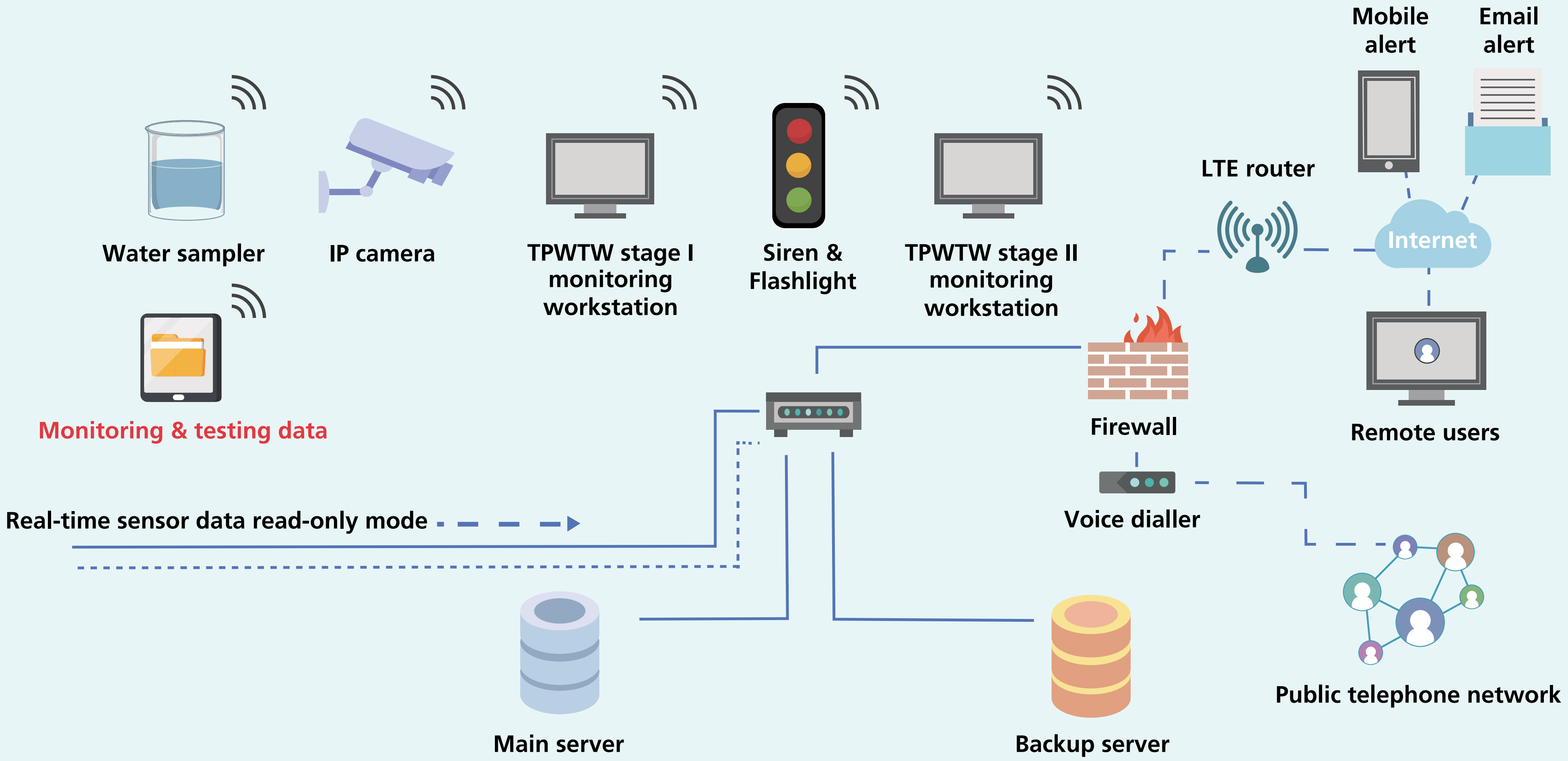
▲ Senior Waterworks Chemist, TANG Ki-lai says the introduction of artificial intelligence into the monitoring system would improve the system's analytical capabilities.

The WSD is responsible for 99.9% of Hong Kong's drinking water supply, making its water quality monitoring expertise unparalleled. Therefore, during the research and development of new systems, knowledge was transferred and shared, making the best use of technology by integrating the information and experience from people from different ranks and fields.

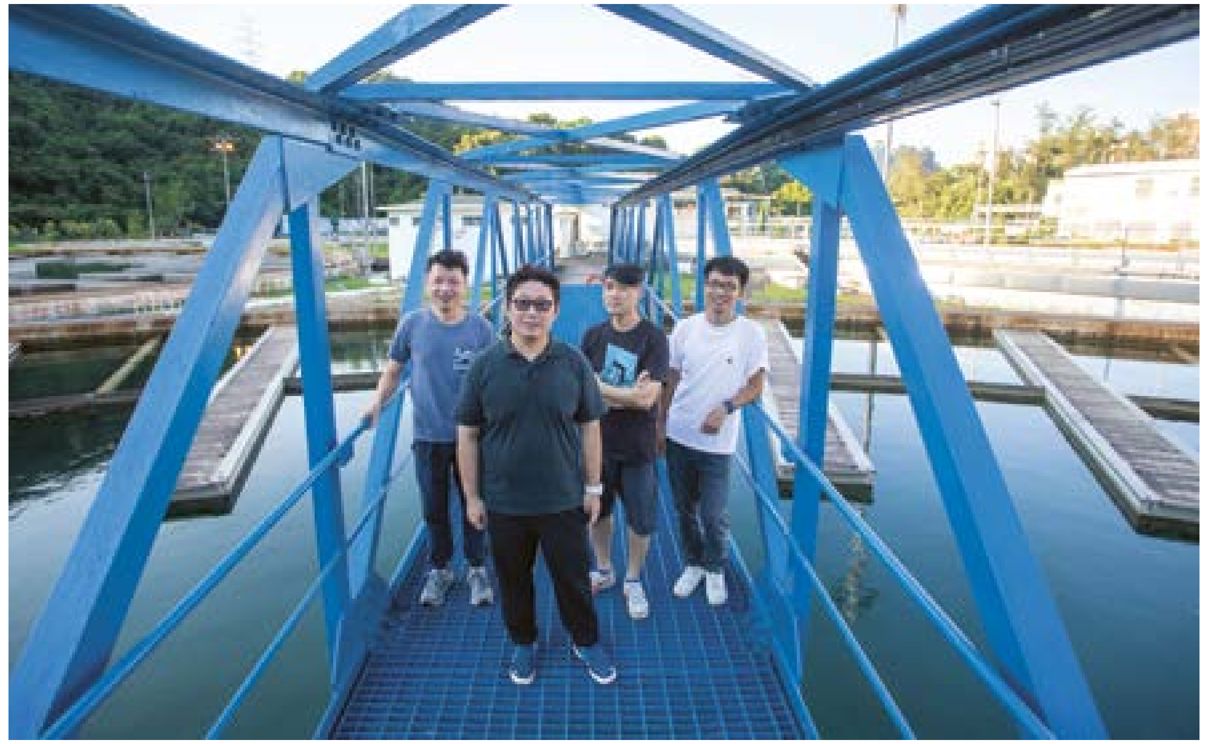
Tang says that the water quality monitoring system is now moving into a new phase of three-dimensional virtual reality. In recent years, the construction industry has also moved into a new technological era, with design of development projects being presented in Building Information Modelling (BIM). The system can be described as a 3-D image of design drawings that gives even non-professionals a glimpse of any uncompleted project." The recent design and expansion of water treatment works, such as the Stream II of Tai Po Water Treatment Works, the South Works of Sha Tin Water Treatment Works and the Tseung Kwan O Desalination Plant, have already been developed using 3-D image-building models. Ways to integrate the water quality monitoring system into the models is now being explored. This will allow the sensor readings to be displayed directly at the corresponding locations in the virtual model, providing an overview of the data and facilitating monitoring and tracking by the water monitoring operators.

The waterworks staff are integrating, on an as-needed basis, various types of popular information technology into "Digital Twin", which is a recent modular application proposed by the technology industry. It is a virtual model presenting a physical system in a one-stop information platform, like a twin in the digital world. (Please refer to the article "Digital Twin Technology to Enhance Water Supply Management" in Chapter 3 for more information on how digital twin technology can be applied in water services.)

Conceptual Plan of the INTEL System at the Water Treatment Works



Water Treatment Works Crisis Management



▲ TANG Cho-fung, the STWTW Plant Manager, says the plant's raw water sources are the most complex amongst all the treatment plants.

A water treatment works receives raw water, turning it into potable water ready for consumption from the tap. Treated water involves a series of processes and tests, and each stage is interdependent. The Sha Tin Water Treatment Works (STWTW) has the largest daily treatment capacity in Hong Kong and is typical of the city's treatment facilities whose uninterrupted operation requires many supporting facilities as well as the collaboration of frontline staff. "The personnel responsible for daily operations always respond to the ever-changing situations," says TANG Cho-fung, the STWTW Plant Manager.

The raw water sources for STWTW are more complex than other water treatment works. Apart from receiving Dongjiang water and raw water from reservoirs, the STWTW also receives rainwater during typhoons and heavy storms. This rainwater is collected through rainwater interception tunnels and vertical shafts between Tai Po and Sha Tin. Previously, when water resources were scarce, they had been built to collect as much rainwater as possible. TANG points out that rainwater typically contains sediments; without having time to settle these sediments remain in the raw water making it turbid. The water quality of recently fallen rainwater is normally not satisfactory and requires extra water treatment. Irrespective of the quality of the raw water, the requirements for treated water quality remain unchanged, reiterating the importance of the water treatment process.

Raw water quality is highly variable in the rainy season, so the operations of the treatment works must be very adaptable to water quality conditions. "Apart from weather forecasting, there is little preparation possible. The quality of the raw water can only be determined through real-time data at the time it is received," explains TANG. In fact, staff at the water treatment works conduct jar tests on every shift. The method involves adding varying amounts of alum to a number of test jars containing raw water samples to determine the optimum flocculation dose. According to Waterworks Chemist CHAN Yuk-chi, if there is an increase in turbidity during rainstorms or a change in the ratio of raw water sources, staff from the laboratory and water treatment works will conduct jar tests more frequently to determine the optimal alum dosage.

Before the current reprovisioning of the STWTW South Works, the STWTW accounted for about a quarter of Hong Kong's total daily production, supplying water to Sha Tin as well as central Kowloon and Hong Kong Island[1]. On top of that, STWTW needs to be on-standby to give emergency support. Maintaining continual water output is crucial, placing an immense burden on frontline workers. TANG states that due to the lower electricity tariff at night, STWTW would activate extra pumps between 9p.m. to 9a.m. daily to increase its capacity. This increased activity puts additional strain on equipment and increases the possibility of breakdowns.

Functioning at the heart of STWTW, the water treatment works' six large pumps transfer treated water from the plant to Kowloon through the Lion Rock Tunnel. A separate electricity substation drives these large motors within the works premises. TANG said that the electricity supply was very stable, but there had been a temporary power outage on one occasion, "The first thing we had to do was to close the gate valve for the intake of raw water. If the raw water had kept coming in while the output of treated water was halted, the system would be in trouble during the emergency repair. The gate valve is operated by electricity, so during the power failure we immediately mobilised six or seven staff to take turns to manually close the gate valve. It took thousands of turns to finally close the gate valve."

▲ Waterworks Chemist CHAN Yuk-chi says that during heavy rainfall, they sometimes require conducting three jars tests in one night.

▲ The chemist determine the alum dosage in raw water through jar tests.

1 Prior to the recent reprovisioning, the STWTW had a design capacity of 1.227 million cubic metres (mcm). The 20 water treatment works in Hong Kong have a combined capacity of 4.68 mcm per day.

Familiarity with Systems to Prepare for Crises

In recent years, many water treatment and water quality monitoring processes in the plant have become automated. To ensure gauges are issuing accurate measurements, it is essential to monitor and maintain the system. “From raw water, flocculated water, sedimented water, filtered water to drinking water, each stage of the water treatment process is equipped with water quality monitoring sensors. When we notice abnormal data, we have to find what is going on. What components or machinery are at fault? What treatment processes will be affected later on? The automatic monitoring system gives us a clue. But, it is up to our colleagues to decide how to remedy the situation,” says TANG.

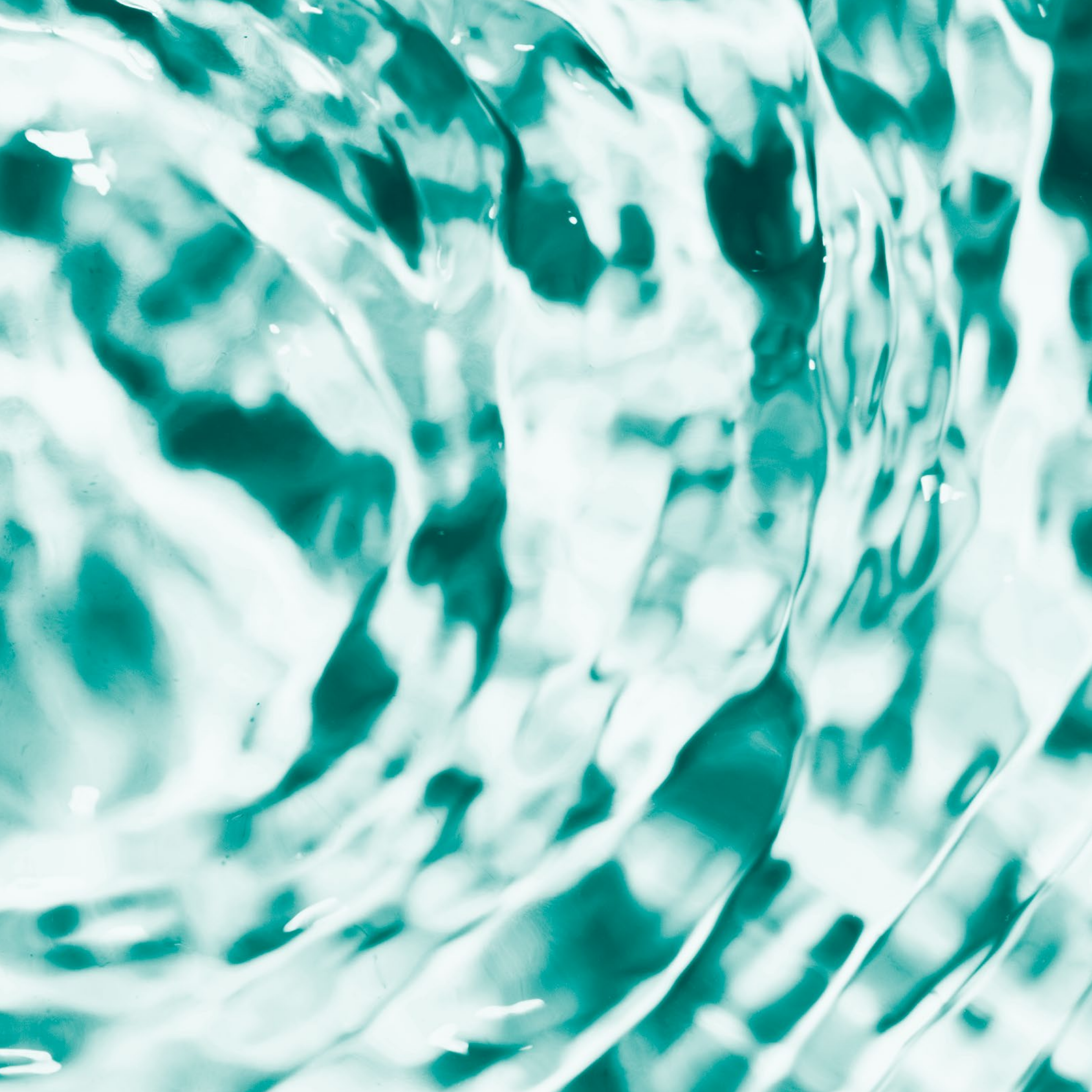
While STWTW has undergone the reprovisioning of the South Works, challenges arising from the transition from the old to the new facilities is inevitable. Normally, the pH level of treated water is adjusted between 8.2 and 8.8 by dosing hydrated lime before output. When the readings show an increase in the turbidity of the treated water, operators know something is wrong. "There was once a partial mechanical failure in the chemical house that resulted in overdosing of hydrated lime to the treated water, hence the turbidity of treated water increase. By then, the treated water had already been delivered to the pump and was ready to be supplied to the service reservoirs for delivery to consumers," revealed TANG.

To handle the situation, the frontline staff promptly implemented emergency measures to prevent the affected water from reaching consumers. Fortunately, a nearby service reservoir was undergoing maintenance and could be utilised. With the collaborative efforts of colleagues, the team closed individual valves to create a separate waterway, eventually isolated and temporarily stored the affected water in the service reservoir. Simultaneously, while the water treatment facilities had handled the affected water, staff had to also swiftly clean the facilities in the shortest possible time before restoring regular services. "We noticed the water level in the local fresh water supply reservoirs was dropping, so we had to speed-up the treatment process to meet the water demands in the area. There was hardly time to make a decision and deal with the problem," says TANG. To avoid similar incidents in the future, the water treatment works has reviewed its operating procedures and engaged a consultant to design a programme that monitors the thickness of the hydrated lime layer in the hydrated lime water to prevent any build-up or dispersion.

Every crisis offers an opportunity to enhance the system. Frontline personnel are able to quickly identify and rectify problems due to their familiarity with the design principles and daily operations of water treatment works. It is this daily appraisal approach that is instrumental in forming and strengthening management expertise.

3

WATER DISTRIBUTION



Behind the Tap -
an Invisible Water Distribution Network

Living near water is natural for humans; and access to a new water source must be found whenever relocation of living place. Similarly, as humans increasingly lived in urban areas, water distribution systems developed in line with the expansion of cities.

The history of water distribution network date back to the Bronze Age, around the mid-3000s B.C., with one famous example being Mohenjo-daro in the present-day province of Sindh, Pakistan. It was an important ancient Indian civilization and city, famous for its sophisticated urban infrastructure and planning. With a population of around 40,000, the city had a well-developed water distribution and drainage system, including a network of more than 700 freshwater wells distributed throughout its neighbourhoods. In addition to supplying water for domestic needs, the water supply was sufficient to support utilities that consume heavy amounts of water, such as public bathhouses.

The basic principles of water distribution have remained unchanged since ancient times. But, its application in different cities has resulted in various designs that consider particular factors, such as topography, hydrology, and geological conditions. Key examples include: Roman aqueducts supported by multiple arches across valleys or plains; and, the qanat in the dry Xinjiang region, where water is diverted by culverts from the snowmelt of mountains into wells.

Ancient hydraulic engineering was founded on experience, however, as ancient civilizations declined, so did engineering knowledge, causing a regression for primitive water supplies built during the Middle Ages. As such, water was mainly collected at central water points by human labour, such as by traders, slaves or users themselves. Progressing into the Renaissance, scientists began to discover the natural laws and principles of hydrology through observation and experimentation. As a result, waterworks engineering design became more precise and accurate over time.

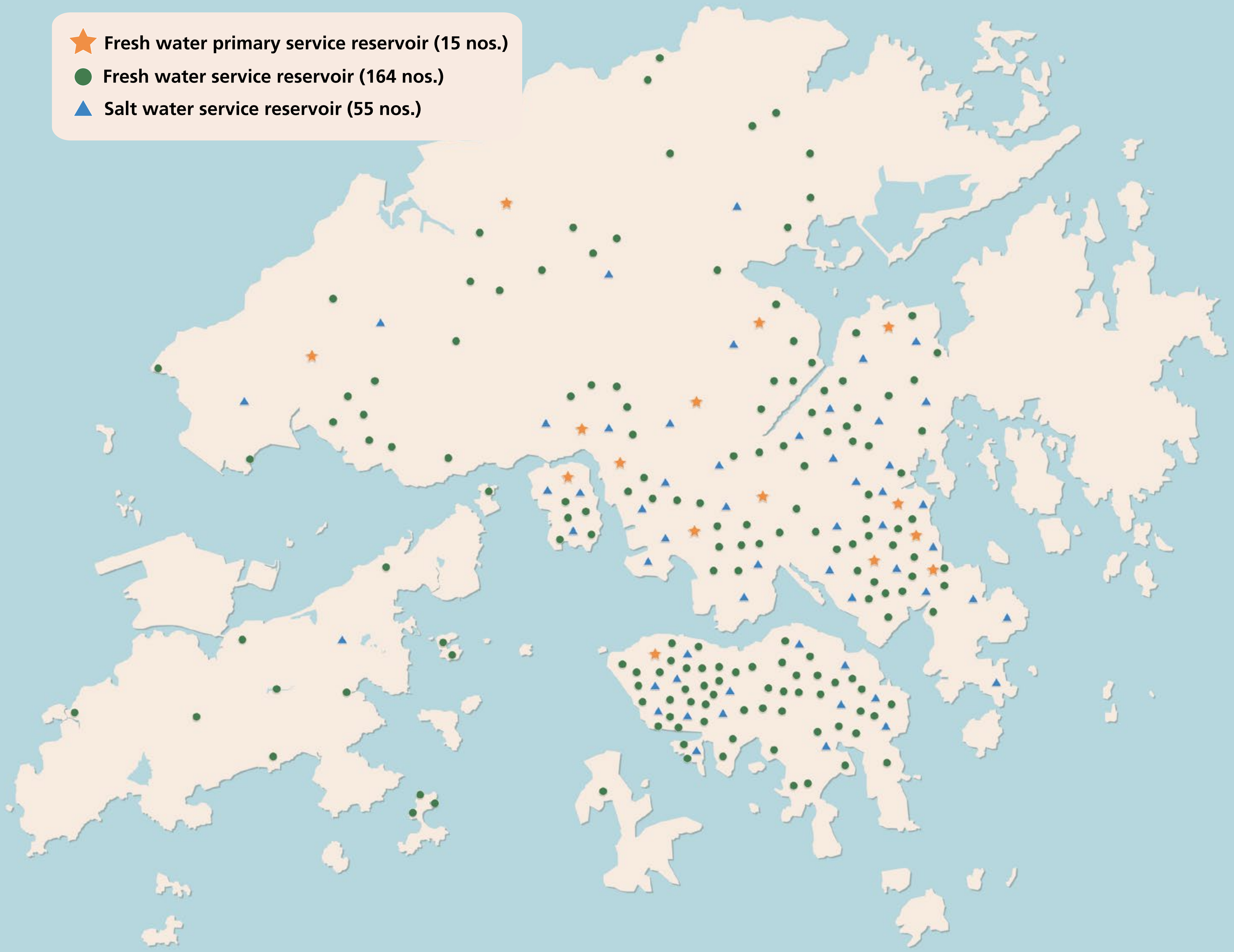
Hong Kong's water distribution network began in the second half of the 19th century. Due to its rugged topography, a lack of flat land for development, and the subsequent development of both sides of Hong Kong harbour, the city's water distribution network was developed in a distinct manner. Riding on the advantage of gravity flow, the network is designed to overcome constraints presented by the different heights of the urban land development areas, and the separation of Hong Kong and Kowloon by the harbour. Consequently, the water distribution network straddles across mountains and sea, making the construction of all water network infrastructure complicated.

The preceding chapter explains the fundamental principles and methodologies employed in water treatment in Hong Kong, along with the progress and advancements that have occurred over time. This chapter will concentrate on the water distribution system, that is, the method of distributing treated water. With urban development, the water distribution system in Hong Kong has significantly expanded and is a complex undertaking. The Government of the Hong Kong Special Administrative Region has been progressing towards smart city and sustainable water use policies in recent years. For a dense city looking towards the future, ensuring a leak-free water pipeline network has also become a challenge.

◀ The Dongjiang water mains in Sheung Shui

▲ Hong Kong's development areas are of different heights

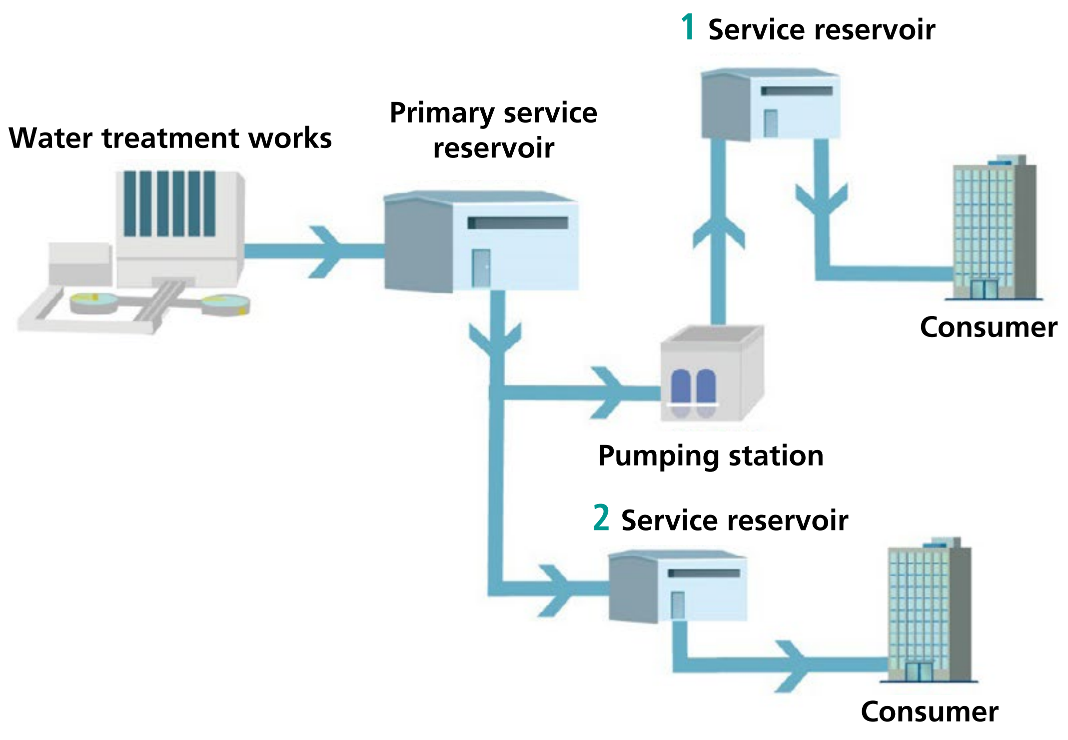
Distribution Map of Service Reservoirs in Hong Kong



The Principles Behind Hong Kong's Unique Drinking Water Distribution Systems

A water distribution system is the link between a water treatment works and its consumers. Comprising a network of pipes, service reservoirs, pumping stations, valves, etc. Hong Kong's drinking water distribution network resembles the blood vessels of the human body, with pumping stations serving as the heart to facilitate the flow of water when needed. A service reservoir serves as a temporary storage area for treated water. Currently, there are 179 fresh water service reservoirs in Hong Kong, comprising 15 primary and 164 secondary fresh water service reservoirs. Drinking water, which is temporarily stored, is then distributed to consumers through fresh water mains, totalling a length of around 6,700 km.

Schematic Diadram of Hong Kong's Drinking Water Distribution System



1	Using pumping stations to transfer drinking water to higher-ground service reservoirs and supply users in upland areas
2	Using gravity flow to transfer drinking water to service reservoirs to supply users in lowland areas

Water Pressure at the Heart of Water Distribution

The growth of Hong Kong's drinking water supply network reflects the city's urbanisation, starting with Hong Kong Island, expanding to Kowloon, and finally reaching the New Territories. Hong Kong has rugged terrain with limited flat areas. In addition to land reclamation, the upward expansion of development areas has necessitated building service reservoirs at higher elevations. Consequently, Hong Kong has established a drinking water distribution system with an unusually high average water pressure, a rarity around the globe.

Before reviewing the development of the water distribution network in Hong Kong, it is necessary to understand the fundamental concept underlying any water supply system: **Water Pressure**.

Water pressure is the force that drives the flow of water, achieved through the gravitational potential energy of incoming water or by pumping. The water distribution system therefore applies both methods to create water pressure.

Gravity flow relies on the difference in height between the water supply facility and the water supply zone, causing water to move downwards under the force of gravity and pressure as so generated. The greater the difference in height, the higher the pressure. In Hong Kong, most urban areas are situated on hills. If water were to flow solely based on gravity, the pressure variation would be too substantial to accommodate users at different elevations. Consumers located at higher elevations may face insufficient water pressure, while areas situated at lower levels may experience high water pressure that could damage pipes, causing them to burst or leak and affect their durability.

Water pumps are powered by a dynamic machine that applies pressure to water. As this pressure rises above the force of gravity, it allows water to flow upwards from a low level to a higher level. In the past, most pumping stations used fixed-speed pumps with only two on/off settings. When retained water in a service reservoir starts to decrease, the pump will reactivate and water is pumped to a service reservoir for replenishment.

Use of Gravitational Flow in Water Distribution

Whenever possible, optimisation the use of gravity is the main principle for drinking water distribution in Hong Kong. If this is not applicable, pumping stations are used to convey water to its destination. As a result, the primary service reservoir is usually situated at a higher elevation feeding service reservoirs at varying other heights, aligned with the corresponding fresh water supply zones. This will more effectively regulate water pressure, reduce energy consumption and act as a buffer for fresh water storage when required.

The Early Development of Hong Kong's Drinking Water Distribution Network

In the past, developed urban areas tended to be situated either on the waterfront or at the foot of hills, with steeper hills behind them. Consequently, water distribution was based on constructing water storage facilities on the highland outskirts of these development zones. By utilising gravity, drinking water could then be distributed to customers through the water supply network of different localities.

The Pok Fu Lam Reservoir was completed in 1863. To address the needs of water supply and firefighting, the government established water supply points throughout the city and the water supply network was then developed. Water collected from the Pok Fu Lam Reservoir was redirected by gravity to Tanks No. 1 and No. 2 located near Bonham Road. From there, the water was transmitted through water pipes to 30 standpipes and 125 fire hydrants in the city. The Pok Fu Lam Reservoir primarily served Sai Ying Pun, Sheung Wan and Central as well as Wan Chai. As the city of Victoria's population grew, it became obvious that the number of standpipes was inadequate. Consequently, fire hydrants also stood-in as public standpipes.

Residents were able to obtain water from standpipes at no cost, or they could submit an application for the supply of tap water. In 1860, the government introduced the Water Supply Ordinance, which stipulated that rates paid by leaseholders would be the main source of funding for the continuing development of water services. As this was a public service cost, it was tied to a property's rental value rather than the volume of water utilised. Rates for the type of housing and its location varied. In the early years, there was a dual system of free and paid water supply on Hong Kong Island. At one point, water supply to paying consumers was disrupted by free water flowing from standpipes.

It was not until the Tai Tam water supply system was built that a relatively complete design was developed for the city. This design incorporated a treatment process as well as a service reservoir for storing treated water. The Albany Fresh Water Service Reservoir (completed in 1888-89), located halfway up the hill in Central, was built in conjunction with the Albany Filter Beds. Situated at approximately 121 metres above Hong Kong Principal Datum (mHKPD), this facility was high enough to provide water pressure for 90% of the homes in the city of Victoria. However, due to the limitations of gravity from the reservoir at that time, the water distribution network did not cover The Peak area and its residents had to rely on wells as their main source of water.

#Fun Fact

The Largest Water Pumps in Hong Kong

The largest pumps in Hong Kong can be categorised in two ways: by the volume of water pumped, or, by its maximum head. The largest pump by volume conveys Dongjiang water to reservoirs, with a daily capacity of more than 320,000 cubic metres of raw water; while the latter is the large pump on Hong Kong Island supplying water to The Peak, with water pressure that allows water to rise more than 480 metres in one go.

District Planning of Water Distribution

Later to enhance water distribution, the Public Works Department, following the advice from Sir Osbert CHADWICK, Consulting Engineer to the Crown Agents, erected pumping stations at Garden Road, Arbuthnot Road, and Bonham Road. These facilities alleviated the limitations of gravity and made it possible to supply fresh water to residential areas from Caine Road to The Peak[1]. However, the water supply to The Peak was unreliable and disrupted whenever the pumping station at Bonham Road was not working or required maintenance. To address this issue, Francis Alfred COOPER, the then-Director of Public Works, suggested to construct a covered service reservoir to store a 10-day supply of water for the whole area. The resulting Peak Fresh Water Service Reservoir, located at the elevation of 533 mHKPD, serves as the highest service reservoir on Hong Kong Island. It is one of five remaining reservoirs that have been in operation for over a century.

CHADWICK proposed dividing the city of Victoria[2] into three water supply zones based on ground elevation - upper, middle and lower - to reduce the height distance and relieve water pressure in the lower water supply zone. This zoning of water distribution according to height also laid the foundation for the water distribution model for the whole of Hong Kong.

The Implementation of a "User-pays" Principle

As the urban development of Kowloon was started later, the government was able to establish a centralised water supply system and introduce a charging policy at the earliest planning stages. A modern water supply network began to take shape and regulations on water charging using water meters were passed two years after the first water supply system in Kowloon was completed in 1895. With the introduction of water meters and a consumption-based charging system, water wastage in Kowloon was reduced. For supplies on Hong Kong Island, the ordinance was amended in 1902 to authorise the installation of water meters throughout the territory. Initially, the purpose was to minimise water wastage. However, due to strong resistance to charging, the government opted for a rider main system instead, requiring owners and residents to install a separate water mains with a regulator valve to be switched-off from the distribution mains. This came at the expense of the owners and residents, and owners paid a quarterly water service levy as a fixed charge. The rider mains system operated until 1932, when it fell into disrepair and owners were reluctant to pay for its repair. The government then amended the ordinance to abolish the system and implement a meters and charges system. Since then, the "user-pays" principle has been in effect for Hong Kong's water supply services.

1 Francis A. Cooper. (1896). Report on the Water Supply of the City of Victoria and Hillside District, Hong Kong, *Sessional Papers for the Year 1896*. Hong Kong: 251

2 The city of Victoria refers to what is now Western, Sheung Wan, Central and Wan Chai on Hong Kong Island. It was the first area to be developed in Hong Kong and has been the seat of government and its business and financial centre.

▲ The first submarine pipeline in Hong Kong was completed in 1930

Development and Improvement of the City's Drinking Water Distribution Network

As Hong Kong progressed, the drinking water distribution network expanded further, spanning hills and crossing Victoria Harbour. Hong Kong has over 260 outlying islands, and many are inhabited. The first cross-harbour pipeline was laid in 1930 to supply water from the Kowloon Reception Reservoir to the densely populated Hong Kong Island. Today, the cross-harbour water mains connecting Kowloon and Lantau Island account for 90% of Hong Kong Island's water supply.

The drinking water supply system in Hong Kong currently covers 99.9% of the population and as new development areas open, the drinking water distribution network also expands. When the New Works Branch of the Water Supplies Department (WSD) carries out mainlaying projects in new development areas, it essentially extends the existing water distribution network. Consequently, it is vital to assess various factors, including: the water supply reservoir and treatment works from which the water is sourced, the existing treatment capacity of the water treatment works and the estimated water consumption for fire-fighting. Prior to commencement of any project, the WSD staff undertakes thorough studies and intricate designs, involving scrutinising water mains alignments, investigating land conditions and conducting impact assessments on the traffic, drainage and environment.

In developed regions, the water distribution system is optimised to accommodate different conditions, such as small villages or housing developments, where some buildings are situated at higher elevations and can no longer be supplied by gravity flow from the original service reservoirs. Additionally, some remote villages, which formerly relied on mountain waters, must now seek drinking water supply from the government as rivers have dried-up. The WSD will expand the current distribution network based on situational assessments.

Zoned Layout of Distribution Network

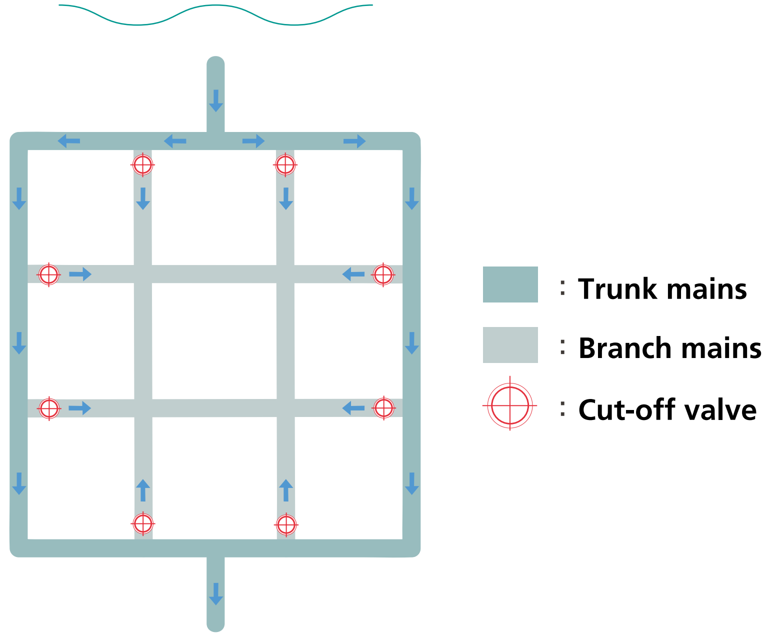
The drinking water supply network in Hong Kong is typically segmented into various water supply zones, based on factors such as population density and topography. These zones can function either independently or be interconnected. In each district, the distribution system's structure generally falls into three categories: the dead-end system, grid-line system and ring system. The choice among these options will depend on the specific situation. The first two distribution networks can be found in previously developed areas, whereas the ring-type system is utilised in Hong Kong. In this case, trunk mains form a ring around the water supply zone, while other branch mains are cross-connected and interconnected with the trunk mains to ensure reliability. This arrangement allows for maximum water supply to each block and is best suited for cities with well-planned streets.

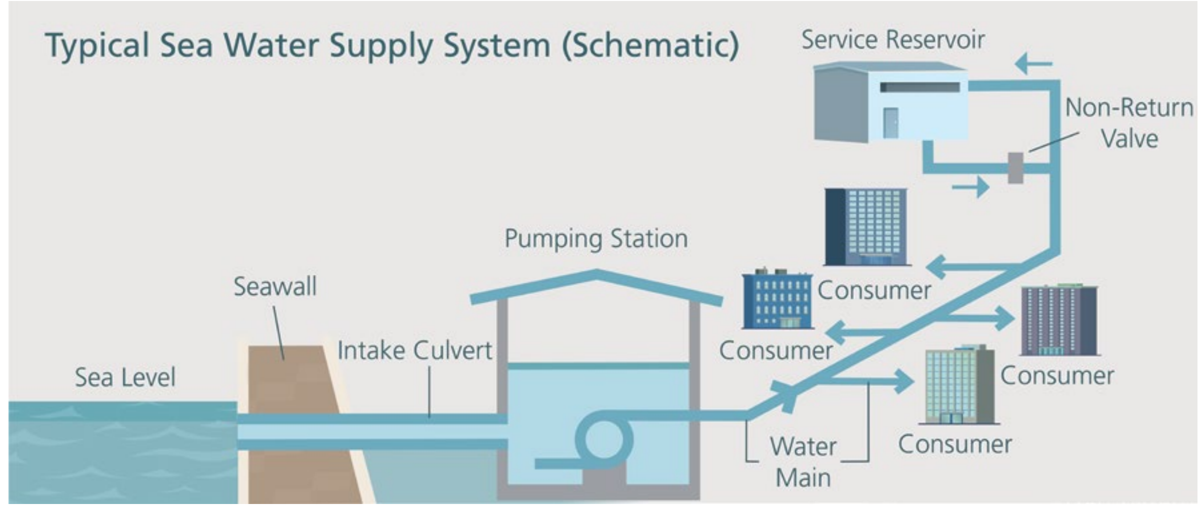
Seawater Distribution System for Seawater

Hong Kong was the first place in the world to make wide use of seawater for flushing, and has long since developed two completely separate fresh water and seawater supply systems, each with its own pumping stations, service reservoirs and distribution mains. These features have contributed to the complicated water distribution network in Hong Kong.

The water supply system in Hong Kong optimises the principle of gravity. However, to enable direct pumping of seawater into the flushing water distribution network, seawater pumping stations are typically positioned at or in close proximity to seawalls to transfer seawater from a lower to a higher level.

Illustration of the Ring System





The seawater first enters the intake culvert to screen-out sizable particles by strainers and is then disinfected with sodium hypochlorite. The flushing water quality after treatment must meet the WSD's requirements on colour, turbidity, odour, etc. The residual chlorine from the sodium hypochlorite also prevents the growth of marine organisms, microorganisms and bacteria in the flushing water supply system.

The treated seawater will flow into the pumping station and be transferred under pressure to the seawater service reservoir for temporary storage. During the process, the seawater will be transferred directly from the pumping station to users en route before the surplus water is sent to the service reservoir at a higher location for storage. This design helps to buffer demand during peak periods. At present, there are 55 service reservoirs and over 1,600 km of water mains in Hong Kong's seawater distribution system.

The City's 21st Century Water Pressure Management Programme

Currently, the daily total water consumption (fresh water and seawater) in Hong Kong averages around 3.7 million cubic metres. This vast amount of water is delivered through a distribution network of over 8,000 km of fresh water and seawater mains underneath the city. Water supply distribution and its pressure stabilisation are not easy due to Hong Kong's uneven terrain and the large variation in water pressure. In many low-lying areas, the water pressure within the network is excessively high, hence increasing the probability of network leakage. In Hong Kong, the average pressure of fresh water supply typically ranges from 60 to 80 metre head. During its early years, Hong Kong experienced inadequate water yields, which led to a lack of priority in regulating water pressure. It was only towards the end of the previous century that pressure management emerged as a primary consideration in the administration of water supply networks.

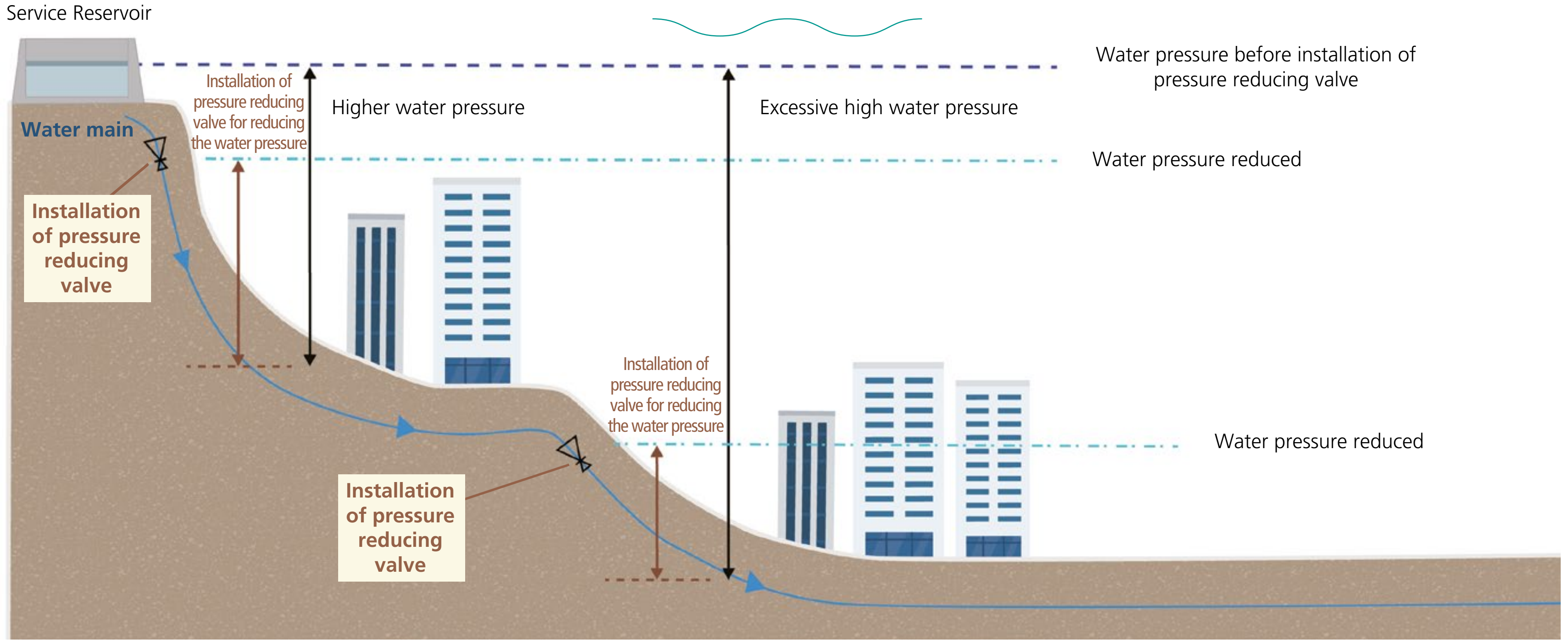
Since 1997, the WSD has been implementing a pressure management programme in selected areas. This has involved the planning and design of pressure management studies and the associated construction and installation works. Pressure management is the operation of dividing water supply areas with high pressure into distinct pressure management zones. It lowers the excessive pressure to a suitable level by implementation of pressure monitoring and using control equipment. With advances in technology, pressure reducing valves have significantly improved in performance. The WSD has extensively incorporated them in water pressure management systems to minimise the possibility of water main bursts, to extend the life of water mains, and mitigate water loss. For a comprehensive understanding of network management, kindly refer to "Smart Technology Management of Water Mains and Water Leakage" in this chapter.

Application of Variable Speed Water Pumping

In accordance with the government's smart city blueprint, the WSD is devoted to examining the use of energy-efficient and productive water supply systems in new development areas.

Variable speed pumping is a technology that has been applied to seawater distribution systems in recent years. Unlike conventional fixed speed pumping, variable speed pumping can adjust pump speed according to the water demand. When the water demand increases, the pump speed will increases. On the other hand, the pumps slow down when demand decreases. Studies have shown that variable speed pumping can save up to 5-10% of energy compared to fixed speed pumping.

Diagram of water pressure management



Better Use of Service Reservoir Rooftop Land

To optimise the use of land resources, the WSD has been opening the open-air rooftop spaces of its service reservoirs for recreational use since the 1960s. As of July 2023, as many as 55 sites above fresh water and salt water service reservoirs have been allocated for use by various government entities and private organisations for use as sports venues, leisure areas, parks, playgrounds and training grounds.

In view of the shortage of land, the government has been actively exploring rock cavern development to release existing land for housing development. The Western Salt Water Service Reservoir on Hong Kong Island West is the first water service reservoir of the WSD built in a rock cavern. The project involved the reprovisioning of the original service reservoir in a rock cavern to free-up space for the development of the Centennial Campus of the University of Hong Kong. The Diamond Hill Fresh Water and Salt Water Service Reservoirs, currently undergoing construction, are expected to be operational in 2026. (For more information, please refer to the article "Waterworks in Underground Caverns" in this chapter.)

▲ People using a service reservoir rooftop for recreational activities

▲ The Yau Ma Tei Service Reservoir Rest Garden above Yau Ma Tei Salt Water Service Reservoir

Smart Technology Management of Water Mains and Water Leakage

The WSD manages and maintains a water distribution network spanning over 8,000 km. Over the years, the WSD has proactively conducted regular leak detection of water mains throughout the city for the early identification and repair of leaks. Nonetheless, identification of potential issues remains challenging due to the expansive and complexity of Hong Kong's water distribution system, and as many of the water mains lie deep beneath the ground.

Due to evolving technology, the WSD has made considerable effort to improve its distribution network management by establishing Water Intelligent Network (WIN). Zones within the fresh water distribution network have been established to monitor and gather data, allowing for quick decision-making and using best network management methods to minimise water loss due to leakage in the water mains. The WSD aims to further reduce the leakage rate of its water mains to less than 10% by the end of 2030.

"The continuous monitoring and data analysis provided by WIN gives us a more accurate picture of the condition of the water distribution network, including water pressure and consumption. This enables us to identify and follow-up on areas where water loss is suspected, and allows us to maximise our efficiency with limited resources," says Chief Engineer of the Development Branch, Ir Simon LEUNG Chi-hung.

◄ Chief Engineer of the Development Branch, Ir Simon LEUNG Chi-hung, explaining that WIN helps the WSD formulate the most effective water network management measures.

Concept of Zone Monitoring

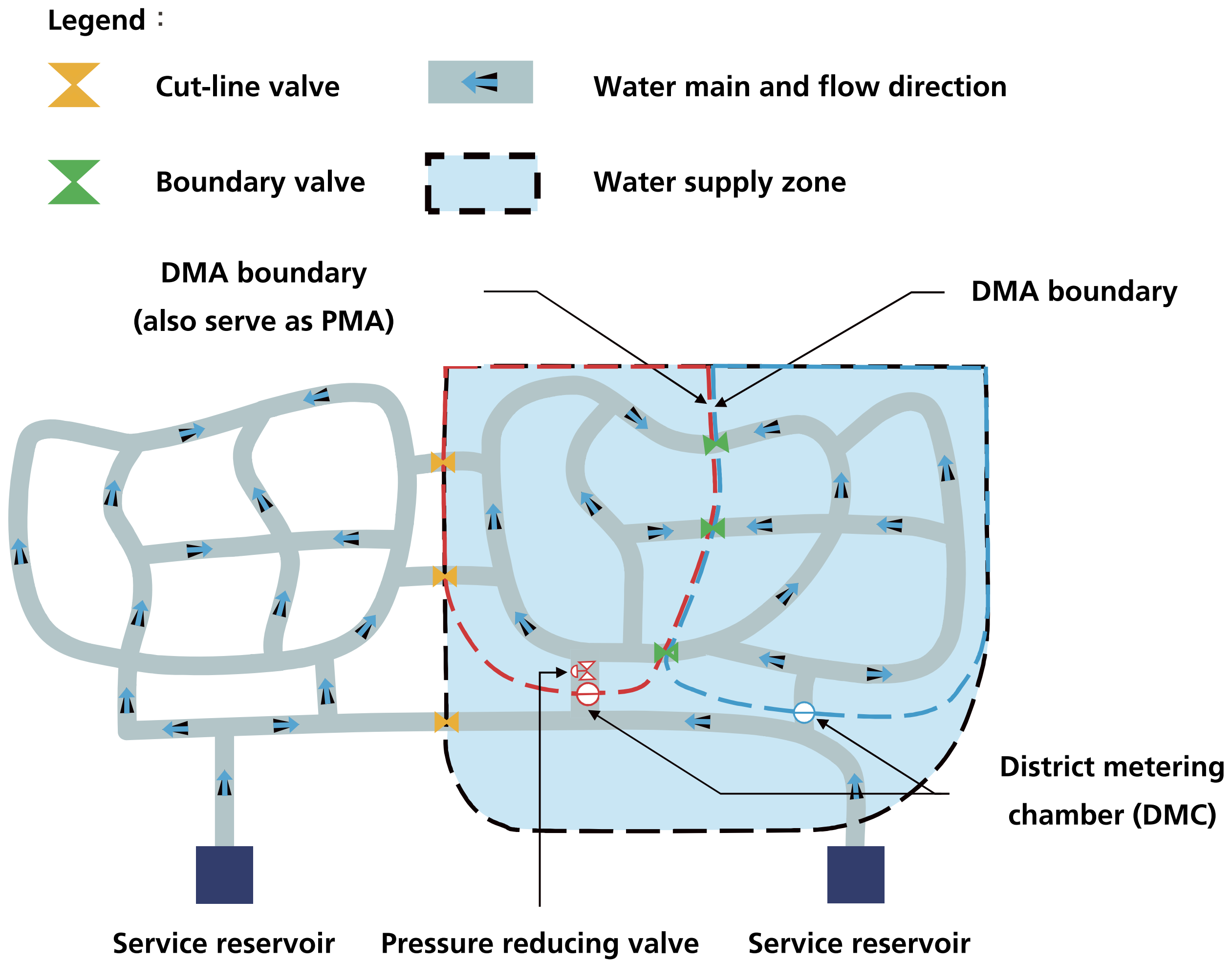
Zone monitoring was initially developed in the United Kingdom during the 1980s. It involves creating a distinct sector within a water distribution network by closing boundary valves or disconnecting water mains. Flow meters and pressure sensors are used to monitor water flow and pressure into respective areas. Analysis to assess potential water mains leaks is done during night-time, a time of low water flow. "Using smart technology, data collection has become fully automated with more monitoring points available to continuously monitor flow and water pressure, resulting in more accurate and efficient management."

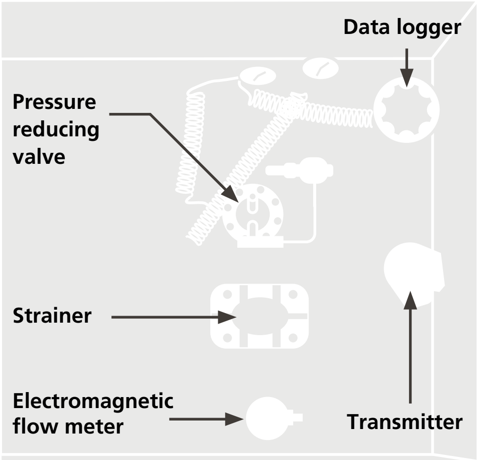
The Water Intelligent Network (WIN)

WIN is a system through which the WSD employs monitoring and sensing equipment to automatically collect continuous 24-hour water flow and pressure data for computer analysis to monitor water loss in a region. Around 2,400 individual District Metering Areas (DMAs) will be installed in the existing water distribution network, based on various factors, such as structural condition, coverage, length of water mains, topography, number and type of consumers.

Without compromising the minimum water pressure required to maintain a normal water supply, the WSD will install pressure reducing valves in the DMA to establish a "pressure management area" (PMA), aiming to implement pressure management, reduce water pressure and minimise water mains leakage. (For further information on water management, please refer to the article "The Principles Behind Hong Kong's Unique Water Distribution Systems" in this chapter.)

Diagram showing the Water Intelligent Network operations





▲ Equipment and device in the District Metering Area chamber

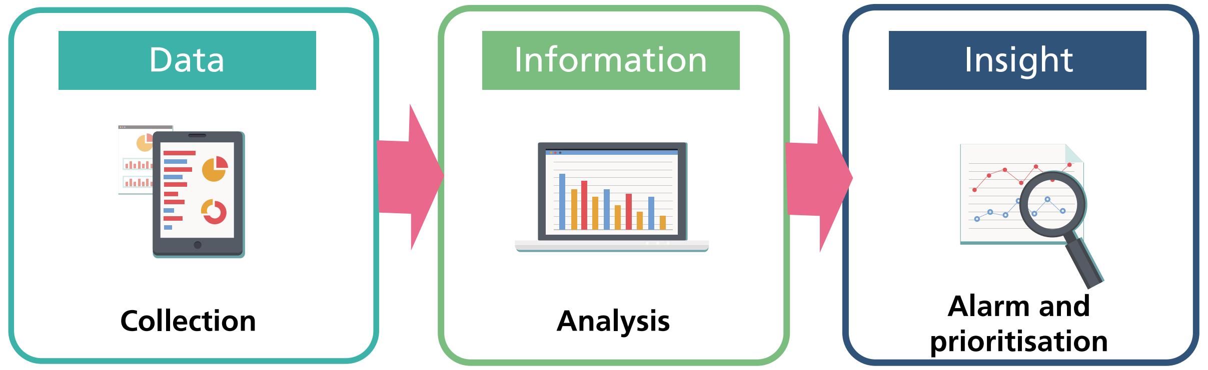
A flow-meter and a pressure data logger will be installed in each individual monitoring area, allowing the efficient collection of water flow and pressure data to monitor water loss in an area. Such monitoring allows the implementation of targeted measures, such as active leakage detection, pressure management, speedy repair of water mains leaks, and replacement or rehabilitation of water mains, etc.

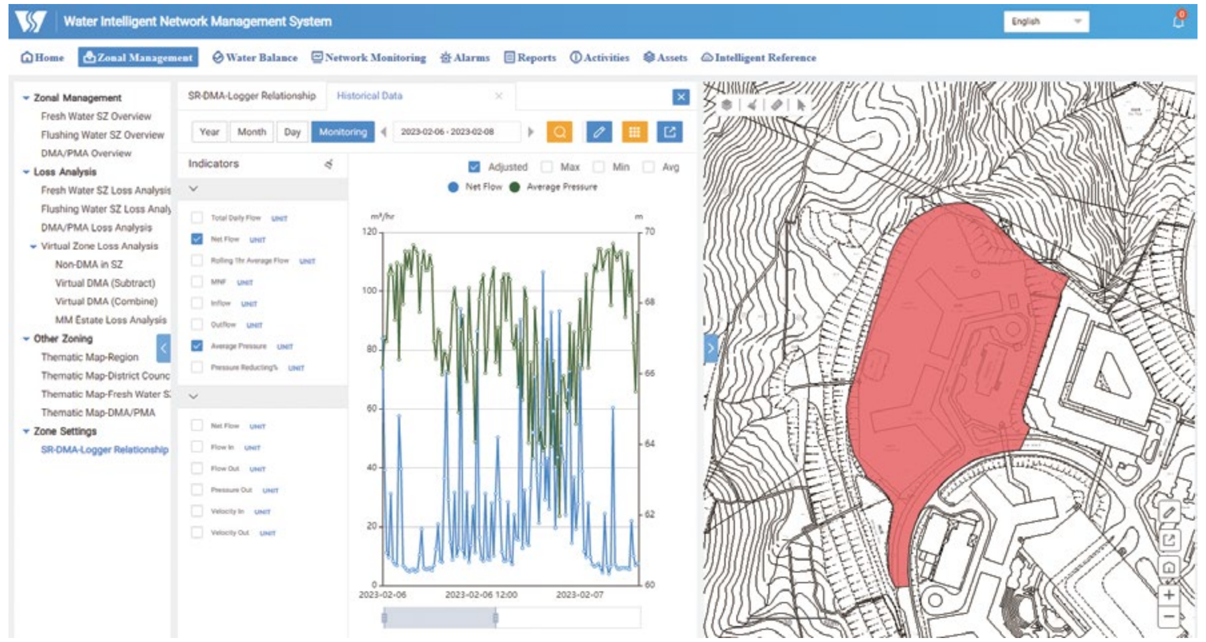
The WSD has established about 1,900 DMAs by September 2023. By analysing the collected data, the WSD conducts further investigation of areas with suspected leakage for follow-up and repair. These repairs have resulted in a substantial reduction in water loss.

Water Intelligent Network Management System

In 2020, the WSD launched the Water Intelligent Network Management System (INMS), which collects data from DMAs and PMAs and uploads them to the computer monitoring system for management and analysis. By using WIN, the WSD staff can identify anomalies in the water distribution network at an early stage, and support the development of cost-effective solutions and prioritise its implementation.

Schematic Diagram of the Water Intelligent Network Management System





▲ The INMS interface

Water Mains Leak Detection

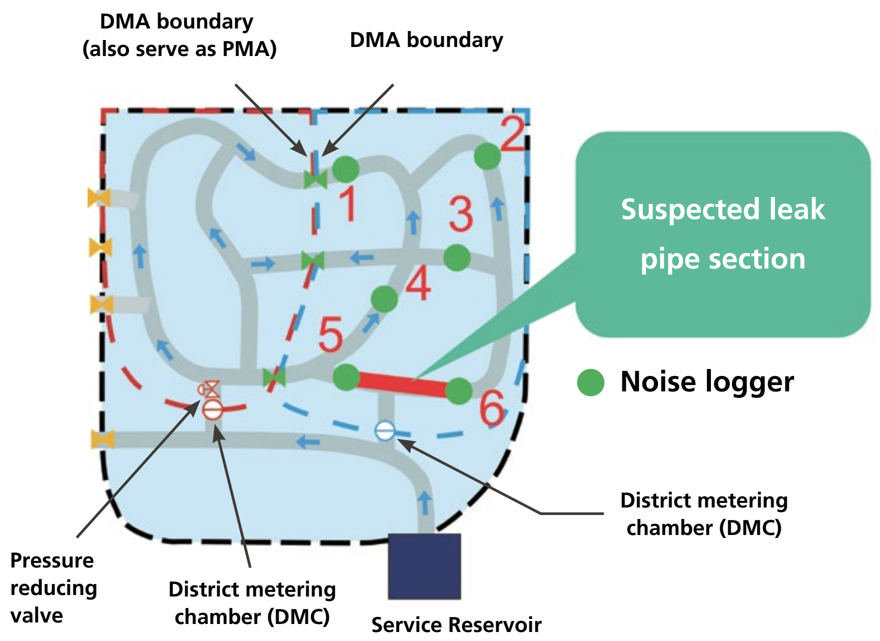
If any anomaly is detected in the network data of a specific DMA, the WSD will conduct an investigation in that area. Once the suspected section of the pipe is identified, the next step is locating the leak points along the underground water mains by performing tests. Then, WSD staff will identify the leaking pipe and locate the leakage point for repair.

Pipe Leakage Detection: Locating Suspected Leaking Pipe Sections

Water pressure in the pipe generates noise at the leak point which travels along both sides of a pipe. Installing noise loggers enables a repair crew to identify the possible location of any suspected section of pipe leakage. Noise loggers automatically activate every night at a set time (typically late night between 2 a.m. and 4 a.m., when the surroundings are quiet), to record any detected noise from the pipes. After analysing the captured soundwaves, the system has the ability to detect any indication of potential leaks in the adjacent pipes, facilitating further inspection of suspected leaking pipes by frontline staff.

▲ Noise logger

Leakage Detection



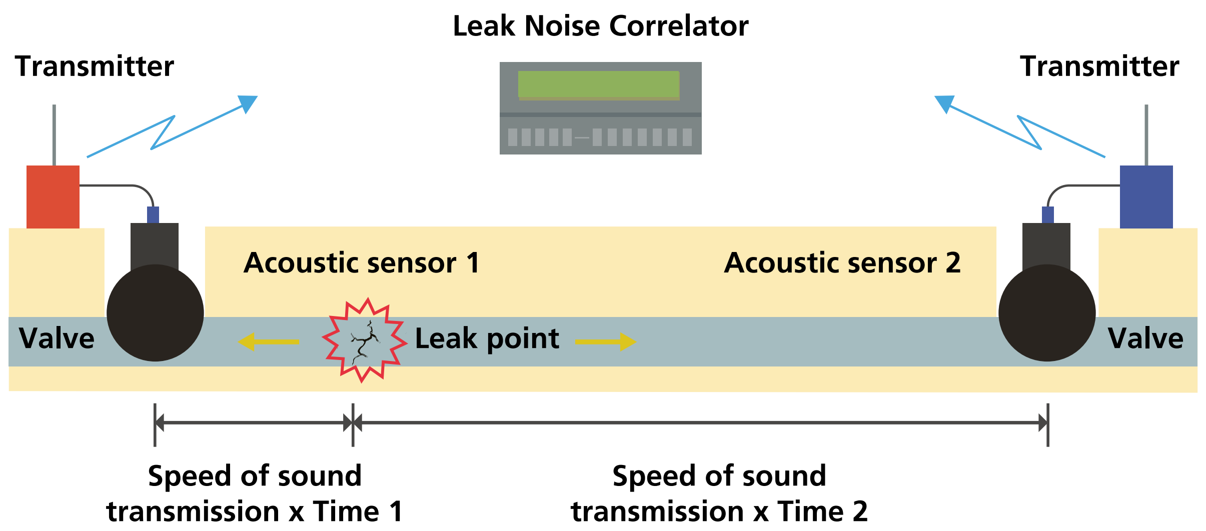
Leak Noise Correlation: Narrowing Down a Leak Area

As the sound wave of a water leak travels along both sides of the pipe, the closer to the leak, the earlier the same noise is detected. Two sensors will be installed at locations with access to the pipe, e.g. the pipe valve. Details such as the pipe's length, diameter and material will be inputted. Afterwards, the correlator will calculate the relative distance between the two sensors by comparing the time difference when both sensors receive the same noise.

Leak Points Identification

Based on the results of the leak noise correlator, staff will use a stethoscope or ground microphone to listen for leaks along the pipe's path and identify the leak point. The stethoscope's design amplifies the leak's sound like a cochlear hearing implant. With the stethoscope directly placed on the ground, skilled and experienced staff can detect the sound and locate the leak point accurately. The ground microphone operates on the same principle, with additional features including the ability to measure sound levels in decibels and perform audio filtering. Leak detection is conducted at night, if required, to reduce noise interference from the surroundings.

Principle of Leak Noise Correlator



▲ Using a stethoscope

▲ Using a ground microphone

Leakage Detection for Large Diameter Pipes: In-line Detection Technology

Most of the leak detection methods in the industry rely on acoustic principles to detect water leaks in pipes. Nevertheless, the intensity of the noise or the decrease in the transmission of the leak will be affected by the material, dimensions, environment, and water pressure of the pipe. For instance, in the case of larger pipes (i.e. pipes exceeding 600 mm in diameter), the above technique may not be sufficient to locate a defective pipe. As a result, additional leak detection equipment, namely in-line detection techniques, may have to be employed.

The WSD has adopted in-line detection technology for leak detection, which involves inserting an aluminum-core ball with a sound sensor inside at the inlet point of a pressurised pipe. As the ball travels along the water flow, the sound is recorded through the pipe. The sound level is usually higher where there is a leak. The ball simultaneously records the location of the noise, helping frontline staff carry out further investigations and repairs.

▲ Q-Leak, the Underground Water Mains Leak Detection Training Centre in Tsing Yi

Q-Leak, the Underground Water Mains Leak Detection Training Centre

The most reliable way to identify the location of leaks is still by noise recognition. However, as the actual environment is highly variable, frontline staff need to gain experience of leak detection by listening or by using instruments in different practice settings. The introduction of big data analysis can help improve the efficiency and accuracy of detection. Consequently, the WSD worked with the Hong Kong Polytechnic University to design and build a underground water mains leakage detection training centre, Q-Leak in 2020. The centre opened in July 2021 to train staff in water mains leakage detection.

Q-Leak plays an important role in the training and research of leak detection, as follows:

▲ Different pavement materials are used to simulate various road conditions in Hong Kong.

Provide Leak Detection Training for WSD Staff

Q-Leak is a water mains leak detection training venue, providing staff with basic knowledge on the procedures and steps required for leak detection, the operation of equipment and the identification of leak sounds.

The road and pipe networks in Hong Kong are extremely intricate. Leakage noise varies depending on the material and diameters of the networks' pipes. Therefore, the WSD has laid a network of water pipes with varying sizes and material, extending over a total length of around 400 metres in the 2,000-square-metre Q-Leak training area. The road surface is also paved with different materials, such as grass bricks, concrete and asphalt to imitate diverse ground coverings, water pipes and road conditions. Various devices, including valves and pressure reducing valves, have been installed in the network to replicate the various modes of water flow.

There are more than 80 simulated leak points on the training ground, where trainees can practise using various types of leak detection instruments in different environments. They can also conduct visual and sounding inspections, noise recording and step tests to narrow down the area of suspected leaking pipes.

Establishment of Industry Accreditation

Apart from government water mains, leaks are also occasionally found in the underground water pipes of private properties. The demand for leak detection in the private sector is expected to grow in the future. The establishment of Q-Leak is a good opportunity to provide the local water industry with appropriate training to identify, access and learn to use the latest leak detection instruments to improve their skills.

Q-Leak also facilitates the assessment of skills in the industry. Due to the versatile arrangement of potential leakage points in the training area, blind tests can be varied, from easy to difficult, to test the full range of leak detection skills of trainees.

Development of Leak Detection Techniques for Hong Kong's Unique Conditions

Building a Sound Spectrum of Water Leaks

Currently, traditional leak detection techniques remain more accurate and reliable than advanced electronic leak detection equipment. Veteran professionals, who possess years of experience, can precisely identify the sounds of water leaking. However, this level of craftsmanship is challenging to pass on and the art will be lost as these experts gradually retire. The new leak detection equipment records the sound emanating from leaking pipes, which can be compiled into a database. In combination with the data collected from other sensors, analysis and learning are made easier.

In fact, every leak produces a distinct sound spectrum. The sound emitted by a leaking plastic pipe or steel pipe differs from the one transmitted through paving blocks or a concrete pavement. Many water leaks can be analysed by artificial intelligence (AI) to recognise acoustic patterns and their correlation with water leakage. Upon identifying the associations, the AI can further simulate the frequency of water leakage in pipes of different sizes. If a similar sound spectrum is identified in the future, WSD staff will be capable of detecting leaks quicker, thereby preventing further burst pipes.

#Fun Fact

The Sound of Leaking Pipes

The noise of leaking pipes varies from one material to another. You may click to hear:

Steel pipe without leak

Steel pipe with water leak

PVC pipe with water leak

Cast iron pipe with water leak

Copper pipe with water leak

Copper pipe with water leak and meter running

Application of Ground Penetrating Radar

Another important objective of the centre's research is to enhance the efficiency of the leak detection process. The installation of noise loggers is labour intensive and requires road closure, equipment installation in manholes, and data collection lasting one to two days, but the investigation area to be monitored is quite limited. To address these issues, the WSD began collaboration in 2022 with the Hong Kong Polytechnic University to study the application of ground penetrating radar (GPR) technology for detecting water mains leakage.

GPR employs radar pulses to detect conditions below the ground surface. The method involves sending radar pulses to the ground surface, followed by recording and storing the intensity and time taken for the signal to be reflected by different substances. Conducting multiple radar surveys in an area enables the combination of various profiles to produce a comprehensive three-dimensional picture for inspection. Originally, GPR is used for pipeline surveys to detect the location of water mains by using photo images. In order to detect water mains leaks, the team had to capture, identify and define the image characteristics of the leaks. Q-Leak plays an important role in this regard. The team utilised GPR to capture the corresponding image features of different types of leaks at known leak points within the training ground to indicate suspected leak points.

Majority of water mains in Hong Kong are situated underneath carriageways. When the WIN data indicates a suspected leak in a DMA, the WSD staff can use a motorised vehicle to tow a GPR along carriageways in the suspected area. Normally, it takes over a week to gather data from 30 to 40 km of water mains using conventional methods. By employing motorised radar, the same distance can be accomplished in about an hour, with a significant reduction in time and cost.

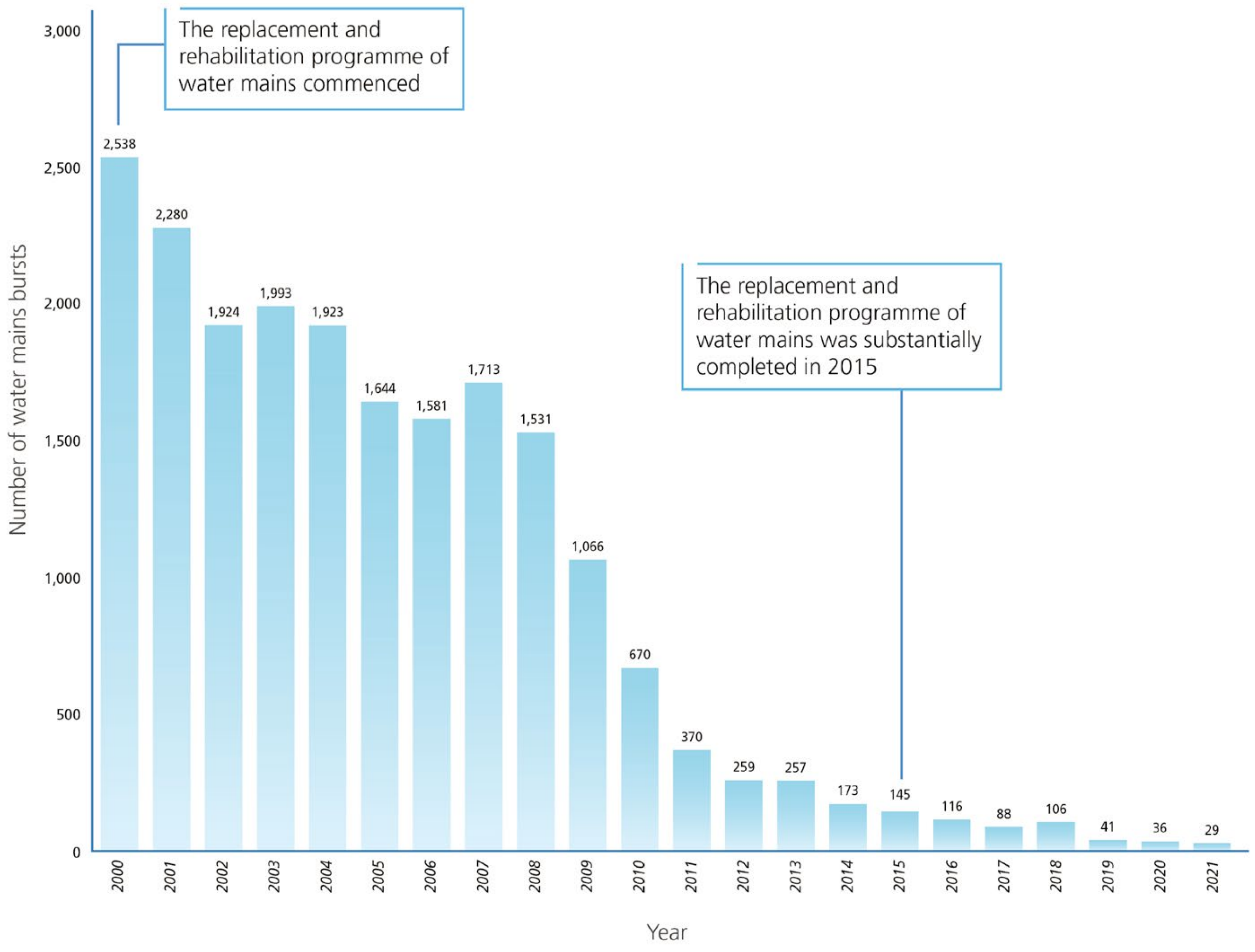
▲ Investigation of groundwater pipes using GPR

Water Mains Asset Management Strategy

Risk-based Water Mains Improvements

Between 2000 and 2015, the WSD launched a large-scale programme to replace and rehabilitate severely aged pipelines or pipelines with frequent burst mains incidents. Under the programme, the condition of about 3,000 km aged water mains were improved. After major replacement and rehabilitation works, the number of burst mains cases has been significantly reduced by about 90%. As the overall condition of the network improves, large-scale replacement and rehabilitation of water mains is no longer the only effective way to maintain the health of the network. The WSD is seeking more cost effective measures and to balance risk, cost and service levels factors. At present, the WSD is implementing a "Risk-based Water Mains Asset Management Strategy" to maintain the health of water supply networks and reduce the risk of burst water mains and leaks. The WSD will assess the risk, and take into account various factors, including the consequences of bursts or leaks, the age and material of water mains, past records of bursts or leaks, and the surrounding environment, etc. Priority will be given to water mains assessed as a high risk to carry out the required improvement works, thus allowing pipe replacement and rehabilitation works to be conducted systematically to reduce the risk of bursts and leaks. Since the implementation of active leakage control and pressure management on water mains, the condition of the water mains network has improved significantly. The number of burst water mains dropped from over 2,500 in the year of 2000 to an average of 40 or less per year in the past few years, representing a 98% reduction. The associated number of water mains leakage cases also fell in the same period.

Water Mains Burst Cases in Hong Kong, 2000-2021

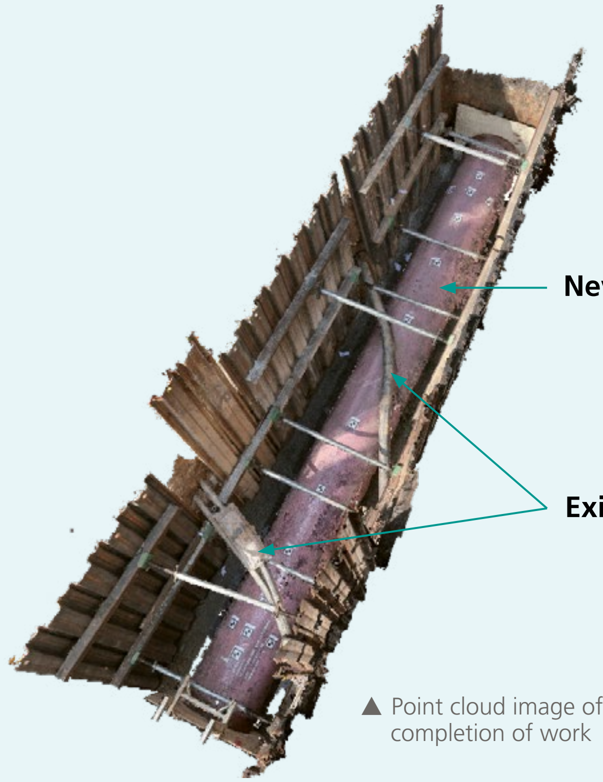


Water Mains Replacement or Rehabilitation

Hong Kong has a dense underground pipe network. Currently, there are about 20 public utilities that frequently carry out road excavation for maintenance works, including for gas piping, fibre optic cables, storm water drainage and electricity cables. The most common issue when constructing water mains networks is the identification of other utilities not shown on a utility's plans during trench excavations. Therefore, it is often not easy to locate underground water mains alignments for pipe replacement or rehabilitation in developed areas.

Hong Kong's water mains are generally laid by open trench excavation, i.e. ground opening, underground water mains laying and subsequent connections. A number of considerations need to be balanced when replacing water mains, particularly the need to avoid conflict with the congested existing underground services as mains are often located deep underground. Another consideration is the impact on water supply to customers and its effect on traffic. At busy road junctions or locations with water mains crossing road sections, the WSD will use "minimum dig" techniques to reduce the impact on traffic.

▲ Staff acquiring data by photogrammetry

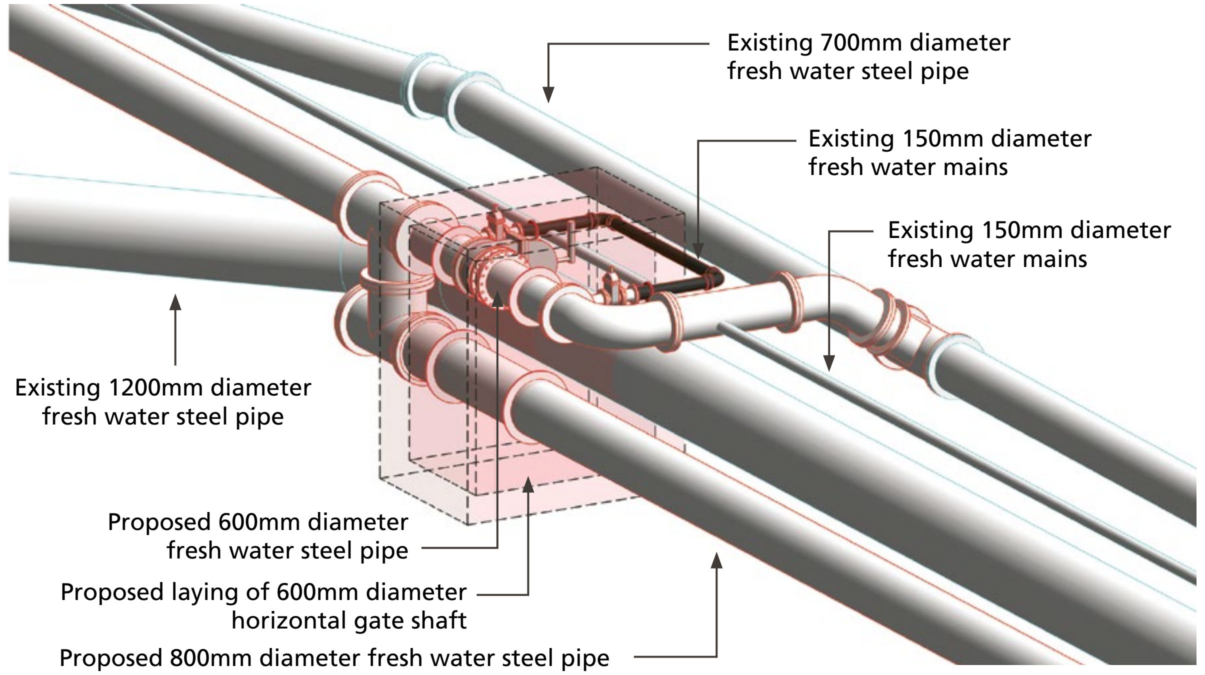


▲ Point cloud image of completion of work

Building of Water Pipes Information Modelling and Point Cloud Storage

Alignment design of large diameter water mains has always been challenging, as it requires the use of limited available underground space and avoiding conflicting with existing pipe alignments. In the past, water mains were mainly planned in a two-dimensional format, but by using Building Information Modelling (BIM) technology, the WSD can generate a precise three-dimensional elevation, which maximises the visibility of underground spaces. This technology enables the early detection of any potential conflicts between proposed water mains and existing pipes, thus reduces time and cost implication due to delayed detection.

In addition, the WSD is conducting point cloud surveys for all newly installed water mains and underground utility pipes found after trenching. The resulting cloud data will be used to create a BIM model of the water mains. All point cloud data and BIM models will be stored in the WSD's database to provide a more accurate record for designing future water mains. This approach will save time and costs associated with water mains laying and reduce nuisance to the public.



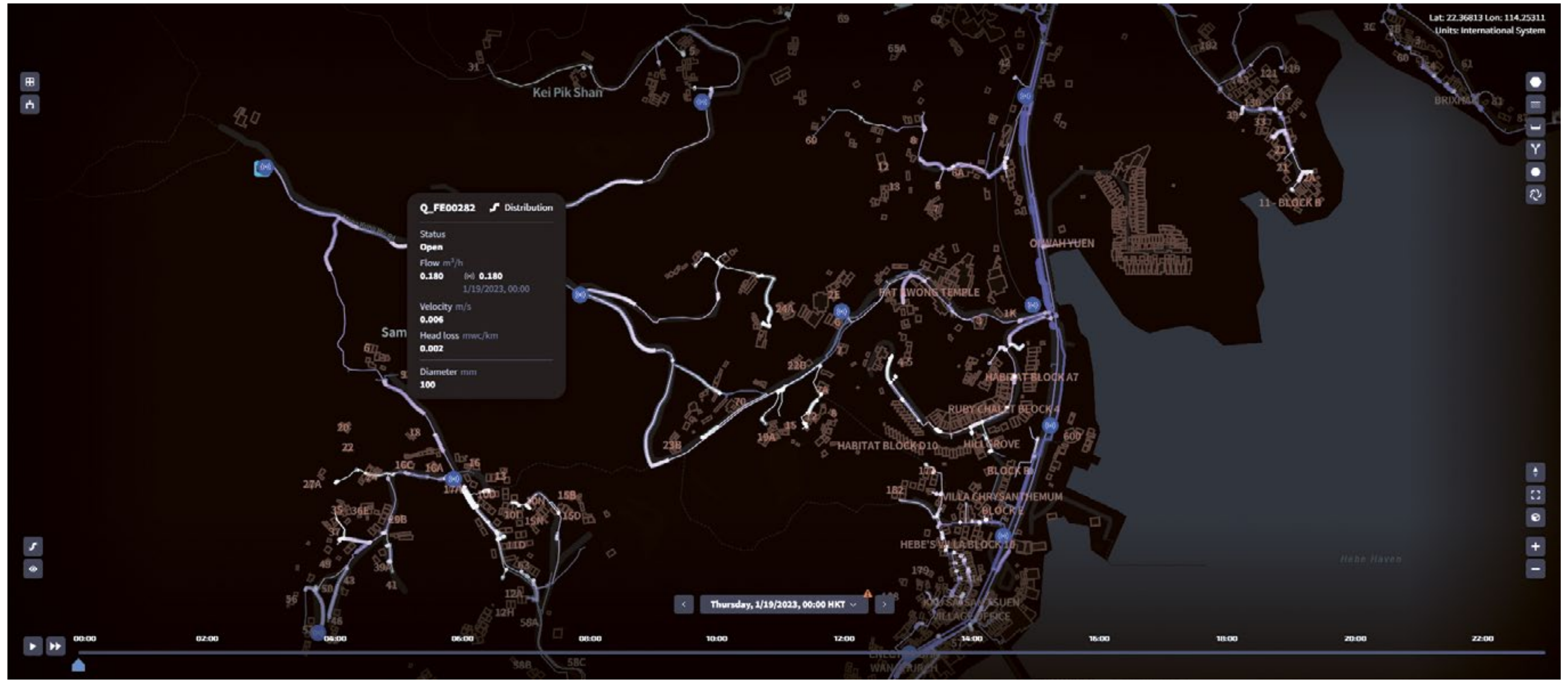
▲ With BIM technology, the design of water pipes can be displayed in three dimensions

Digital Twin Technology to Enhance Water Supply Management

Water supply management would be more efficient and effective if there were a virtual water treatment and water supply network that could accurately simulate changes in water quality, flow, pressure and the operation of pumps, valves and other equipment. This would also assist in lowering energy consumption and encourage a more proactive operational management strategy.

Since 2000, there has been a significant emphasis on computerization and digitization on collecting and application of big data. Digital twin technology merges conventional and professional computing models of product or system design with real-time data received from sensor devices. As a result of data analysis, a product or system's operations can be depicted as a realistic image, giving rise to an identical twin of the real and virtual worlds. Some information technology research institutes in the United States have repeatedly recommended that the ability to develop a digital twin be recognised as one of the top ten current technological trends and a fundamental aspect of Industry 4.0 development.

Following the release of the "Hong Kong Smart City Blueprint" in 2017, the HKSAR Government published the "Hong Kong Smart City Blueprint 2.0" in 2020. The new blueprint presents 130 initiatives across 6 domains, including on "Smart Government". Various departments are now exploring the potential development for smart services. In 2020, the WSD implemented digital twin technology, which is being tested and studied in water treatment works and water distribution workflows. The article "Research and Development of Automated Water Treatment Monitoring" in Chapter 2 introduced the progressive integration of water treatment works from automation and remote control systems to a digital twin technology in recent years. This article describes the development of water supply and distribution networks in this respect.



▲ Schematic diagram of the digital twin for the water distribution system

A Digital Twin for a Water Supply Network

The water supply network in Hong Kong serves a population of more than seven million people. It spans water treatment works to the service reservoirs in each district and then to water supply points in every street and building. This is arguably one of the most intricate systems in the world for a single water utility serving such a high density of customers. With the development of the Water Intelligent Network (WIN) (as detailed in the article "Smart Technology Management of Water Mains and Water Leakage" in this chapter), the territory's fresh water distribution network is being divided into approximately 2,400 District Metering Areas, each with fitted sensors to capture data on particular pipe sections, facilitating the monitoring and control of water leakage, and ultimately reducing overall water loss.

As the data collection network is gradually being established in the system, the implementation of digital twin technology will allow for greater utilisation of the data. In fact, the use of this technology in water facility management has proven effective in other parts of the world.

Digital twin is the outcome of merging various technologies that are well established in research and development, including machine learning and artificial intelligence. Hydraulic models are built in the digital twin system based on information on the configuration of the water supply network, the distribution of customers and their water consumption. Combining the hydraulic models together with data collected from WIN and other WSD systems, the digital twin system operates as a simulation of the water supply network. The system was first tested in a smaller area of New Territories East to gain experience in preparation for future digital twins for all of Hong Kong's water supply networks.

Possible Future Applications

When implemented in a water distribution system, digital twin technology can enhance the accuracy of predictions, leading to more effective water pressure management and higher energy efficiency. By obtaining accurate data on water demand, water pressure can be adjusted to the appropriate level by reducing the operation of certain pumps. It is worth noting that pumps tend to be one of the most energy-consuming components of a water supply system. If greater efficiencies can be achieved, substantial energy savings will follow over the long term. In addition, it is often essential to adjust water direction or flow to minimise any disruption before undertaking maintenance on the water supply system. Implementation of digital twin technology to simulate outcomes enables waterworks staff to make better preparations.

Waterworks Mechanical and Electrical Maintenance ‘Base Camp’

The commissioning of a facility is only the start of its public service. Daily maintenance is always required to ensure a facility’s condition and performance is kept at an optimum level. The routine maintenance of the city’s waterworks facilities can be broadly divided into two major categories: mechanical and electrical engineering, and civil engineering. The former involves three main disciplines - mechanical, electrical, and instrumentation. The WSD has maintenance workshops that ensure its facilities - whether over 100 years old or newly completed - are continually and sustainably maintained. To support its work, an apprenticeship scheme from basic to specialised levels for staff has also been established.

Mechanical and Electrical Facilities Maintenance

Although there are no specific heavy industries in Hong Kong, the water supply system serving Hong Kong requires large machinery, and electrical and instrumentation systems, to function. This infrastructure must be capable of transporting raw water from outside the region to reservoirs, then transferring to water treatment works, and finally delivering to households in the city’s different districts. This must all be done while overcoming the geographical challenges posed by hilly terrain and the requirement of operating round the clock throughout the year. For many years, the WSD has nurtured a team of maintenance and repair experts to tackle many technical issues of different complexity, the far-ranging issues they deal with include: pumps that must supply over 320,000 cubic metres (m^3) of water each day to households; metering devices able to monitor the water consumed by each household; and, the constant testing of water pipes to ensure water safety. Their stories often reflect those of Hong Kong industry.

The WSD Lung Cheung Road Mechanical and Electrical Workshop (M&E Workshop), located on the Beacon Hill hillside, is the works depot for all the WSD's mechanical and electrical workshop equipment. It provides professional services for the repair and testing of pumps, motors, water meters and various measuring and remote control equipment. After its completion in 1990, the WSD’s different workshops, including the mechanical workshop, the electrical workshop and the instrument workshop, were consolidated into one maintenance facility. Chief Electrical and Mechanical Engineer Ir LAU Chin-hung, who has been working with the WSD for nearly 30 years and is now responsible for overseeing all mechanical and electrical repairs and maintenance, says that there are 20 water treatment works and about 200 pumping stations in Hong Kong, which require a wide range of equipment and instrumentation. Some of the equipment is large and requires corresponding space and tools for maintenance. This workshop centralises the process and its maintenance equipment is shared amongst staff for more cost-effective management.

Ir LAU described pumping stations and water pipes as being like the heart and blood vessels of the water supply system. Any issues with the facilities will affect the water supply. Regular inspections and maintenance are necessary to prevent problems before they arise. For instance, a water pump’s motor is sent to the workshop for major maintenance every five to ten years and those for pumping seawater are more susceptible to corrosion and wear out quicker. There are two teams of maintenance staff attached to the workshop, one in the field and another in the workshop. One team attends to outside facilities for daily inspection and maintenance, while the other carries out the overhaul and repair of waterworks equipment in the fully-equipped workshop. According to Ir LAU, the WSD formulates a maintenance schedule based on past years of experience and arranges equipment to be periodically sent back to the workshop for repair and replacement. These measures help maintain facilities at an optimum level.

► Chief Electrical and Mechanical Engineer Ir LAU Chin-hung says that the mechanical and electrical maintenance team is the backbone of the water supply system

Maintenance by Categories

The M&E workshop at Lung Cheung Road comprises Mechanical and Electrical workshops in Block A; a Material Testing Laboratory in Block B; and, a six-storey office building in Block C. The workshop is divided into three main technical areas of expertise: mechanical, electrical, and instrumentation. The mechanical workshop, for example, is equipped with five main workshop areas of expertise, commonly known as "Che, Luo, Pao, Mo, Chuen"[1]. It also houses a variety of auxiliary equipment, including hydraulic jacks, cranes weighing up to 20 tonnes, electric conveyors and lifting platforms.

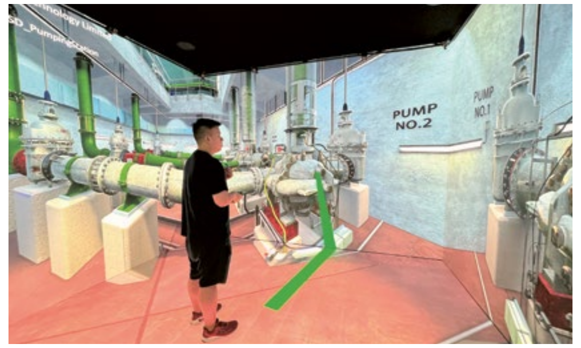
The workshop has around 700 staff who have mostly completed the WSD's apprentice training scheme. Also, the WSD openly recruits people with relevant experience who work in the workshop's sections based on their expertise or interests. The workshop's work covers mechanical facilities, and components such as pumps, valves, and gears, while the electrical equipment maintained covers devices, such as high voltage switchboards, low voltage switchboards, and motors. The maintenance of instrumentation equipment encompasses electronic devices, electrical meters and remote monitoring systems, etc.

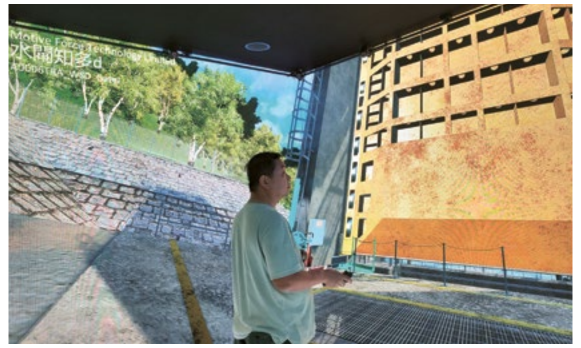
▲ The M&E Workshop at Lung Cheung Road

Introducing New Technologies in a New Era

Ir LAU points out that mechanical and electrical maintenance is a traditional craft skill, which requires knowledge of facility design and principles, as well as maintenance guidelines. He says, "Practices passed-down over the years are crucial for maintenance. Also, we have recently developed remote control devices to collect real-time performance data on our facilities. The maintenance staff can simultaneously monitor the performance of M&E systems in multiple locations from the control room. This enables more effective and accurate problem identification, resulting in timely response and maintenance."

Due to Hong Kong's ageing population, there has been a shortage of new, younger entrants willing to join the apprentice training scheme to replenish the retired staff in WSD. To alleviate succession gaps in the maintenance of waterworks facilities, the WSD has recently produced additional training materials, particularly for facilities for which staff may only have a rare chance to experience their maintenance. These materials are based on the experience and knowledge of senior maintenance staff and are presented in a virtual reality format. This allows a range of staff to understand the key aspects of maintenance work, as if they were on site. Ir LAU explains: "The largest water pump in Hong Kong is located at the Muk Wu Raw Water Pumping Station in the Frontier Closed Area. It is usually maintained once every few years, and the local private sector has no maintenance experience on a similar scale. As a result, only a few experienced maintenance staff have been able to participate in its maintenance. The development of virtual reality material will enable more staff to gain knowledge in its maintenance." It is hoped that learning material will be more widely used in the department. Although hands-on experience is necessary for the transfer of actual maintenance skills, virtual reality does a better job than solely relying on photographs, as was done in the past.





▲ Maintenance staff can learn in a virtual reality environment about the maintenance of large machines, that they previously might not have had the opportunity to be involved

1 This Chinese acronym refers to the skills required for operating the lathe, milling machine, planer, grinder and drilling machine.

Also, another technological development is the installation in 2022 of a 5-Axis Computer Numerical Control Machine. Similar to three-dimensional replication technology, this machine fabricates machine components that are no longer in production. This technology will assist in extending the life of the WSD's facilities and preventing facility obsolescence solely due to any discontinuation of the supply of individual components.

Three Generations of Craftsmanship and Workmanship

Ir LAU says that in recent years, the WSD has been committed to improving its service quality, energy management and asset management by respectively obtaining ISO9001, ISO50001 and ISO55001 accreditation. He believes that, "The maintenance division is particularly proud that there are fathers and sons, and even family members from three generations working together, similar to artisan workshops of the past. All our maintenance staff can learn a skill and land a decent job that gives great work satisfaction."

▲ 5-Axis Computer Numerical Control Machine

Mechanical and Electrical Workshop Tour

1 Water Pump Repairs

The water supply system comprises over 700 pumps of varying sizes located in pumping stations, water treatment works and service reservoirs. These pumps are responsible for delivering water to all parts of the city. It is crucial that they operate efficiently to prevent any interruption in the water supply. The maintenance team regularly monitors pump efficiency by listening to machinery sounds, measuring motor temperature and voltage, and comparing the electricity consumption with water output. This ensures that the pumps are maintained in good condition.

The optimum lifespan for a pump typically ranges from 15,000 to 50,000 hours, depending on the model. Once a machine reaches its service life, it must be returned to the workshop for maintenance. For example, huge effort is required to transport the WSD's largest pump, responsible for delivering Dongjiang water to Hong Kong, from the city's northern district to the M&E workshop at Lung Cheung Road for repair.

▲ Maintenance workers aligning the centre-line in the pump impeller

▲ Maintenance staff inspecting the joint surface of the pump

▲ Workshop staff produce components according to the wear-and-tear of each machine

▲ An apprentice adjusts the position of the impellers of a multi-layer pump ensuring that each impeller is in the middle of the pump to maintain maximum pump efficiency.

2 Motor Repairs

WSD's facilities have a total of 700 motors which form the primary component in its operating pumps. On average, they require maintenance after four to six years of operation. Larger motors, with a power capacity of over 37 kW, must be dismantled and sent back to the workshop for repair due to their size. In most cases, these motors only require routine inspection and have no serious problems. Workshop staff will test each motor to determine if its performance has deteriorated. Staff will firstly disassemble the motor components one-by-one, checking for worn bearings or deterioration of the protective film on coils, then, associated cleaning and maintenance will be done, as necessary. Once the components are reassembled, the motor will be dried in a motor baking oven before its return to the relevant facility.

The largest motor baking oven in the workshop is over two-storey high. Motors located at the Muk Wu pumping station (see photograph below), for example, are the largest of their kind and need to be baked at 105°C for nearly 100 hours, or about four days, after their maintenance. The total time required to repair this type of motor is about two to three weeks.

▲ The electrical workshop is equipped with a large crane to facilitate the movement of motors.

▲ The motor workshop is equipped with a large motor baking oven to extract moisture from a motor to ensure its insulation.

3

Testing and Repair of Water Meters

The residential water meter is the most commonly used water service equipment in Hong Kong households for recording water consumption and calculating water bills. Accuracy is crucial to ensure fairness to customers. The water meters currently used in Hong Kong are imported. Each new water meter has been tested in the manufacturer's factory and the WSD conducts sample tests to ensure accuracy. In the past, people used a trick for reducing the water bill by dripping the tap to prevent the meter from ticking-over. This urban myth will be further explained in the Chapter 4 article "The Development of Hong Kong's Water Meters."

The M&E Workshop at Lung Cheung Road also includes two units: the Metershop and the Meter Testing Laboratory. The former mainly conducts quality assurance testing for newly procured water meters, while the latter is an accredited laboratory providing meter accuracy testing services for the public as well as for the Department's internal use. If a customer disputes the accuracy of their water meter, they can apply for a meter test. The meter will be removed and delivered to the Meter Testing Laboratory for testing. The WSD will invite the customer to witness the testing process. If the meter proves to be more than 3% inaccurate, the water and sewerage charges will be adjusted accordingly and no charge shall be payable for the meter testing. However, if the meter proves accurate, the customer will be required to pay the meter test fee.

The WSD currently serves approximately three million customers and has a similar number of water meters in service. A typical household water meter measures consumption in cubic metres using an eight-digit indicator with decimal point accuracy. The upper measurement limit of the meter is 9,999 m^3. Currently, the average water consumption per person in Hong Kong is about 130 litres per day and, on average, a family of four consumes about 190 m^3 of water annually. In theory, the meter will not reach its capacity limit for several decades. However, to ensure their normal operation, the WSD arranges for their replacement on a regular basis. Every year, the WSD reviews the data of all water meters in Hong Kong, including their service life, usage rate (i.e. cumulative total flow rate) and average monthly flow rate, and other relevant factors. Meters are monitored for a higher rate of wear-and-tear, and preventive replacement is arranged if necessary.

▲ New water meters are sample-tested for accuracy in the Metershop

▲ The Meter Testing Laboratory provides meter accuracy testing services for the public.

▲ The laboratory instruments for water meter testing are calibrated.

4

Materials Testing

▲ Laboratory staff tests the quality of water from a registered tap

A customers' water service system inside their private premises is not under the purview of the WSD. However, the HKSAR Government launched the "Action Plan for Enhancing Drinking Water Safety in Hong Kong" in 2017 (please refer to the article "A Lead-free Water Supply System" in Chapter 5 for details). This plan proposes stronger regulation of plumbing materials. The WSD has now implemented a pre-approval system for plumbing products, which after approval are known as 'General Acceptance (GA) products'. To further enhance verification that GA plumbing products meet GA requirements after their qualification, the WSD is implementing a monitoring plan for all GA products. Samples of GA products are randomly selected by the WSD and tested in the M&E Workshop's Material Testing Laboratory. The range of GA products cover water pipes, water pipe fittings, solder, valves (pressure reducing valves) and toilet flush valves.

To ensure drinking water safety, product samples must pass monitoring tests for their chemical composition (e.g. metal elements of metal parts in direct contact with drinking water) and the main functions of plumbing devices to ensure they meet specification requirements.

5

Training and Development

▲ Apprentices can undertake mechanical maintenance tasks in the workshops.

Every year, the WSD and the Electrical and Mechanical Services Department (EMSD) jointly recruit staff for Technician Trainees II positions. Recently, the training programme has been streamlined to run for a two-year duration, in response to feedback, enabling trainees to attain the qualification of Technician Trainee II quicker. Each year, the WSD recruits between three to six Technician Trainees II (Mechanical), and one or two Technician Trainees II (Electrical) to participate in the training programme. Trainees attend theory courses at the Hong Kong Institute of Vocational Education each week, during which they undergo a mechanical or electrical internship programme with the WSD. Participants will be assigned to different units during the internship, including in the Metershop, regional mechanical maintenance teams, the mechanical and electrical workshops, regional electrical maintenance teams, electrical protection and testing teams, etc. Graduates are eligible to apply to become government artisans after completing the training programme.

The Importance of Learning and Experience in Facilities' Maintenance

The maintenance and repair of the city's water supply systems requires both knowledge and extensive hands-on experience. Since 2000, there has been an increase in efficiency and meeting improvement targets within the maintenance division, as well as more direct customer contact. Frontline staff must be equipped with a wide range of skills requiring systematic training and learning new knowledge.

A majority of management staff in the maintenance division are now considered to be 'master craftsmen'. They graduated from the Apprentice Training Scheme, launched by the government in 1955 to recruit young people to address the shortage of engineering talent after the Second World War. At that time, the Waterworks Office[1] under the Public Works Department, together with the Electrical and Mechanical Office (now the Electrical and Mechanical Services Department) and the Kowloon-Canton Railway Department jointly organised the first training courses and enrolled 16 apprentices to be educated in the required skills. Over the next 40 years, the demand for technical skills in the engineering profession increased and apprenticeship programmes were expanded to include a five-year craftsman apprenticeship programme, and a four-year technicians apprenticeship programme. In 1980s, an electronics apprenticeship programme was introduced.

Due to the professional and unique nature of water facilities maintenance, the WSD launched an apprentice training scheme in 2015. Approximately ten trainee technicians II are recruited each year to undergo on-the-job training. As of 2022, the WSD has organised eight apprentice training schemes and trained 59 trainees.

1 The Waterworks Office was initially a section under the Public Works Department, then upgraded as an independent department in 1982 and renamed as the Water Supplies Department (WSD).

▲ Chief waterworks inspector KI Tak-sun (right) instructs Koey KAO Fuk-yee, a graduate of the WSD apprentice training scheme, on how to dismantle a water meter using the correct ergonomic posture.

From Apprentice to Chief Waterworks Inspector of the Mechanical Workshop

KI Tak-sun, who now works at Lung Cheung Road Mechanical and Electrical Workshop and will soon retire, joined the apprenticeship programme in 1977 at the age of 15, as one of 60 fellow apprentices in that year. He has since had a career spanning almost 45 years with the WSD. His father was also an artisan in the Waterworks Office, continuing the family relationship with the waterworks.

During the first six months of the programme, KI said he received basic training at Morrison Hill Technical Institute, which included courses in Chinese, English and mathematics, as well as classes in craft theory. In the second half of the year, he attended the apprentice training centre[2] in the Electrical and Mechanical Office (now the Electrical and Mechanical Services Department) on Caroline Hill Road to receive professional technician training. Trainees were also required to study at technical colleges after class to acquire practical skills. The entire programme provided comprehensive and intensive on-the-job training, "I remember receiving my first month's salary in cash, which was $375. As the first day of work that month was the 5th, I received a prorated deduction of $30. That was my first ever wage," KI recalled.

After completing one year of basic training, apprentices were assigned to various government departments based on their preferences, such as the Waterworks Office and the then Hong Kong Fire Brigade. This decision not only determined their area of study for the next three years, but also their career path. As KI's father worked as an artisan in a salt water pumping station of the Waterworks Office, he had developed a keen interest in waterworks. "I'd heard him talk about his day-to-day work from time to time, and even visited his workplace. The deafening sound of multiple engines running is a very vivid memory, sparking a keen interest in machinery." It was a natural choice for him to pursue an apprenticeship at the Waterworks Office, which only had three machine apprenticeships available. After being interviewed he was accepted, "I was interviewed and hired by the chief waterworks inspector of the mechanical workshop and have since been promoted to the same position. It is amazing how life works," said KI.

During his four years of training, he learnt the basics of mechanical maintenance, including for pumps, water treatment equipment, plumbing and engine installation. After passing examinations, he became a mechanical artisan at the Waterworks Office. He first worked in the mechanical maintenance team of the Sha Tin Water Treatment Works, which was considered a "training ground" for the department. During his time there, he gained experience in maintaining various waterworks facilities. He continued studying alongside his senior colleagues after work and gradually progressed from Artisan to Works Supervisor II. Over time, his scope of work expanded from mechanical maintenance to include the operation of water treatment works. In 1994, he was promoted to Assistant Watersworks Inspector.

In 1997, he was assigned to the newly completed Ma On Shan Water Treatment Works. The facility had just been equipped with the latest computerised automatic control system for water treatment and quality monitoring. The transition from a manual to a fully automatic operation was not a simple process. There could be no margin for error as any interruption at the water treatment works would adversely impact the daily water needs of the public. "In the beginning, my colleagues were concerned about their ability to handle the new operations, particularly during night shifts when staffing was limited. If the system were to fail, our staff would need to respond quickly and take direct control of the water treatment works. To prepare, we initially trained our staff to operate the system manually, ensuring that the whole team was familiar with each part of the operating system before gradually transitioning to full automation. The transition was seamless, and we all felt a great sense of accomplishment afterwards," said KI.

▲ Chief Waterworks Inspector KI Tak-sun (left) shares his knowledge of water meters with Koey KAO Fuk-yee, a WSD apprentice training scheme graduate.

2 The apprenticeship training centre was demolished in 2019 and the site, together with the surrounding recreational land, was rezoned for commercial, government & institutional use.

Even in an era of advanced technology, traditional maintenance techniques remain essential. As the Chief Waterworks Inspector of the mechanical workshop, KI Tak-sun is responsible for training new staff and apprentices to continue the skills and legacy he learned from his mentors.

Female Apprentice to Consumer Services Inspector

Mechanical maintenance was traditionally male-dominated. KAO Fuk-yee, the first female apprentice under the WSD's apprentice training scheme, acknowledges that the physical work of mechanics can be more challenging for women. However, she is fortunate that many processes are now mechanically operated and she exercises every week to extend her physical fitness.

Although KAO studied business at secondary school, she was influenced by her friends and instead opted to study engineering. "I knew that my friends had enrolled in the first WSD's Apprentice Training Scheme and learned a skill that would provide them with a stable job in the future. I found myself wanting to do the same kind of work, because I'm not the type of person who likes desk work," said KAO. However, she was also not one of those mechanical geeks who grew-up disassembling clocks to study how they worked. So, to prepare, she first enrolled in the Construction Industry Council's Basic Craft Course (Plumbing & Pipe-fitting). In the same year, she was accepted into the WSD's Apprentice Training Scheme, the only female in her class. During her two-year course, she gained experience in six different work divisions, including the Water Treatment Works, Water Loss Management Unit and Distribution Section. She gained a thorough understanding of the water distribution system including checking water quality, detecting leaks, and assisting with emergency water main bursts.

In 2018, KAO completed the Apprentice Training Scheme and was subsequently employed by the WSD as an Artisan. Currently, KAO works as a Consumer Services Inspector in the Customer Services Section. Her main responsibilities include replacing and conducting accuracy tests on old meters, as well as handling customer enquiries on water quality and supply. KAO recognises that water supply is a daily necessity, and any issues that arise can be a significant inconvenience to customers. Taught by her managers to be sensitive to a customers' needs, her strong communication skills come in handy. The knowledge gained during her apprenticeship also comes into play. "Basic knowledge is crucial for customer service, particularly for public enquiries. We strive to answer questions and address their concerns professionally, earning their trust and respect," says KAO.

Water Mains Improvement and Works Emergency Repairs

▲ Improvement to Dongjiang water mains P4 - insertion of a reshaped polyethylene pipe into the existing water mains during large-scale rehabilitation work.

As mentioned in the article "Waterworks Mechanical and Electrical Maintenance 'Base Camp'" in this chapter, disassembled components will be sent to the M&E Workshop for maintenance and repair. Components that cannot be disassembled will be classified as civil engineering works for maintenance. Of these types of maintenance works, the public may most be familiar with the replacement and rehabilitation of water mains. The WSD will replace or rehabilitate high-risk water mains after assessing the level of the asset management risks. However, careful planning and preparation are necessary before any maintenance is undertaken as many water mains are located in public areas. This involves coordinating with government departments and stakeholders to plan temporary traffic arrangements and apply for excavation permits.

Recently to minimise disruption during maintenance works, the WSD uses an engineering technique to rehabilitate existing water mains instead of replacing them. This involves inserting a re-shaped polyethylene pipe into the existing water mains through a valve chamber or shaft; the insertion would then be reverted to its original size to form a lining close to the existing pipe. This method reduces extensive road excavations and has less impact on road traffic.

In any emergency situation, the WSD's Supply and Distribution Branch will deploy a turncock team, as needed. To ensure prompt resumption of water supply, a duty turncock team is always on-call, and can depart within 15 minutes of notification to attend the site. Handling of an emergency incident is a race against time. The following is an overview of the workflow of the emergency teams, taking a water mains burst as an example.

The Workflow of the Turncock Team

Customer Telephone Enquiry Centre (CTEC)
After receiving a report from the public regarding a burst water mains, staff at the Centre promptly notify the **Regional Coordination Centre (RCC)** to further investigate the incident.

RCC will assign the case to a **turncock team** (or 'multi-skill service and emergency team', MSSET). The team must depart within **15 minutes** to attend the site.

Are there any emergency road incidents related to the water mains burst?

Yes: In the event of an incident, such as road subsidence, the Road Management Office under the Hong Kong Police Force may close a road. The WSD should promptly notify its contractor to carry out emergency repairs on the road and water mains. The contractor shall bring all necessary equipment, including road closure signs.

No: The emergency team will carry out leakage detection and valve operation tests based on the **water mains record drawings** to determine the type and location of the burst water mains.

Once the location of the burst point is identified, **the burst water pipe will be isolated.**
The following tasks will be carried out:
- Narrowing-down the area of supply interruption
- Carrying out work according to safety guidance procedures
- Complete the repair within the target time
- Record the burst pipe's location and relevant information

In the event of water supply disruption, can standpipes be installed?

Yes:

Install a standpipe at the fire hydrant for temporary water supply.

No:

Arrange for water wagons or water tanks to supply water.

In general, the WSD will first assess and provide temporary emergency water supply to the affected consumers by water wagons, water tanks or standpipes in the following situations:

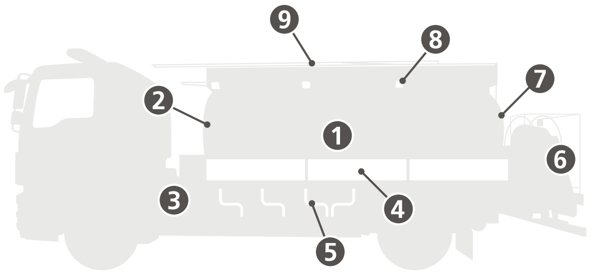
- Problems with the water supply that affect essential facilities, such as hospitals and airports
- Problems with the water supply that have a serious impact on residents, e.g. the incident takes place during meal preparation hours
- Water supply is not expected to be quickly resumed

Alongside the turncock team are the WSD's signature utility vehicles, including water wagons and maintenance vehicles.

WSD (Duration of Supply Interruption) Performance Targets in 2022/23

- Provision of emergency temporary fresh water supply within three hours in 90% of cases, after the isolation of a burst mains
- Resume water supply within seven hours in 70% of cases after repair of burst fresh water mains
- The WSD achieved the above service targets in 2021/22

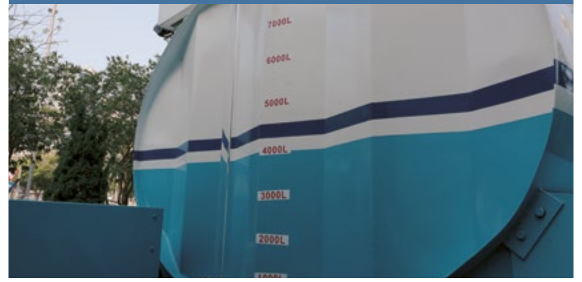
A WSD Water Wagon



▲ In the event of any unexpected situation, the WSD will deploy water wagons to supply emergency temporary fresh water to affected consumers.

① Water tank with a maximum capacity of 8,000 litres

② Water-level gauge indicating the amount of water remaining in a tank



③ Water inlet valve

④ Tool-box

⑤ Water taps, four on each side for a total of eight

⑥ Worktop

⑦ Water tank ladder

⑧ Lighting

⑨ Water tank cover

If there are other fresh water mains in the vicinity of the affected area, the WSD will install a standpipe at fire hydrant to provide water supply in the shortest possible time. Otherwise, water wagons will be deployed to provide temporary fresh water supply.

While temporary water supply is arranged for the affected residents, RCC will inform its contractor to carry out repair work as soon as possible. If the works area involves roads under the purview of the Highways Department, the WSD will immediately apply for an Emergency Excavation Permit and supervise the contractor to carry-out the repair works. Work progress will be monitored and the time for resuming water supply will be regularly reviewed. After the work is completed, the WSD will inspect and confirm its completion. Then, the emergency team will restore valves that were previously in operation. They will also ensure that any trapped air is released from the empty pipes through fire hydrants or washout manholes before resuming water supply. Finally, the CTEC and RCC will be informed for coordination.

WSD Maintenance Vehicles' Equipment

The WSD will deploy their maintenance vehicles whenever a water mains burst is reported. These vehicles are brightly coloured and equipped with various equipment, such as standpipes, valve assemblies and traffic cones used during the inspection and maintenance of emergency burst pipe incidents. This fleet also transports maintenance personnel to the scene of an incident.

In addition to water mains bursts, the WSD will also handle water main leaks, yellowish or abnormal smelling in fresh water, abnormal water pressure, water supply interruptions and even extreme weather events or accidents, and will arrange emergency water supplies if necessary.

▲ The WSD maintenance fleet

▲ A maintenance vehicle equipped with a variety of equipment

Repairs as a Matter of Urgency

Emergency Repairs During Super Typhoon Mangkhut

Waterworks facilities must be maintained on a daily basis to ensure they remain in the best operating condition. However, unpredictable natural disasters can cause disruption and even damage to facilities. The WSD frontline staff have experienced maintenance challenges after several natural disasters.

Super Typhoon Mangkhut became a significant collective memory for Hong Kong people in 2018. Resembling a scene from a disaster movie, the typhoon's aftermath was devastating, with fallen trees throughout the city, sunken roads, and traffic at a standstill. More accustomed to stability and security, the typhoon was a shocking experience for residents. The eye of the storm passed Hong Kong at midnight on 16 September 2018, more than ten hours before major and devastating destruction took place around the city. The waterworks facilities in Tuen Mun and Cheung Chau were affected and, due to a power failure, the Lok On Pai Salt Water Pumping Station was at risk of flooding. Additionally, a large tree had collapsed and ruptured a water pipe, putting the Cheung Chau Fresh Water Service Reservoir at hilltop on the island in danger of emptying and causing a large waterspout to burst during the rainstorm. Despite harsh weather conditions and overcoming many difficulties, the WSD staff from both districts were able to reach these sites for emergency repairs.

Tuen Mun: A Stormy Road

That night after Typhoon Signal No.10 was hoisted, Assistant Electrical Inspector CHAN Fat-lung received a call from his supervisor informing him that Lok On Pai Salt Water Pumping Station in Tuen Mun had stopped operation. CHAN Fat-lung, who has been working with the WSD for more than 30 years, recalled this event: "The suspension of the pumping station would affect the supply of sea water to hundreds of thousands of people in Tuen Mun and Yuen Long causing great inconvenience." After the cancellation of typhoon signal No. 10, CHAN and his colleagues promptly began assessing the situation, hoping to quickly resolve the issue. Starting from his home in Ma On Shan, he drove to Tuen Mun to pick up Senior Technical Officer PANG Chi-keung. The storm made the usual one-hour drive difficult, causing the car to drift. Fallen trees made the trip dangerous and many sections of Tuen Mun Highway were blocked, which forced him to turn back Sham Tseng and head to Lok On Pai from Castle Peak Road. Upon arrival with three hours taken, they still had to overcome some difficulties to access the pumping station.

Their inspection eventually showed that the pumping station had stopped working because of damage to the distribution substation, resulting in a suspension of the electricity supply. To restart the control system, including the electrical protection and distributed control systems, a number of tests needed to be performed. After the system was restored back to normal, the pumping station experienced another problem with the water flow. Emergency staff continued with the urgent repairs and worked round the clock to restore the sea water supply as quickly as possible while typhoon signal No. 8 was still hoisted.

Cheung Chau: A Fall into the Mud

Meanwhile in Cheung Chau, Artisan YIP Kei-ching and Workman II LEE Wai-sum were battling the typhoon's elements. The island's hilltop service reservoir supplies water to Cheung Chau households through a large 450 mm diameter water pipe built along the hill. However, during the typhoon, an uprooted tree tore into the pipe, causing it to burst into a water column that could be seen from as far as the seashore. YIP said he was most concerned about the water in the service reservoir being completely depleted. LEE Wai-sum, a junior officer at the time, joined his supervisor, YIP Kei-ching, and two other colleagues for heading to there to close the valves. The usual hiking trail was impassable due to landslides. Having grown up in Cheung Chau, YIP knew the island terrain well. He led the team along a trail. Due to the strong wind, and pacing along the wet and muddy path, LEE, who was ahead of the team, accidentally fell with half his body falling into the mud. Fortunately, the team was able to help him and together they continued to climb hundreds of steps to reach the service reservoir and with great determination complete their mission.

Throughout the night during the typhoon, the WSD teams in both districts successfully prevented any further water supply incidents. Relieved after the storm had passed, the teams each enjoyed a hearty breakfast in the morning. However, despite taking great pride in their emergency response there was still much work to be done. Looking back, they were glad to have overcome the difficulties caused by the typhoon and avoided causing further inconvenience to the public.

▲ From left to right: Assistant Electrical Inspector CHAN Fat-lung, Senior Technical Officer PANG Chi-keung, Artisans LEE Wai-sum and YIP Kee-ching recalled the danger when working to maintain water supply during Super Typhoon Mangkhut.

▲ Retired Senior Engineer, Ir TANG Hon-yin (left) and retired Chief Technical Officer, TSE Wan-lung (right), have both been responsible for the operation and maintenance of waterworks in different regional offices and have previously experienced numerous storms.

A Comprehensive Emergency Water Supply by Land, Sea & Air

The Hong Kong Observatory recorded the highest hourly rainfall ever in Hong Kong at that time - 145.5 mm of rain between 8a.m. and 9a.m. - on 7 June 2008. The total rainfall for the day was over 300 mm, causing flooding in many areas of Hong Kong. A landslide caused road subsidence on Keung Shan Road near Tai O, disrupting the area's only road access and causing severe damage to a number of water mains. TSE Wan-lung and Ir TANG Hon-yin, who previously held the positions of Chief Technical Officer and Senior Engineer respectively before their retirement and were involved in the emergency repairs at Tai O during this once-in-a-century emergency. "It's all about the professional judgement of our colleagues as well as the cooperation of the entire team," said TSE and TANG.

During the heavy rain, the water supply to Tai O Water Treatment Works was suddenly interrupted. Ir TANG explained that the plant primarily receives raw water from Yi O catchment and Shek Pik Reservoir through a long water supply network. The treated water will then be distributed to the nearby areas. The lack of incoming raw water to the treatment works suggested an issue with the raw water network or other waterworks facilities. However, the cause could not be located. Ir MA Lee-tak, the then-Director of Water Supplies, went to the scene on the night of the incident to understand the situation. By that time, TSE and frontline staff had already done a full day of inspections. "Our colleagues checked along the two raw water supply networks and identified the damaged locations and its severity, and carried out emergency repairs. Once the repairs were completed, they notified their colleagues at the treatment works to reopen the valve for an operational check. If water supply did not resume to the water treatment works, it meant there was further undetected damage to the supply network. "Our colleagues had to continue checking along the water supply network and make further repairs," said TSE. At that time, communication in Tai O was disrupted and smartphones were not widely available, the entire team had no option but to use an older push-button mobile phone to make long-distance calls to the water treatment works via a mainland network. Furthermore, the team had to walk between the water treatment works and the reservoir for almost two hours to manually confirm whether their repairs were successful.

Tai O: Emergency Water Supply Amidst Rescue Efforts

In the meantime, water supply to Tai O was halted and the WSD needed to provide an emergency temporary water supply for over 6,000 residents. Due to the complete closure of Keung Shan Road, water wagons could not be arranged by a land route. Water, using large water tanks, could only be delivered by boat to Tai O Public Pier using the sea route for residents living along the shoreline. Additionally, the WSD also arranged a contractor to deliver bottled water to residents in affected areas by using dinghies. Since the telephone communication network was down, Ir TANG Hon-yin and his colleagues had to trek up mountains, braving heavy rain to inspect the situation. "The heavy rain and landslides made the streams muddy. Some residents were evacuated due to the lack of water and food supplies, while others, such as the frail and elderly were unable to go down the mountain. We saw the Government Flying Service (GFS) dropping food and bottled water to hill residents and wondered if we could use helicopters to lift water tanks up the mountain," said Ir TANG. They were able to make the necessary arrangements after contacting the GFS, setting a precedent for helicopter-assisted water tank delivery in Hong Kong.

▲ The WSD provided bottled water to Tai O residents during the area's disruption of water supply

▲ Residents queueing for water as the WSD made emergency temporary water supply arrangements

While the water mains to Tai O Water Treatment Works were still under repair, there was another emergency unfolding at the Cheung Sha Water Treatment Works on the southern side of Lantau Island. Incoming water was mixed with sludge from the heavy rain, making it difficult for the water treatment works to process the influx. As a result, the water level of the fresh water tank in the service reservoir dropped sharply. TSE arrived quickly at the scene by speedboat and dispatched his colleagues from the Cheung Sha Water Treatment Works to inspect pipes for a possible burst mains. "We discovered that firemen were using the fire hoses connected to street fire hydrants to wash away the mud on the streets, causing a significant drop in water levels at the service reservoir. We had to ask the firemen to halt washing". To ensure an adequate water supply, the WSD also urgently requested the Food and Environmental Hygiene Department to deploy their six recently purchased water wagons. For 24 hours a day, they transported treated water from Silver Mine Bay Water Treatment Works, running along the South Lantau Road to keep filling-up the Cheung Sha Fresh Water Service Reservoir. Meanwhile, KWOK Yau-ding, the Chief Waterworks Chemist before his retirement, was tasked with overseeing the cleaning of the water treatment plant and storage facilities at the Cheung Sha Water Treatment Works. He worked with his team for four consecutive days and nights to prepare for the resumption of the water supply.

Diagram showing emergency repairs and water supply incidents on Lantau Island

Shek Pik Prison & Sha Tsui Correctional Institution: Temporary Water Supply Arrangements

The water supply to Shek Pik Prison and Sha Tsui Correctional Institution[1], both located on the south-western side of Lantau Island, was also disrupted after the heavy rain. Shek Pik Prison's water supply comes directly from the Shek Pik Reservoir and is then treated by the Correctional Services Department's own facilities. However, due to the prolonged rainstorm, the water in the reservoir became extremely discoloured and the WSD had to arrange temporary water supply to the prison. TSE explains: "Water treated at Cheung Sha Water Treatment Works was pumped along South Lantau Road and Shui Hau Pump House to the Tai Long Wan Fresh Water Tank. Our emergency staff installed a temporary pipe system and laid a one-kilometre-long plastic pipe along Shek Pik Reservoir Road connected to a temporary tank placed in front of Shek Pik Prison."

The emergency team spent four days and nights identifying the location of water mains damage near the Tai O Water Treatment Works. Simultaneously, they repaired six sections of the water mains, restoring the incoming water supply to the Tai O Water Treatment Works, and enabling the plant to gradually resume water treatment. However, some of the distribution mains connecting to Tai O households were clogged by mud. The only approach to clean these pipes and inside service components was by flushing with treated fresh water. According to TSE, frontline staff had to dismantle and flush the water meters of each of the approximately 600 affected households before the water supply was resumed to prevent sand and mud reaching households and clogging water meters. The WSD had to mobilise staff from the Regional Office of Hong Kong and Islands, and Kowloon to assist after their own work was complete. Bringing to Tai O their own tools, light food and drinking water and as land transportation had not resumed, some took a boat from Tung Chung Public Pier, while others took land transportation to Keung Shan Road, then walked to the scene. Over 200 staff were mobilised and managed to finish the pipe flushing and replacement of water meters overnight. The water supply resumed at noon on the following day. In total, the emergency repair operations by the WSD and its contractor was for five days and four nights – whilst all personnel were grateful that the work was completed in a timely manner.

1 Prior to 2009, it was called the Sha Tsui Detention Centre

Waterworks in Underground Caverns

Hong Kong has extensive experience in utilising its steep hilly terrain to develop rock caverns for use by various public facilities. In December 2017, the HKSAR Government issued policy guidelines on cavern development to increase land supply and formulated a territory-wide Cavern Master Plan. The plan identifies 48 strategic cavern areas with potential for development and provides planning and technical information for government departments and the private sectors to reference and encourage rock cavern development to optimise land use. The WSD has been proactive in relocating and accommodating waterworks facilities in caverns. This includes fresh and salt water service reservoirs and water treatment works with the goal to release more land for housing or other beneficial uses.

Hong Kong's geology predominantly comprises hard granite, which makes it highly suitable for cavern development. This is especially the case on the urban fringes, where it is easily accessible, benefiting both construction and future users. Some countries, such as Canada, Finland, Japan, Korea, Norway, Singapore, Sweden and the United States, along with cities in the mainland, have developed sophisticated techniques for constructing caverns that serve a wide range of purposes, ranging from sewage treatment works and waste transfer stations to popular community and recreational facilities. In Hong Kong, a number of government facilities have been built in caverns since the mid-1990s, including the Island West Transfer Station, the Stanley Sewage Treatment Works and the Kau Shat Wan Explosives Depot.

◀ Western Salt Water Service Reservoirs built inside a cavern

The Western Salt Water Service Reservoirs

The Western Salt Water Service Reservoir and Western No. 2 Salt Water Service Reservoir completed in 2009 are the first two WSD service reservoirs built in caverns. As part of the development of The University of Hong Kong's Centennial Campus, the WSD commissioned the university to relocate two nearby salt water service reservoirs into caverns, and convert the original salt water service reservoirs into fresh water service reservoirs. This was done to vacate ground-level space for the construction of a new academic building.

Situated at Lung Fu Shan near The University of Hong Kong, the cavern is the first of its kind in Hong Kong to be bored into a tunnel, 100 metres in length. It houses two salt water service reservoirs of the same size, with the span of the cavern for each service reservoir reduced. This approach helped to lower the difficulty of construction and its cost. The project was executed through drilling and excavation instead of blasting, avoiding extensive slope cutting and tree felling, thus ensuring minimal environmental impact. The three historic buildings at the former Elliot Pumping Station and Filters, the Senior Staff Quarters, Workmen' Quarters and Treatment Works Building, have all been preserved.

The cavern has a mechanical ventilation system that extracts air inside the cavern through air chutes at the bottom of the tunnel passageway, allowing fresh air to flow through the cavern inlet. Air detectors are installed to maintain safe air levels in conjunction with the ventilation system. The ventilation system can either be controlled manually, automatically or by remote control. The ventilation system will automatically activate if the air quality inside the cavern falls below the set standards.

▲ Entrance to the Western Salt Water Service Reservoir and Western No.2 Salt Water Service Reservoir

Information on Western Salt Water Service Reservoir and Western No. 2 Salt Water Service Reservoir
Location: The University of Hong Kong
Opening year: 2009
Distance from adjacent housing: Less than 100 metres
Size of each cavern: 50 metres long, 17.6 metres wide and 17 metres high
Storage capacity: 12,000 m³
Purpose of construction: Free-up ground space for the Centennial Campus of The University of Hong Kong

A heat detector is also installed to sound an alarm when the temperature inside the cavern reaches 57°C. A closed-circuit television system is also in place to ensure the safety of staff working inside the cavern, allowing other staff to observe the cavern from the entrance.

As it is Hong Kong's first cavern water service reservoir, it has become a popular tourist attraction. In 2013, the Hong Kong Institution of Engineers named it as one of the "Hong Kong People Engineering Wonders in the 21st Century".

▲ The salt water service reservoir within the cavern was designed in the form of a 100 metre long tunnel

▲ The Water Treatment Works Building at the former Elliot Pumping Station and Filters, located next to the Western Salt Water Service Reservoirs, has been graded as a Grade III historic building.

Increasing Housing Supply by Relocating Other Waterworks Facilities to Caverns

In recent years, the WSD has been actively pursuing a number of projects to relocate waterworks facilities to caverns. The Diamond Hill Fresh Water and Salt Water Service Reservoirs at Shatin Pass Road, Wong Tai Sin, will be relocated to a cavern complex inside the body of the mountain at the south of Lion Rock. This will release about four hectares of land at the original site by 2027 for housing development, government, institution or community use.

Other relocation projects being explored include the relocation of the Tsuen Wan No. 2 Fresh Water Service Reservoir near Cheung Shan Estate to the Smuggler's Ridge cavern area in north-east Kwai Chung. After completion of the relocation project in 2029, together with the adjacent slopes, over six hectares of land will be released for public housing development.

Schematic illustration of the relocation of Diamond Hill Fresh and Salt Water Service Reservoirs to a cavern

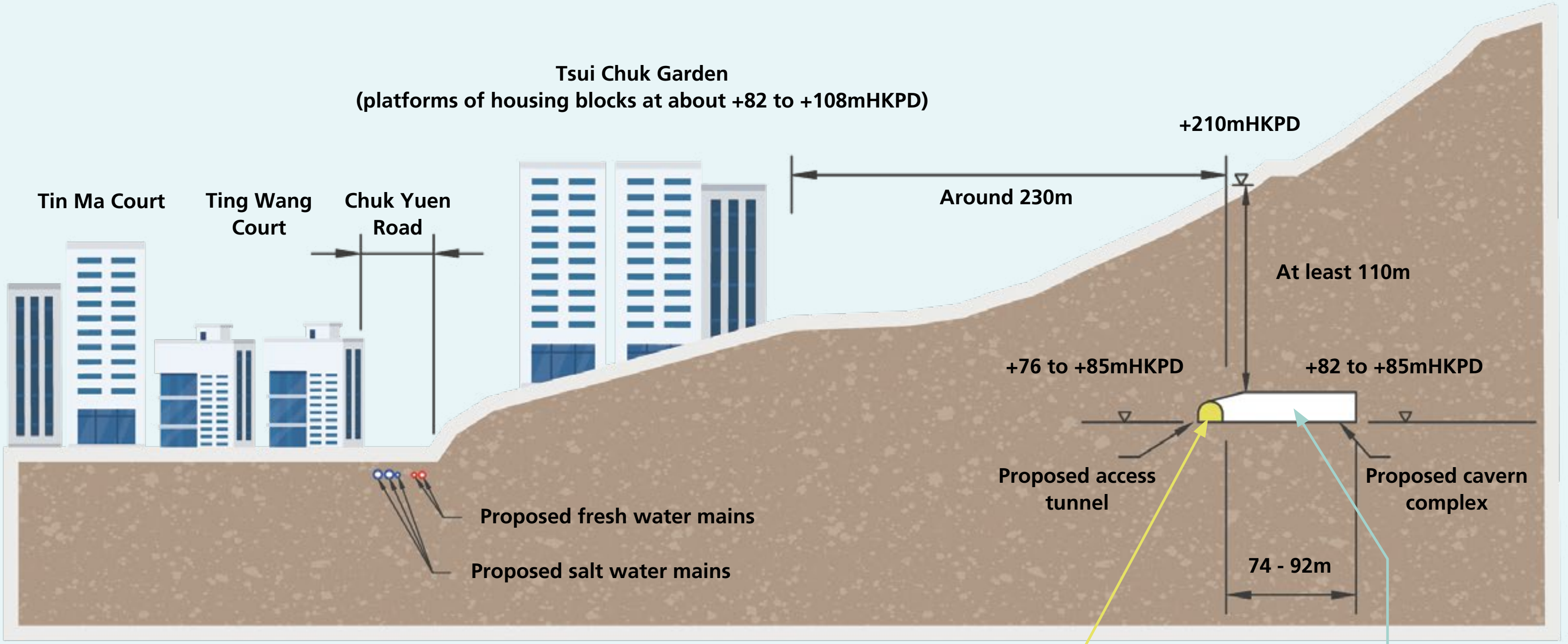
Proposed access tunnel

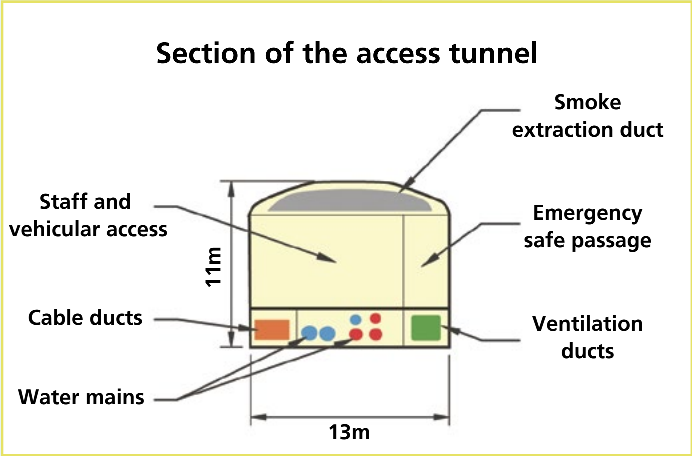
Proposed Diamond Hill Fresh Water and Salt Water Service Reservoirs and Pumping stations

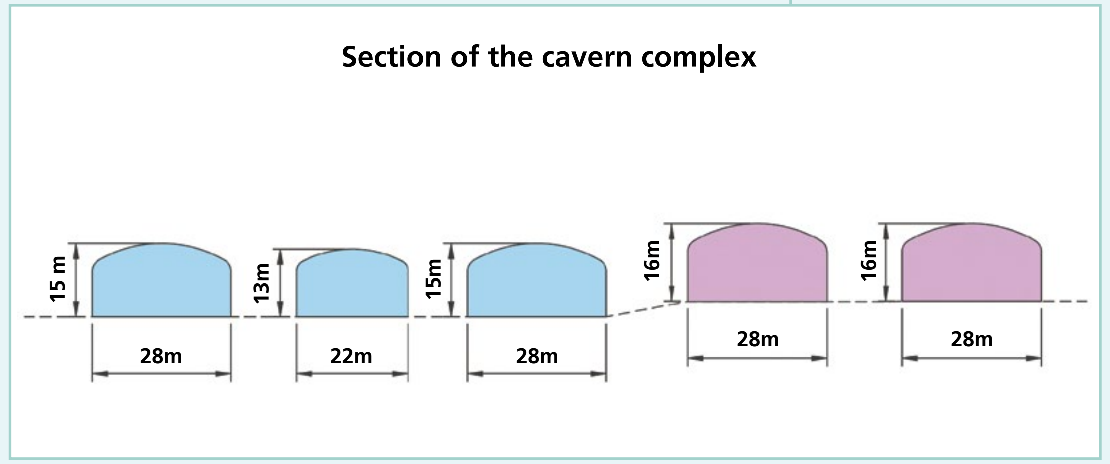
Existing Diamond Hill Fresh Water and Salt Water Service Reservoirs, and Pumping Stations (about four hectares)

Proposed ventilation and other associated E&M facilities at access tunnel portal area (conceptual drawing)

Side view of the cavern complex







+mHKPD = metres above Hong Kong Principal Datum

The City's Historic & Remarkably Built Service Reservoirs

The preservation and granting of a Grade 1 historic building status to the long-decommissioned Ex-Sham Shui Po Service Reservoir by the Antiquities Advisory Board (AAB) in 2021 set a precedent for the assessment of the city's underground historic buildings. The building and reservoir's preservation allows the public a glimpse of the century-old gravitation water supply system and the internal structure of its huge water storage facility, revealing excellent engineering design that had previously been hidden from the public. Hong Kong's first service reservoir, the Albany Fresh Water Service Reservoir in Mid-levels, has been serving the city for over 130 years and is still in operation today. In a rapidly developing city like Hong Kong, it is one of the very few historic public facilities that have maintained their original use.

Grade 1 historical buildings are defined as those of "outstanding merit" due to their historical, architectural, social, rarity, and/or group value. In addition to the city's large-scale reservoirs and related buildings and facilities, the AAB has also granted five underground and hidden service reservoirs as Grade 1 historic buildings in 2021. This official recognition acknowledges their heritage value.

Hong Kong's Service Reservoirs Graded as Historic Buildings

Year of completion	Name	Location	Capacity (m³)	Grading
1888-89	Albany Fresh Water Service Reservoir	Mid-levels, Central	25,912	1
1894	Ex-Yaumati Service Reservoir	Yau Ma Tei	740	1
1897	Peak Fresh Water Service Reservoir	The Peak, Hong Kong Island	1,859	1
1903	Mount Gough Fresh Water Service Reservoir	The Peak, Hong Kong Island	961.5	1
1904	Ex-Sham Shui Po Service Reservoir	Sham Shui Po	9,900 (Reduced to 4,800 after alteration in 1951)	1

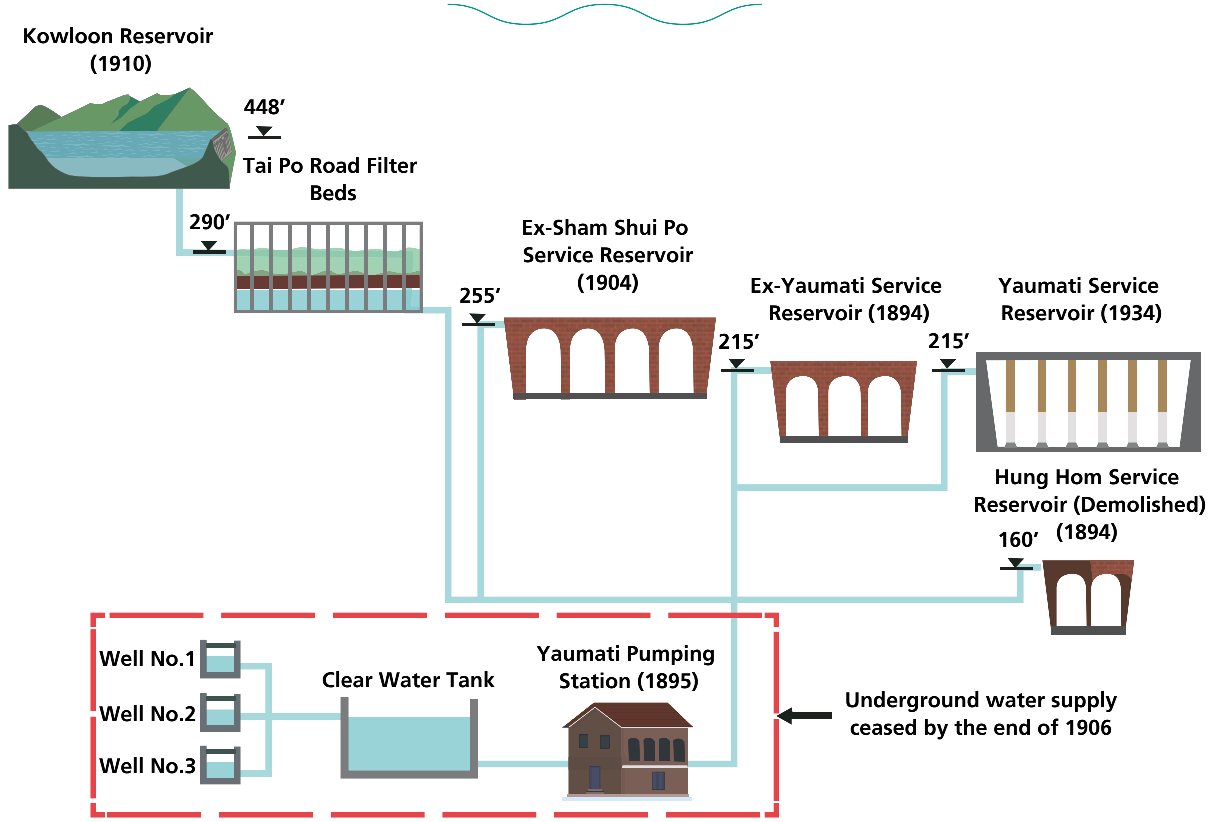
The Ex-Sham Shui Po Service Reservoir

The Ex-Sham Shui Po Service Reservoir dates back to the leasing of the New Territories by the British from China in 1898, a time when Hong Kong's population and demand for water was significantly increasing. During the construction of the Kowloon Reservoir, the Hong Kong Government made plans for the development of the water supply system throughout Kowloon. As part of this expansion, the Ex-Sham Shui Po Service Reservoir was built as a supporting facility. Kowloon had previously relied on only three wells for its water supply, providing a very limited volume of water. The construction of this service reservoir is a testimony to Kowloon's urban development and the corresponding increase in water demand. The Ex-Sham Shui Po Service Reservoir is the first service reservoir to be graded as a historic building. Until recently it had been closed for half a century, but nowadays it is an historic water facility open to the public and located amongst green hills and a popular recreation area for local residents.

The old Kowloon water supply system comprised the Kowloon Reservoir, the Filter Beds at Tai Po Road in Cheung Sha Wan, and the Ex-Sham Shui Po Service Reservoir. It was also connected to the Ex-Yaumati Service Reservoir and Hung Hom Service Reservoir (now demolished), which had been in use since 1894. This system relied on the principle of gravitation to deliver water from an elevated point to a distant low-level user without the need for an electricity-consuming pumping system. The Ex-Sham Shui Po Service Reservoir was initially designed as a balance tank. It temporarily stored any excess water that had not been transferred to the filter beds or directly to consumers.

▲ Interior of the Ex-Sham Shui Po Service Reservoir

Early stage of Kowloon Waterworks Gravitation Scheme



The Ex-Sham Shui Po Service Reservoir is the first circular-shaped service reservoir in Hong Kong, covering an area of 1,600 m². The circular shape was designed to achieve the maximum area with the shortest perimeter, saving on the cost of the reservoir's wall construction. When it was completed, it had a diameter of 46 metres, a floor-to-ceiling height of 6.85 metres and a capacity of 9,900 m³, ten times the capacity of the earlier service reservoirs built at Yau Ma Tei and Hung Hom in Kowloon. However, due to leakage, the wall of this service reservoir was thickened during repairs in 1951 and its inner diameter was reduced to 38 metres. As a result, the capacity of the reservoir was also reduced to 4,800m³.

Architectural Design Features

The architectural design of the service reservoir placed emphasis on its capacity and span, which required considering feasible construction practices and materials. The concrete ceiling of the Ex-Sham Shui Po Service Reservoir was cast in-situ. As such, the weight of the concrete ceiling and topsoil was transferred from the interior vaulting to the granite spring rocks on either side, and then down to a number of brick arches and their associated 108 rectangular granite piers. It is interesting to note that the rusticated rectangular granite support blocks have been revealed to be of a stunningly even design. These blocks provide a slightly varied visual rhythm within the overall simplicity of the structure, it is both practical and aesthetically beautiful.

In addition to the structure, the service reservoir also includes inlet and outlet components. These include an inlet pipe at a high level, a stilling well, and an outlet at a lower level that extends to a central location. The difference in position and height allows water to efficiently flow in and out, preventing stagnation.

In 2021, the WSD conducted temporary strengthening works for the service reservoir. Also launched at the same time is an interactive virtual tour on the WSD website and in-person on-site guided tours for the public to see the service reservoir's previously inaccessible waterworks facilities. The tours also provide education to the public on how the current modern water supply system provides convenience in daily life.

Virtual Tour of the Ex-Sham Shui Po Service Reservoir

▲ Inside the Ex-Sham Shui Po Service Reservoir, three types of building materials have been used, each with its own functional consideration.

◀ Stilling well, inlet and outlet pipes in the Ex-Sham Shui Po Service Reservoir

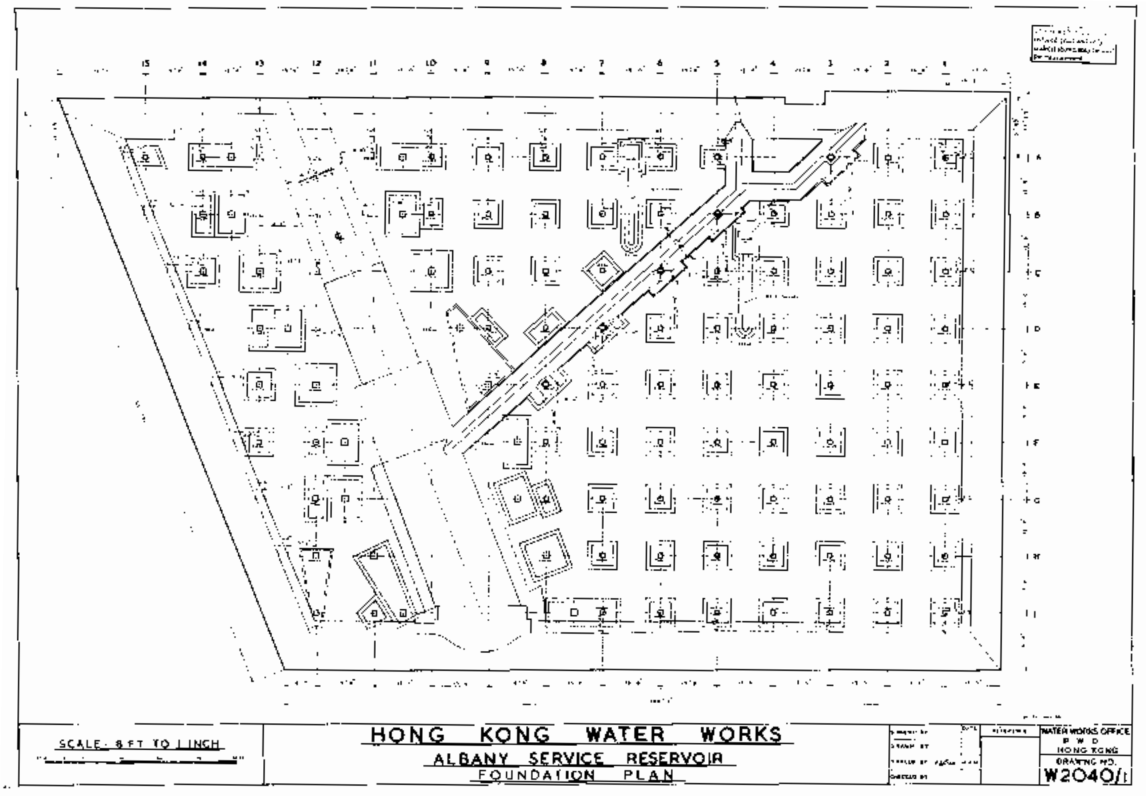
Older Heritage Water Service Reservoirs

Albany Fresh Water Service Reservoir

The Albany Fresh Water Service Reservoir is the oldest preserved service reservoir in Hong Kong. Located near Magazine Gap Road in Mid-levels in Central, the service reservoir is one component of the Tai Tam Reservoir System built in Tai Tam Valley to transport water to the old city of Victoria, now the Central and Wan Chai areas. The service reservoir has been operating since being developed in the 1880s and is connected by a tunnel that passes through Wong Nai Chung Gap and features a water channel that connects to Bowen Aqueduct. As water descends the hill along the Albany Valley, it is filtered through the filter beds before being transferred to the Albany Fresh Water Service Reservoir for storage.

Originally designed as an open reservoir, the Albany Service Reservoir is 45.7 metres wide and 9.1 metres deep, with a capacity of 25,912 m³. It is the largest of the city's five reservoirs that have survived for over a century. It can cater to a maximum water level of approximately 116.9 metres above Hong Kong Principal Datum (+mHKPD). This service reservoir was originally designed to deliver water by gravity by delivering it along cast iron pipes to households in the coastal areas of the city of Victoria. Water originally flowed downwards running through two pumping stations located at Garden Road and Arbuthnot Road at that time, generating hydraulic power to transfer water to the then Peak Road Fresh Water Service Reservoir and another south of Bellilios Terrace on Robinson Road.

The Albany Service Reservoir is a concrete structure with perimeter walls faced with rubble (i.e. irregular gravel). The western part of the service reservoir was built over a culvert, with an arched structure arranged from large to small in the storage space. In 1929, a dividing wall was added to create two separate water supply storage spaces, allowing for maintenance works to be carried out without interrupting the water supply. In 1953-54, a reinforced concrete roof was added to the service reservoir. Before this addition, the reservoir was uncovered, and the water quality was affected by rain. The historic building is still in service, but not open to the public as it still holds fresh water.



▲ Layout plan of Albany Fresh Water Service Reservoir

▲ The interior of the Albany Fresh Water Service Reservoir after emptied of water

The Ex-Yaumati Service Reservoir

The Ex-Yaumati Service Reservoir was constructed in 1894 and is the oldest service reservoir in Kowloon, predating the Ex-Sham Shui Po Service Reservoir. Prior to the British leasing of the New Territories, there was insufficient high ground in Kowloon to construct reservoirs. As a result, the only means of obtaining water was by digging wells and using a pumping system to deliver fresh water directly to consumers. The surplus water was pumped to two service reservoirs, the Ex-Yaumati Service Reservoir at King's Park and the now-demolished Hung Hom Service Reservoir, both used to control the water supply.

The rectangular Ex-Yaumati Service Reservoir covers an area of approximately 163 m², with a building height of around 5.21 metres at its highest point. The service reservoir had a water capacity of 740 m³. It is significantly smaller in scale than other reservoirs. The walls, cove ceiling, arches and piers are all made of red brick, imitating Roman civil engineering. The roof is supported by six piers with a span of 2.89 metres and 3.48 metres. Although the building has survived, it has been out of use since 1934, probably due to severe leaks or replaced by a newer service reservoir.

▲ The interior of the Ex-Yaumati Service Reservoir emptied of water

The Peak Fresh Water Service Reservoir

The Peak Fresh Water Service Reservoir, situated on Victoria Peak with a maximum water height level of +533mHKPD, was constructed in 1897. It is located at a higher elevation than its water supply reservoir, Pok Fu Lam Reservoir. Initially, when Hong Kong's first reservoir was completed, the residents of the Peak were not an immediate priority and their water supply was mainly from wells. The government proposed a reservoir-based water supply system for the Peak only after a further decade of population growth. To support the water supply system, a pumping station at Bonham Road was required as the Peak area is higher than the supplying reservoirs.

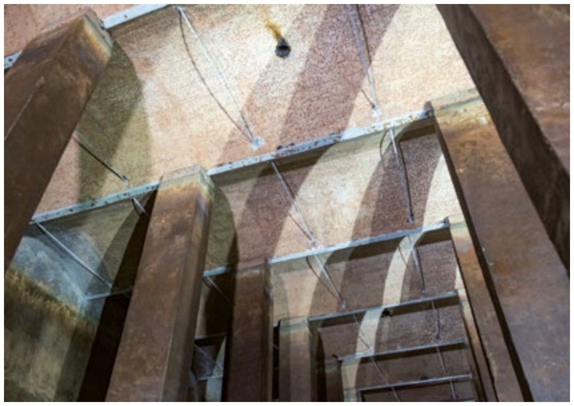
Today, the Peak Fresh Water Service Reservoir is still in use, with water supplied from either Tai Po or Sha Tin Water Treatment Works. Although different from its original design, the structure is still connected to the surviving heritage group of the Pok Fu Lam Reservoir water supply system. Its longevity is a testament to the excellent development of the water supply system in those early years.

▲ The interior of the Peak Fresh Water Service Reservoir after emptied of water

The Mount Gough Fresh Water Service Reservoir

The Mount Gough Fresh Water Service Reservoir completed in 1903 was the second service reservoir built for the Peak area. Its original design received fresh water coming from the Tai Tam Reservoir. Raw water was conveyed through the Tai Tam Tunnel and Bowen Aqueduct to the Bowen Road Filter Beds. From there, the Bowen Road Pumping Station pumped water to this service reservoir for storage. It has a top water level of approximately +462mHKPD and a capacity of about 961.5 m³. Following the demolition of the Bowen Road Filter Beds and Pumping Station, the Mount Gough Fresh Water Service Reservoir is now supplied by either the Tai Po or the Sha Tin Water Treatment Works. Fresh water is pumped to this service reservoir from various pumping stations through a cross-harbour mains.

Architecturally, the southern wall of the Mount Gough Fresh Water Service Reservoir is backfilled to the top, while most of the exposed northern wall is paved with masonry. This gives the service reservoir's façade a magnificent-looking appearance.

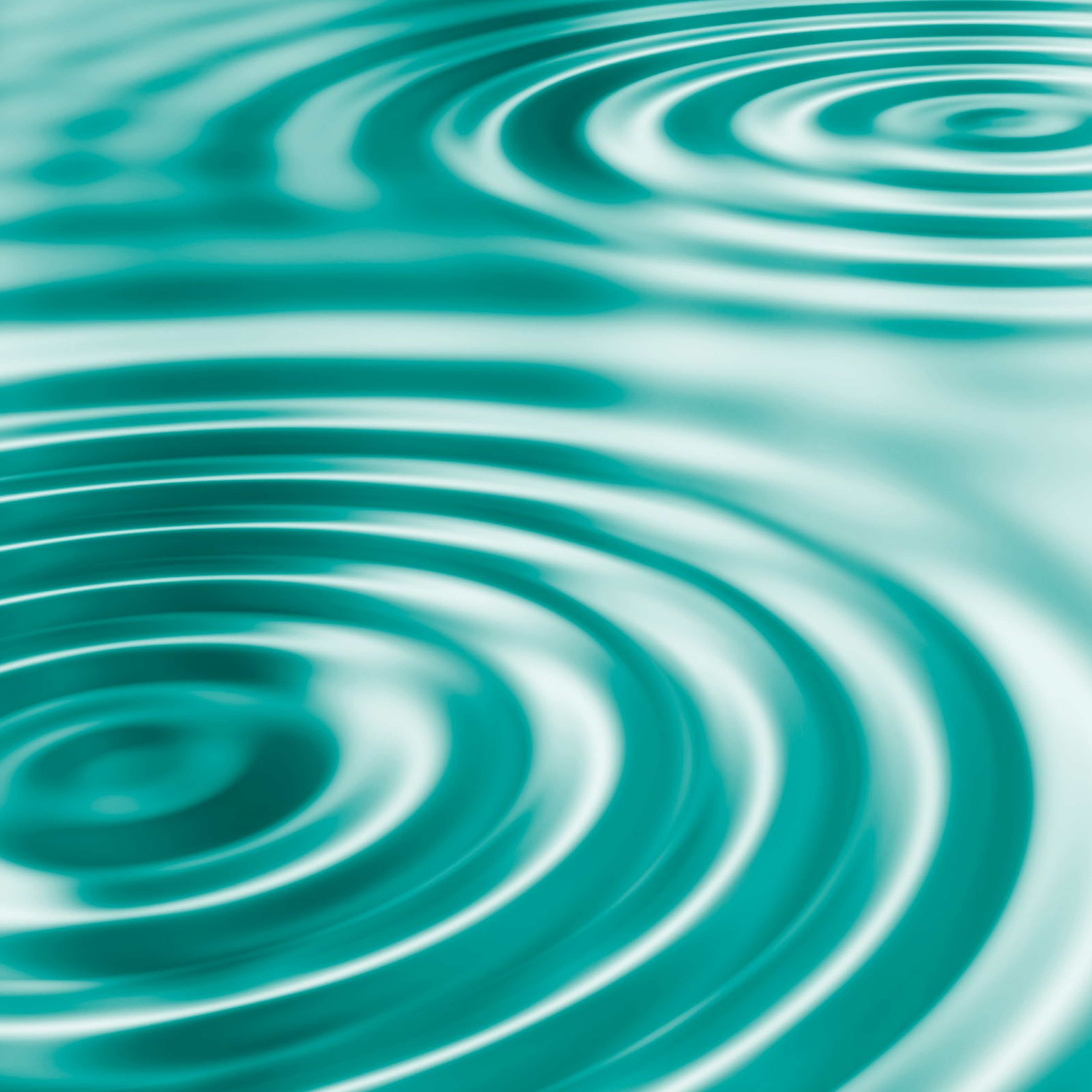


▲ The interior of the Mount Gough Fresh Water Service Reservoir after emptied of water

▲ The external masonry wall of the Mount Gough Fresh Water Service Reservoir

4

INSIDE SERVICE FOR WATER DISTRIBUTION



The Water Supply Closest to Home

Since the city's earliest days, the Hong Kong government undertook the responsibility of developing the territory's entire water supply services. A comprehensive water supply system was planned and began to take shape: beginning with the development of water sources, treatment and purification, the construction of distribution networks, and then the delivery of water to all parts of Hong Kong. The previous chapter introduced the development and principles of the city's water distribution network. This chapter covers the final component of the city's water supply system, known as the "inside service". Although closer to the consumers, it is less noticeable to them.

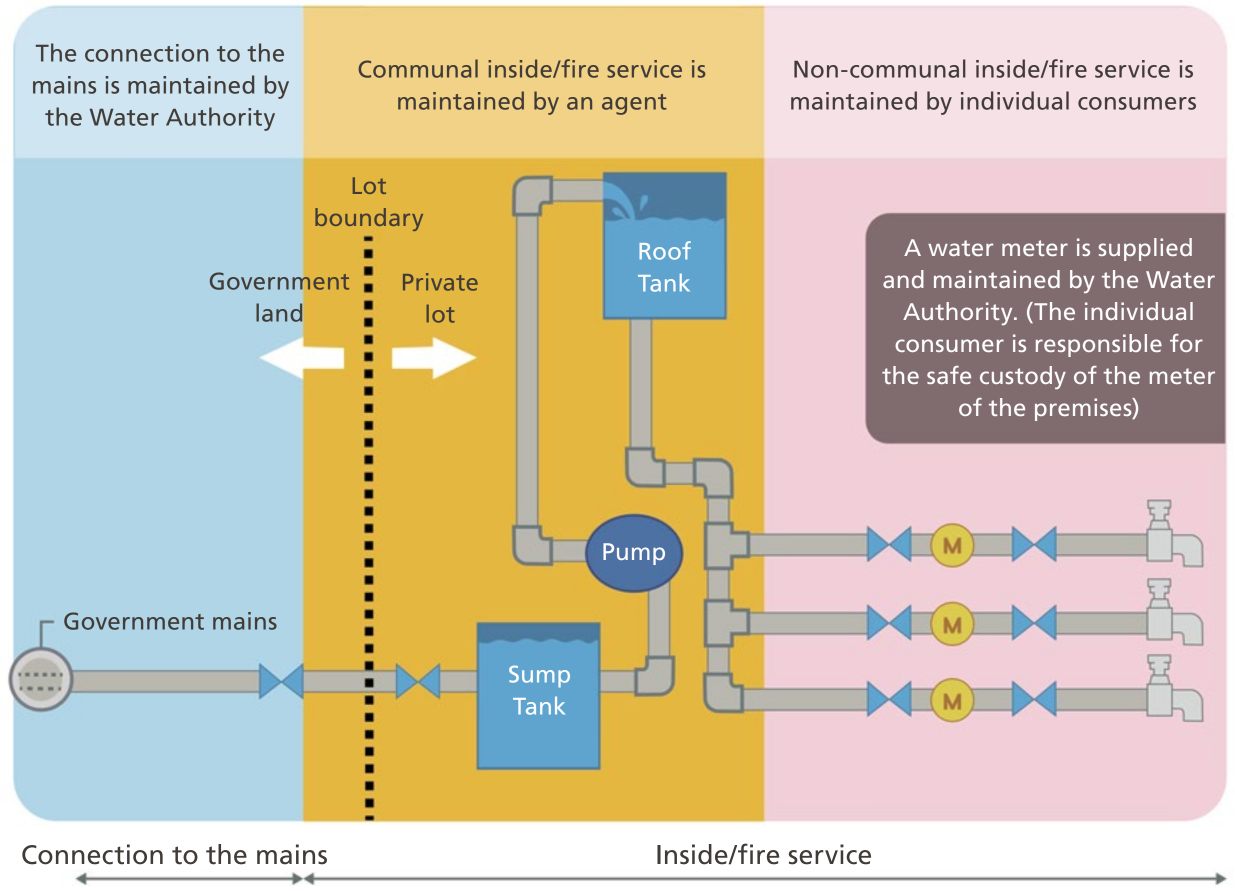
Inside service refers to a building's water system that starts and is supplied from the connection point to the mains located generally near to a lot boundary, where the water mains of a housing estate or building is connected to the Water Supplies Department (WSD) mains, and ends at the tap inside an individual consumer's premises. The inside service is divided into two sections: a communal service and a non-communal service. The communal parts of the inside and fire service, including pumps, tanks, communal water pipes as well as other ancillary utilities, are generally held and maintained by a registered agent[1] (e.g. owners' corporation and property management representative). The non-communal parts of the inside service are solely for water supply to individual premises and refers to the pipes and taps in the flat connected to the communal pipes. It is the responsibility of individual consumers[2] (e.g. an owner or occupant of the premises) to maintain and repair their part.

This chapter, Inside Service for Water Distribution, begins by assessing the legislation, providing an overview of the background and subsequent changes in the inside service. As a result, the licensed plumbing profession has evolved to be responsible for the plumbing works (including installation, maintenance, repair, etc.) to the inside service of buildings.

Over the years, buildings in Hong Kong have become increasingly taller, from an average height of 3.6 storeys in the early 20th century to 9.39 storeys in the 1960s. Nowadays, new buildings often are dozens of storeys in height. Consequently, the scale of plumbing works has expanded significantly. With the raising concern about water safety, the WSD has recently been collaborating with the industry to improve the professionalism of licensed plumbers.

As a public service provider, the WSD has a supervisory role. It also has a commitment for providing customer satisfaction, spearheaded by the introduction of a work performance pledge in 1993. The pledge's 30 performance indicators serve as the basis for the WSD to annually review its performance and improve its service quality.

Schematic diagram of the government mains connection and the inside service



1 Under Section 2 of the Waterworks Ordinance (the Ordinance), an agent is a person who is recognised as an agent for a public water supply system under Section 7 of the Ordinance.

2 Under Section 2 of the Ordinance, a consumer is a person who is recognised as a consumer of a fire service water supply system or an inside service under Section 7 of the Ordinance.

Inside Service:
Its Development and Principles

▲ WSD water meters connected to a building's inside service

Comparable to the territory-wide water distribution system, the inside service is similar in function by receiving water at a single intake point and distributing it to different individual outlets. However, the difference between the two is not only in scale, but also in the construction and maintenance responsibilities between public and private water supply systems. From this perspective, an acceptable inside service, including a water distribution system, must ensure three features:

1. The fresh water in the system must be clean and hygienic;
2. Water is delivered at a sufficient pressure to each consumer, and
3. All system components are in good condition, and free from leaks or external contaminants from entering the system.

An acceptable inside service must therefore meet the above requirements from design to maintenance.

It Begins with Tap Water

The history of inside service can be traced back to the very first introduction of tap water in Hong Kong. The water supply system at Tai Tam Reservoir was completed in 1888 and a water distribution network was gradually established throughout the city of Victoria. To discourage water wastage, the government implemented the "user pays" principle, which included the introduction of a tap water system and use of water meters to record consumption. It then became an owner's responsibility to connect domestic water mains to the government water mains.

In 1890, the government enacted the Waterworks Ordinance (the Ordinance) to regulate for the first time the inside service conveying the supply of tap water. The Ordinance stipulates that an owner or occupier of any tenement who wishes to construct, alter or repair an inside service is required to make application to the Water Authority and pay relevant water charges. All the plumbing works involved to construct, or alter inside service must be carried out in accordance with the requirements of the Water Authority, and comply with the prescribed specifications on water pipe materials, quality and dimensions and any other aspects. All plumbing works must be inspected and tested by the Water Authority before the water supply is officially connected[1].

The Ordinance has undergone a number of amendments with the development of the city's water supply system. In 1938, the Ordinance made it the responsibility of the consumer to "keep the inside services clean". If any part of an inside service is discovered to be dirty and contaminating the water in the mains as considered by the Water Authority, a notice will be issued to the consumer. They will be required to clean the system within three days or otherwise have the water supply disconnected. Other regulations also included:

- The first introduction of a licensed plumber system (see the article "Evolution of the Licensing System for Plumbers" in Chapter 5 for more details), which requires anyone who constructs, alters or repairs inside service for a household must hold certificates issued by specified bodies;
- Setting quality standards for all types of materials used in plumbing works. At that time it was specified that lead pipes or solder could not be used for inside services or fire services;
- To specify that the use of booster pumps shall not be permitted except where water cannot reach the roof level by gravity. In order to avoid direct pressurisation of the water mains, such buildings require a sump tank at a level where it can be supplied from the government mains by gravity, from which the fresh water can be pumped up to a roof tank.

The sale of separate units of flats beginning in the 1940s changed the ownership of a building from a single owner to multiple owners sharing the land. As a result, the responsibility for management and maintenance of the inside service has been shared between a registered agent and the registered consumers of a whole building or estate.

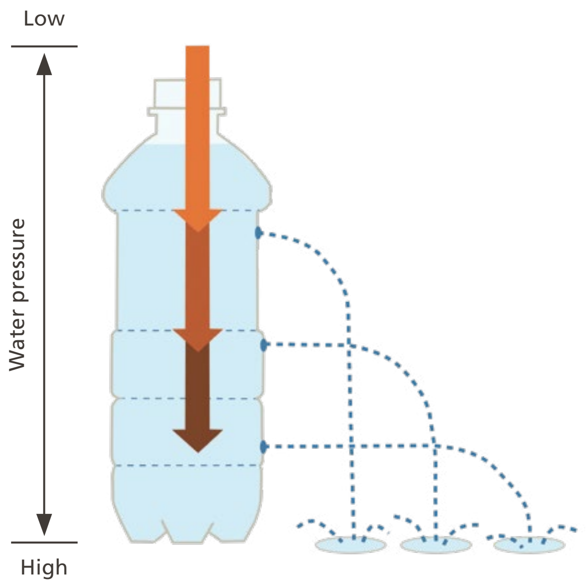
1 Government Notification -- No.343. *The Hong Kong Government Gazette*. 16th August 1890 https://sunzi.lib.hku.hk/hkgro/view/g1890/656245.pdf

The Operating Principle of the Inside Service

The water distribution network in Hong Kong is designed to allow water to flow by gravity as far as possible through a network of water mains for distribution to customers throughout the city. Therefore, water in the mains is always kept under pressure. To ensure adequate water supply pressure, the WSD has a performance pledge to maintain fresh water pressure of 15 to 30 metre head. However, buildings in Hong Kong are situated on terrain of varying heights, and in recent years, they have become increasingly taller. This represents a significant challenge for the inside service to provide adequate water pressure to consumers on both higher and lower floors, without damaging the water supply components.

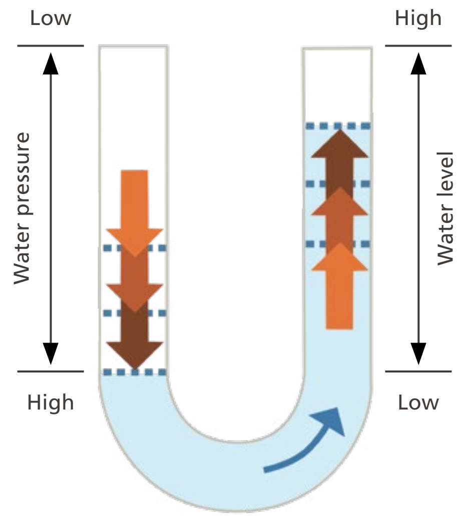
Since the introduction of the water pump, water flow is no longer restricted in a mode from high to low ground. Also, with external pressure, water can flow in the opposite direction from low-lying to higher-level land. The pressure of water varies according to the height during these two types of conveyance:

Two Modes of Water Delivery: Using Water Pressure and Height



Top-down Water Supply

The water in the lower part of the bottle experiences greater pressure due to gravity. The water pressure can be determined by the distance from the water jet.



Bottom-up Water Supply

Water can flow uphill when subjected to pressure greater than gravity. Water can reach higher-level positions as the pressure increases. However, the water level rises less as the pressure increases due to the counteracting effects of gravity.

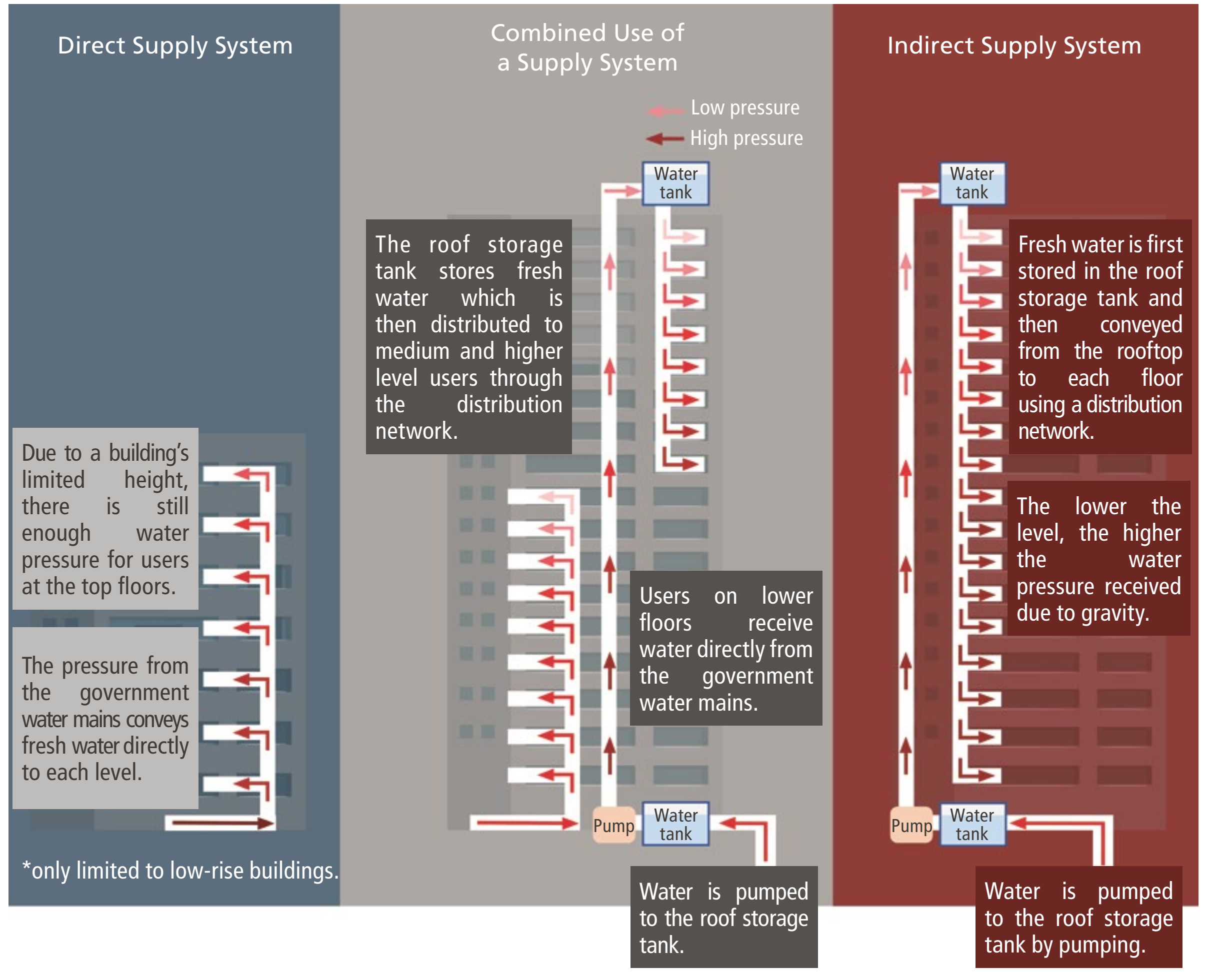
A water pressure of 15 to 30 metre head is a stated WSD's performance pledge, and sufficient to deliver fresh water directly from the government mains to the building up to six to seven floors. This mode of using mains pressure to supply fresh water to the upper floors is known as the "direct supply system". It was commonly used in low-rise tenement buildings in the city's early years. During periods of high water consumption, users at a building's upper floors may experience low water pressure. This situation is famously captured in the quote from many movies of the 1950s and 1960s: "Those of you living downstairs, turn off the tap!"

In theory, increasing water pressure can transfer fresh water to higher floors to meet water pressure requirements. However, excessive water pressure increases the risk of damage and bursting of lower floor water pipes. Therefore, to deliver water to upper floors, a separate water supply system, known as the "indirect supply system", is required.

The primary distinction between a direct and an indirect supply system is whether the water supply passes through a roof storage tank. As buildings increase in height, a combination of direct and indirect supply systems is generally employed. The diagrams on the right provide a brief explanation of how they function.

Using solely direct or indirect water supply systems in high-rise buildings can result in a significant difference in water pressure between users on upper and lower floors. Water pipes on lower floors are particularly prone to damage, leakage and burst due to excessive water pressure. Therefore, most buildings have adopted a combined supply system, where water is supplied directly to the lower floors, and the middle and upper floors are supplied with water from roof storage tanks.

Principle of the Inside Service



Inside Service at a Glance

The inside service is divided into fresh water supply, flushing supply and fire service supply[2] according to their purpose. Each has its own supply system, which includes an underground storage tank, a roof storage tank, a master water meter, a pump and pipes. However, for buildings completed before March 1987, the Water Authority and the Director of Fire Services may approve the use of the existing fresh water tanks for fire services, subject to structural and space limitations.

#Fun Fact

Why is Tap Water Milky White?

Have you ever turned on your water tap one day and found that the water is milky white?

This is a common occurrence when the water is resupplied after cleaning a building's storage tank. Prior to cleaning the tank, the cleaner will first turn off the inlet valve and drain the water from the tank through the drainage pipe before thoroughly cleaning the tank. During this process, air enters the outlet pipe. When the tank is refilled, the water supply system is restarted and the water, along with air, is conveyed through the water pipe to the household taps. Due to the water pressure and turbulent flow in the water pipe, the air in the water is impelled to form numerous tiny bubbles, which visually gives the water a milky white colour.

Once the water is left for some time, the air bubbles disappear, and the water becomes clear again. These bubbles, however, do not affect the water quality. The WSD recommends consumers turn on a tap for about two minutes after cleaning the building's storage tank to allow air to escape.

Underground and Roof Storage Tanks

The indirect supply is provided with additional underground and rooftop storage tanks. The underground tank buffers the water pressure in the government water mains, and facilitates the pumping of fresh water to the rooftop. The rooftop tank is used for temporary storage of fresh water delivered to consumers.

To achieve a 24-hour uninterrupted water supply, it is crucial to accurately calculate the size of the storage tank. If a roof storage tank is too small, it would increase the building's energy consumption by activating the water pump too often. If the tank is too large, it would increase the weight of the building. Additionally, the longer the water is stored, the greater the risk of deterioration in water quality. Therefore, the WSD has developed a formula for calculating the capacity of storage tanks. Consider a residential building as an example: the capacity of its rooftop fresh water tank is calculated based on the total number of households to be served. Assuming that the first 10 households each consume 135 litres and the remaining households each consume 90 litres, the calculated capacity ratio of the underground and roof storage tank should be 1:3[3].

While the WSD regularly monitors the quality of fresh water in the distribution network, it is the responsibility of the consumer to maintain the quality of fresh water once it enters the inside service. In addition to managing the water supply system properly, regular cleaning is also important, especially for water tanks where fresh water is stored. The WSD recommends cleaning water tanks at least once every three months, because stored water can accumulate dirt and impurities due to a long standing time.

▲ Fresh water storage tanks in buildings

Water Meters and Master Meters

In Hong Kong, water meters were first introduced in 1897 to record the consumption of water used by each consumer during a recording period.

Recently, the WSD introduced smart water meters to improve the efficiency of collecting water consumption data from customers. A smart water meter uses technology that automatically records the water consumption of an entire building and of individual units. Consumers can check their water consumption using their mobile phones or computers. Any abnormalities in the system, such as leakages, can be detected early by checking recorded data and to arrange maintenance. This technology has reduced water wastage and eliminated the need for manual meter reading.

The master meter was introduced in response to the Water Authority's endorsement of the "Master Metering Policy" in late 2005. This policy requires that all new buildings include a master meter position in a plumbing layout design. The first stage of this policy applies to new housing estates with two or more blocks, while the second stage applies to large estates that are already occupied. The master meter room is typically situated within and near the boundary of the housing estate to measure the total amount of fresh water supplied to the development. The fresh water system located downstream of the master meter requires that all domestic units or water points must have individual water meters. The water consumption recorded by the master meter will be compared against the total water consumption logged by each individual consumer to detect leakage or unlawful taking of water from the inside service.

Providing the public with a basic understanding of their building's inside service will help maintain water safety in the long run and benefit consumers.

▲ A master meter measures the total amount of water supplied by the WSD in housing estates

2 Under the Fire Safety (Buildings) Ordinance implemented in 2007, the HKSAR Government requires the separate installation of fire service installations, such as water tanks, sprinkler systems, etc. in premises.
3 (March 2018) 'Appendix A1: Checklist for vetting plumbing proposals', *Handbook on Plumbing Installations in Buildings*. Hong Kong: Water Supplies Department. 48. https://www.wsd.gov.hk/filemanager/en/content_1369/HBonPIB.pdf

The Development of Hong Kong's Water Meters

▲ Waterworks staff installing water meter

Water meters are an integral part of Hong Kong's water supply system and have been in use since the late 19th century. Because clean water is such a valuable resource, meters are installed in every Hong Kong household to record a consumer's water consumption. Over time, water meter models have changed and evolved. For example, water meters were replaced in the 1970s following the adoption of the metrication policy that changed the measurement of volume from imperial gallons to cubic metres. The campaign to promote the adoption of metrication at the time has signified Hong Kong's move towards internationalisation. In recent years, water meters have become increasingly intelligent and these models are gradually being installed in new urban development areas. This initiative is another step towards the automation of all data recording.

Water meters are installed in both commercial and residential units and individual consumers are allocated their own. Domestic water meters are typically 15 mm in diameter to cater for a small flow rate, while commercial water meters vary in size depending on the needs of the customer's industry and the size of the business. For instance, a "cha chaan teng" (restaurant serving local fast food) usually requires a 25 mm diameter water meter, whereas a Chinese restaurant with a high water flow may require a 100 mm diameter meter. For large-scale operations, such as amusement parks, the diameter of the meter can be as large as 200 mm. The WSD determines the required meter size based on demand during review of supply application.

Explaining an Urban Myth

A Hong Kong urban myth from the past says the elderly used to collect water from a trickling hosepipe, and due to its weak water-flow the meter's water counter would not correctly operate, resulting in a lower water bill. The myth is actually true, as water meters need a certain strong flow of water to drive the inside gears to measure the water volume flow. However, with the adoption of advanced technology, water meters now accurately measure the flow and there is no longer any "free water".

Smart Meters and Advanced Metering Infrastructure System

The WSD has recently introduced the Advanced Metering Infrastructure (AMI - formerly named the Automatic Meter Reading (AMR)) system, which combines the functions of a new generation of smart meters, AMI Outstation and AMI Master Station. The AMI system provides the Water Authority (WA) with timely and historical metering data, status information and alert signals for the operation and monitoring of smart water meters. Consumers in buildings with smart meters can download the AMI mobile application to access on-demand water consumption data and an estimate of water charges at their convenience. Information from the AMI system assists in long-term water resource management and water conservation.

The government now includes the AMI system in the land sale conditions of suitable new sites and into the design of new buildings to be built on those sites. As of August 2022, the WSD has received over 100 applications for AMI systems, involving over 250 new buildings and around 70,000 smart water meters. This will assist Hong Kong in progressing towards a greener and smarter community.

▲ The WSD's mechanical water meters

The New Generation Smart Water Meter System: Advanced Metering Infrastructure System Accessories and Equipment

Wired Smart Water Meter

Wireless Smart Water Meter

Water Meter Cabinet

Meter Interfacing Unit

Smart Water Meter

AMI Outstation

AMI Panel

Battery Charger Panel

Battery Panel

AMI Master Station

AMI Server

Uninterrupted Power Supply

Examples of WSD Water Meters from the Past

Dial water meter

Water meters from the 1930s to 1950s

This is one of the earliest water meters preserved by the WSD and has an exclusive emerald colour. It uses water flow to drive the gears and a pointer to indicate the amount of water used. The meter reading is in gallons and has a protective cover.

Imperial rotary piston water meter

Imperial water meters in the 1960s

The 1960s rotary piston water meter is coloured blue, representing water. The water meter is fitted with a filter at the water inlet to stop debris, and the flow measurement has been changed from a velocity to a volumetric measurement for better accuracy.

Metric rotary piston water meter

Metric water meters in the 1970s

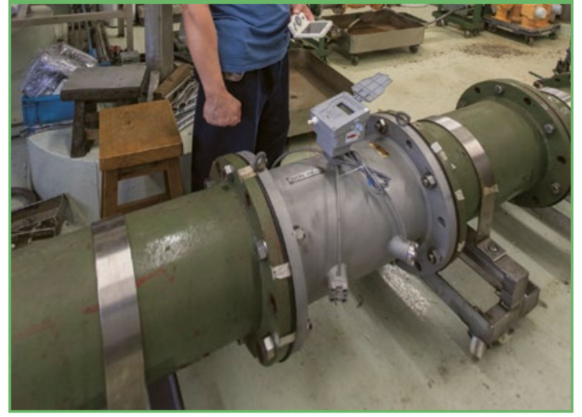
After the 1970s the unit of measurement was changed from the imperial gallon to the decimal cubic metre, in keeping with Hong Kong's change to decimal units of measurement. It signified entry into a new era of globalisation.

Large-diameter Water Meters for Other Commercial Uses

Water meter of 50 mm diameter

Water meter of 100 mm diameter

Water meter of 200 mm diameter



Reading a Water Meter Successfully

▲ Meter Reader HO Tak-chiu (left) and Senior Meter Reader TSANG Chi-kai (right) have travelled all over Hong Kong for meter reading.

By the end of August 2023, the WSD had around 160 meter readers who travel across Hong Kong for meter reading and checking every day of its about 3.21 million registered consumers. At times, meter readers occasionally work in remote areas, including the countryside or outlying islands, and may encounter snakes, insects, and stray dogs. To help in their fieldwork, they keep a collection of tools colloquially called the "Six Treasures for Meter Readers".

HO Tak-chiu has been working as a meter reader for 28 years and enjoys his job as it allows him to travel to many places in Hong Kong. He still finds satisfaction in his work, even after all these years. "By the end of each day, our departmental supervisor passes out a list of consumers' addresses, walking routes and the water meter information to be completed for the next working day. We then have to check the map and prepare for the trip. The destinations are never the same", says HO.

Hong Kong's urban areas are densely populated. A meter reader can read about 600 meters a day while working in a public housing estate. However, it becomes more difficult reading for consumers scattered in remote areas, such as Kau Sai Chau, Yim Tin Tsai and Kai Lung Wan on the outlying islands of Sai Kung. Meter readers must travel by a specially arranged shuttle boat to reach these places. After disembarking, they have to find their way to scattered village houses and are only able to read 50 water meters a day. All WSD consumers are treated equally with the same quality of services. HO believes it is his mission to serve the public.

The Importance of Carefully Reading Meters

After 38 years on the job, Senior Meter Reader TSANG Chi-kai, who used to work in the Kowloon East regional office, explains that a meter reader's job is much more than just taking meter readings, they also inspect the condition of the water meter and are watchful for any sign of abnormalities. Rapid or unusual activity revealed by a meter can indicate water leakage or unlawful water taking. However, a water meter that runs too slowly or remains motionless for an extended period may indicate the need for repair or that the customer has been away from home for a long time. As each situation is different, the meter reader should draw on their past experience and look for other information to make a better assessment. Whenever necessary, they should conduct a basic inspection or report the case to their supervisor for further investigation.

Wisdom Learned from Experience

Meter readers often work in dimly-lit back alleys or outside village houses where meters are located. Unfortunately, domestic dogs can react aggressively and bark when a 'stranger' is seen. TSANG recalls that none of his old teammates had managed to escape from dog attacks. In recent decades, the incidence of dog attacks has decreased, possibly due to a better awareness by dog keepers to constrain larger dogs. He added, "However, meter readers still face hazards such as snakes and poisonous insects in back alleys and small yards, and the bad smell in alleys is sometimes unbearable."

HO Tak-chiu stated that meter readers have learnt the wisdom of carrying essential work tools with them. These tools are known as "the Six Treasures for Meter Readers". They include a torch for extra lighting, a screwdriver for opening pit covers, sanitizing wipes for cleaning, protective gloves for hand protection, a toothbrush for cleaning a water meter's glass reading dial, and a walking stick to keep them safe from dogs.

▲ Meter readers usually carry a reading route map as water meters in village houses can often be in various locations.

Customer Service: Quality Services and Statutory Enforcement

▲ Walk-in customers inside a Customer Enquiry Centre

The WSD is one of the few government departments that deals directly with its customers and the range of provided services reflects the breadth of its customers' different needs. Apart from ensuring consumers receive quality service, the WSD also enforce the Waterworks Ordinance and the Waterworks Regulations.

The WSD has five Customer Enquiry Centres (CECs) throughout Hong Kong to handle enquiries and applications for change of consumership, meter testing and fishing licences for walk-in consumers. On top of that, the CEC in Tai Kok Tsui is responsible for selling water tickets for shipping purpose.

Uninterrupted Customer Services

In 1999, the WSD established a Customer Telephone Enquiry Centre (CTEC) to provide a "one-stop" service to handle enquiries and complaints about mains bursts, leakages, supply interruptions and billing. Information technology was used in the early years to divert public enquiries to the relevant sections of the WSD, later a dedicated 24-hour customer service hotline was introduced.

WSD Customer Enquiry Hotline

2824 5000

According to KWOK Hing-wing, the Assistant Call Centre Manager of the WSD, their service staff are the first contact point for any matter relating to water usage. "People may call us for any matters such as water coming out of a manhole and water seeping from house ceiling. It is important to patiently understand the situation from callers, so we can responsibly provide assistance," says KWOK.

During Typhoon Mangkhut in 2018, the WSD received many reports from the public about water supply interruptions. The operation of pump sets had been affected due to power outages in many areas of Hong Kong: "We received more than 3,000 calls from the public that day, and our colleagues worked non-stop for more than 40 hours. We had to understand the situation from each caller, while at the same time liaising with colleagues in various regional offices to provide temporary emergency water supply or other repair work," explained KWOK. For similar large-scale incidents, the WSD will work with other government departments to activate the Emergency Monitoring and Support Centre to coordinate all arrangements. "For example, during Typhoon Mangkhut, the District Officer of the Southern District expressed concern about the overflow of the Tai Tam Reservoir would flood nearby downstream villages. We subsequently contacted our frontline staff to lower the reservoir's water level to make room for rainwater storage," said KWOK.

In 2022/23, the CTEC received a total of nearly 675,000 telephone hotline enquiries and service requests. As an officer providing customer service, KWOK says he contacts customers every day and strives to understand their needs and difficulties in order to give quick and appropriate assistance. "I remember a case that happened on the first day of the Easter holidays when a customer complained about no water supply to his home. After investigation, we found that the previous tenant had moved out, but the current tenant had not yet applied to take-up the existing water account. Usually, once the payment deadline had passed, the water meter would be removed and the water supply cut-off. After discussion with the customer, we found that his family had special needs and it would have been very disruptive to have the water supply suspended for several days over the holiday. As the customer promised to come to the CEC immediately after the holiday to set-up the new water account, we addressed his special needs by arrangement of re-fixing the water meter. Later, we received a commendation from the customer."

▲ KWOK Hing-wing, Assistant Call Centre Manager

▲ The Customer Telephone Enquiry Centre

An Expanding Water Supply Network

Currently, newly developed areas are well-planned with the necessary infrastructure built, including the construction of water supply and road networks. In the past however, a project developer was required to apply to the WSD for an extension of the water supply network to a new development area. Chief Waterworks Inspector of the Prosecution Unit, WONG Chi-lo, recalled that the water supply application for the Discovery Bay development area in 2000 was probably the largest project he had ever handled. Discovery Bay's developer had been responsible for local water gathering and treatment since the area's development and construction in the 1980s. However, the water level in their reservoir had subsequently declined due to population growth. Coupled with the completion of the new Hong Kong International Airport at Chek Lap Kok, Discovery Bay then applied to the WSD for water supply to all its residents by extending the water supply network through the Discovery Bay Tunnel at Cheung Tung Road.

▲ Chief Waterworks Inspector of the Prosecution Unit WONG Chi-lo explains that customer service duties include the processing of water supply applications and water meter installations.

The potable and fire services supply system in Discovery Bay were originally both privately managed, whilst currently they are regulated by the WSD as inside services and thus must comply with the WSD's standards and requirements. The new water supply connection was seamlessly completed in December 2000, upon several years of forward planning. WONG recalled that it took six months to install 6,064 new water meters. In addition, the WSD had to supervise piping rehabilitation and leak control works. This was achieved in collaboration with various WSD teams. "The Inspection Team was responsible for preliminary inspections and vetting, as well as checking the compliance of plumbing materials, and water sampling. The Meter Reading Section was responsible for taking meter readings two days before the water supply was connected. Those readings served as an account's baseline for future water charge calculations. The Customer Accounts Section assisted in opening accounts and issuing bills," said WONG. It is unusual to have such a large-scale water supply diversion, but fortunately everything went smoothly on the connection day.

Inspection, Enforcement and Prosecution

In addition to providing water supply-related services, the WSD executes the Waterworks Ordinance and Waterworks Regulations, and carries out enforcement and prosecution actions. To enhance public awareness of the associated legislation, the Prosecution Unit has also enhanced education and publicity in recent years. For instance, Regulation 47 of the Waterworks Regulations was enacted in May 2021 to deter owners of subdivided units from overcharging tenants for water. The Prosecution Unit organised meetings with stakeholders, including estate agents and concerned groups of subdivided units, to publicise the details of the new regulation.

The Prosecution Unit also regularly conducts surprise inspections at target premises and makes prosecutions as appropriate. According to WONG, car parks are a black spot for the unlawful taking of water. People often take water from a fire service outlet for car washing. "In fact, the main reason for the unlawful taking of water is mostly for convenience. This problem indicates a need to install additional taps for cleansing in car parks. The WSD approves water supply applications for car parks on a case-by-case basis. The occurrence of unlawful taking of water at car parks has significantly improved in recent years."

Fun Facts about Taps

Why do taps hide dirt and grime?

It may not be immediately obvious to the naked eye, but even taps which run water every day, it can still accumulate dirt. Similar to other domestic appliances, taps also require regular cleaning. Even though water has been treated at the treatment works with contaminants removed, the water may still be contaminated at the tap because of easily contact of a tap with raw meat, seafood, detergents or chemicals, and even pet's saliva. These tiny particles, bacteria or chemicals are all potential sources of contamination. It is essential to clean taps to ensure water safety "from source to tap" - do not fail short of success for lack of a final effort!

How do I clean my taps?

Many households install water flow controllers or filters at the tap spout, which can accumulate impurities and dirt. These devices should be removed and cleaned regularly and disinfected by wiping with alcohol. The WSD also advises to run fresh water for two minutes to flush away any residue after cleaning and before using taps again. To make the best use of resources, the flushed water can be saved for non-potable purposes to avoid wastage.

What is limescale? How to remove it?

The treated water in Hong Kong is soft, but still contains trace amounts of minerals such as calcium and magnesium. You may notice a thin white deposit, known as "limescale", at the bottom of your water boiler or kettle. This is caused by the accumulation of minerals in the water - primarily calcium and magnesium compounds - but does not affect water quality nor human health. To remove limescale, add lemon juice, baking soda, or white vinegar to the water and boil it for a few minutes.

▲ Lemon juice, baking soda or white vinegar help remove limescale

5

WATER SAFETY

Drinking Water Safety: Minding What You Drink

All stages of Hong Kong's water supply process, from raw water collection to water treatment and distribution, are strictly controlled to ensure that drinking water quality meets the required standards. The Water Supplies Department (WSD) literally takes to heart the Chinese saying, "Illnesses enter through the mouth", as unclean drinking water can be a source of sickness.

Hong Kong's quality of drinking water is comparable to that of other developed countries in the world. The WSD continuously ensures that the quality of drinking water supplied to connection points of buildings meets the standards of the World Health Organization's "Guidelines for Drinking-water Quality". However, the actual quality of drinking water inside high-rise buildings is dependent on a building's inside service. The widely-reported "lead in drinking water incidents" in 2015 exposed the potential risks to a building's inside service. It is essential all stakeholders ensure there is professional and regular inspection and maintenance of a building's inside service during and after construction.

The Government of Hong Kong Special Administrative Region (HKSAR Government) took these incidents seriously and within two weeks established an inter-departmental "Task Force on Investigation of Excessive Lead Content in Drinking Water" to investigate. This was followed by the establishment of a "Commission of Inquiry into Excess Lead Found in Drinking Water" with the power to summon witnesses to investigate the causes of the incident. As a result of the Commission's Report, a series of measures to enhance drinking water safety were implemented. This was an important recent step in ensuring the development of drinking water safety of Hong Kong's modern drinking water supply.

This chapter summarises the lessons learned from the above incidents. The WSD has adopted more proactive approaches in its overall strategy toward drinking water safety, these include: routine consultation with international experts to gather opinions, establishment of a Drinking Water Safety Advisory Committee to monitor WSD's performance and water quality, and promulgation of drinking water standards that are applicable to Hong Kong. In addition, the WSD has updated the commissioning requirements for plumbing works and materials, strengthened the management and training of licensed plumbers, and raised public awareness of the importance of drinking water safety. Owners of buildings are also encouraged to conduct risk assessments and regular maintenance of their internal plumbing systems.

To further implement these measures, the government has proposed relevant amendments to the Waterworks Ordinance. The proposed amendments to the current legislation will ensure water efficiency and to regulate overcharging of water bills in subdivided units to meet current environmental and social needs.

A Lead-free Water Supply System

Behind every crisis lies an opportunity, but even quality management does not always offer quick solutions. Rather, it involves taking lessons learned from shortcomings and then turning these into opportunities for innovation.

In early July 2015, domestic water samples from Kai Ching Estate in Kowloon were found to contain lead levels higher than the standards set by the World Health Organization (WHO). Subsequently, further cases were found in the same district arousing widespread public concern. Within two weeks, the HKSAR Government set-up an inter-departmental "Task Force on Investigation of Excessive Lead Content in Drinking Water", and later established a "Commission of Inquiry into Excessive Lead Found in Drinking Water", with the power to summon witnesses to ascertain the cause of the incident. The inquiry confirmed that the excessive lead content in drinking water was caused by the use of leaded solder in pipe jointing (see the summary table at the end of this article for highlights from the two investigation reports). The Commission then recommended a series of specific measures, including legislation amendments for enhancing regulation and clarification on the roles and responsibilities for the construction, maintenance and safety of the inside service, as well as addressing the potential risks of water contamination of the inside service concerning different types of properties.

Improving Drinking Water Safety in Hong Kong

The direct cause of the incident was the use of leaded solder in pipe jointing work, a process failure that prompted the government to conduct a holistic review of the city's drinking water safety regime. In addition to the establishment of the International Expert Panel on Drinking Water Safety in 2016, an expert consultancy was commissioned to develop an "Action Plan for Enhancing Drinking Water Safety in Hong Kong," which was announced in September 2017. The action plan comprises five major areas for improvement, including: a "Drinking Water Standards and Enhanced Water Quality Monitoring Programme", "Plumbing Material Control and Commissioning Requirements of New Plumbing Installations", "Water Safety Plans (WSP)", "Water Safety Regulatory Regime" and "Publicity and Public Education", these are highlighted as follows:

1 Drinking Water Standards and Enhanced Water Quality Monitoring Programme:

- To establish Hong Kong Drinking Water Standards, with reference to the WHO, the European Union, and seven overseas countries in setting the strategy, rationale and practise for water standards (see the article, "Hong Kong's Drinking Water Standards" in this chapter for details);
- From December 2017, the WSD has been collecting drinking water samples from the taps of randomly selected consumers throughout Hong Kong and testing the presence of six metals; and from May 2021, additional tests on residual chlorine and *Escherichia coli* have been conducted (see the article, "The Enhanced Water Quality Monitoring Programme" in this chapter for details).

2 Plumbing Material Control and Commissioning Requirements for New Plumbing Installations

- Updated the plumbing material standards in the Waterworks Regulations, which took effect from July 2017;
- Launched a Voluntary Labelling Scheme for pre-approved plumbing products in April 2017 to help the public identify products and materials that meet the standards;
- Introduced in July 2017 a systematic flushing procedure for new water pipes as part of a building's commissioning work to reduce metals leached from new pipes and fittings, with requirements, including six-hour stagnation water sample tests;
- Launched a Surveillance Programme in October 2017 to spot-check plumbing products with valid General Acceptance using a verification test;
- Promulgated the "Technical Requirements for Plumbing Works in Buildings" in August 2018 to provide comprehensive information for the plumbing industry to reference;
- Legislation amendments to define the duties of licensed plumbers, setting out clearly the designated persons for carrying out plumbing works and their responsibilities, which came into force on 15 February 2018;
- Enhancing the knowledge and professionalism of licensed plumbers, including strengthening the syllabi of licensed plumbers' training courses, implementing a voluntary Continuing Professional Development Scheme and carrying out random inspections by the WSD of new plumbing works under construction.

3 Water Safety Plans

- In accordance with the recommendations of the WHO, the WSD developed and implemented the departmental WSP in 2007 for use within the department, with a forward-looking perspective on risk management, which was further developed to a Drinking Water Quality Management System in 2017 (see the article "Water Safety and Its Monitoring" in this chapter for details);
- Promote the "Water Safety Plan for Buildings (WSPB)" - under the enhanced "Quality Water Supply Scheme for Buildings - Fresh Water (Management System)" - to property owners and management managers, as recommended by the WHO, and provide incentives to encourage their participation.

4 Water Safety Regulatory Regime

- In January 2018, the Development Bureau (DEVB) set-up a Drinking Water Safety Advisory Committee, comprising academics and experts of the related fields, to give advice to the DEVB on various drinking water safety issues.
- A dedicated team was set-up in November 2018 to oversee the performance of the WSD in respect of water safety, including formulating monitoring mechanisms to monitor WSD's performance on drinking water safety, regularly examine WSD's water quality monitoring data, and conducting auditing and surprise inspections.

5 Publicity and Public Education

- To take forward the above action plan - notably the Enhanced Water Quality Monitoring Programme and WSPB - it is necessary to raise public awareness and gain their endorsement. Therefore, continuing publicity and education are planned using various channels, including a dedicated website, announcements of public interest, teaching materials for students, leaflets, posters and seminars, etc. (refer to Chapter 6 for details of the WSD's publicity and education efforts in recent years).

The above initiatives were all rolled-out in the three years following the lead in drinking water incident. The incident raised the public's awareness of the responsibilities of property owners and consumers on the maintenance of the inside service. In particular, there is a need for regular cleaning and maintenance after taking possession of a building. The WSD has also stepped-up monitoring and technical support by extending its risk assessment of water safety from "source to connection point" to "the tap" of each building unit. In addition, the WSD also provides continuing support, encouragement and education to the public.

Investigation Report 1

Verifying that the lead content in solder joints was the source of excessive lead in drinking water

Chaired by then-Deputy Director of Water Supplies, the Task Force on Investigation of Excessive Lead Content in Drinking Water comprised inter-departmental representatives, and three experts and academics. The Task Force completed its investigation three months after its establishment and submitted its final report to the DEVB. The investigation involved dismantling over 100 pipes and fixtures from the Kai Ching Estate and Kwai Luen Estate, and conducting leaching tests, elemental analyses of various components, lead isotopic analysis and mathematical modelling. It also compared these results with the water supply chain of a reference housing estate using stainless steel pipes without soldering. At the same time, nine other water samples were examined, all of which were from the inside service of the housing estates that had excessive lead content. The pipes used were similar in the design and installation specifications to those in buildings in the lead incident. Upon comparing the three sets of data and information with each other, it was found that the test results for the water samples without soldered pipes did not exceed the standard. Whereas, the pipes of the other two sets of water samples with excessive lead were all soldered.

The Task Force is of the view that the incident reflected a lack of awareness among stakeholders in the construction industry of the use of leaded soldering materials and its detrimental effects on the quality of drinking water. To avoid similar incidents in the future, the Task Force recommended a series of measures to prevent the use of leaded solder materials, and non-conforming pipe fittings. The report also recommends the WSD to investigate alternative piping materials.

▲ Soldering material and copper elbow

Investigation Report 2

Revamping the regulatory and monitoring system

The government established and appointed the Commission of Inquiry into Excess Lead Found in Drinking Water to ascertain the causes of the incident and to review and evaluate the regulatory and monitoring system in respect of drinking water in Hong Kong. The Commission was chaired by then-Judge of the Court of First Instance of the High Court, Mr. Justice Andrew CHAN Hing-wai, who also served as a member of the Commission. Another member appointed was former Ombudsman, Alan LAI Nin. The Committee then appointed three expert witnesses to assist it in the hearings.

The Committee held hearings for a total of 67 days, summoning 72 witnesses to give evidence. The report was completed after a seven-month investigation, and found that there were no statutory provisions to clearly define the quality of water at the water tap and who should bear the respective responsibility; this resulted in regulatory and monitoring deficiencies.

Hong Kong had banned leaded water pipes in buildings as early as 1938. The use of leaded solder in plumbing works was prohibited in 1987. However, there was still a lack of standard values for lead content in potable tap water, nor were there any clear indicators for the community to follow.

Finally, the Commission recommended a series of improvement measures that the WSD has subsequently implemented, leading to a revamp of the city's entire water safety strategy.

Hong Kong's Drinking Water Standards

It is internationally recognised that access to clean and safe drinking water is a fundamental human need and right. The quality of drinking water can be analysed and assessed by testing contaminants in four aspects: microbiological, chemical, radiological and physical.

The WHO has recommended a "health-based" target to ensure drinking water safety. Most consumers assess the quality and acceptability of drinking water via its appearance, odour and taste. It is the WHO's advocacy and international practice that individual places establish their own drinking water standards suitable and appropriate to their local context. Since September 2017, the HKSAR Government has established the Hong Kong Drinking Water Standards (HKDWS) and continues to conduct related studies and reviews. In April 2021, the government announced the revised HKDWS, which now covers 60 water quality parameters.

Setting Drinking Water Quality Standards Based on Health Concerns

Unclean drinking water is the vector of transmission of diseases. Microbial contaminants, including pathogenic bacteria, viruses, protozoa and worms, are the most common culprits. These pathogens mainly cause gastroenteritis symptoms, such as temporary diarrhoea, abdominal pain and vomiting. Raw water before water treatment also contains various chemicals. Taking fluoride as an example, which is a natural mineral and an important component for healthy bones and teeth: insufficient fluoride intake increases the risk of tooth decay, but excessive amounts can lead to fluorosis and even poisoning. Therefore, health-based standards for drinking water ensure that the risks of each quality parameter are scientifically assessed, in order to select the most appropriate parameters for water testing.

The WHO has defined the following four categories of 'health-based' targets: health outcome, water quality, specified technology, and performance. Hong Kong's drinking water is safe for consumption when the test results of individual parameters fall within the standards of the HKDWS.

Aesthetic Guidelines Based on Consumers' Acceptability

The appearance, odour, and taste of water can be affected by the microbiological, chemical and physical constituents in drinking water. Although these constituents may not have direct health implications, consumers may regard drinking water with any objectionable appearance, taste and odour to be unsafe for consumption. Therefore, when assessing the quality of drinking water, aesthetic aspects must also be taken into consideration.

Review of Hong Kong Drinking Water Standards

The WHO first published the Guidelines for Drinking-water Quality (the Guidelines) in 1984. Until 2022, four editions of the Guidelines have been published, with the most recent editions being released in 2004 and 2011. With reference to the Water Safety Plan (WSP) of the 2004 Guidelines, the WSD developed and implemented its own WSP to review the city's water supply system and drinking water quality using risk assessment and management strategies. In 2017, the WSD reviewed the WSP and developed an integrated "Drinking Water Quality Management System" to enhance the WSP. This system also outlines the water quality policy and management principles of the WSD. (See the article "Water Safety and Its Monitoring" in this chapter for details)

In September 2017, the HKSAR Government adopted the WHO's guideline values and provisional guideline values of its 2011 edition as the HKDWS. Subsequently, the government commissioned an expert consultant to review and develop the drinking water standards more appropriate to Hong Kong's situation. The recommendations were accepted by the Drinking Water Safety Advisory Committee and promulgated in April 2021. The number of parameters was revised to 60 to serve as the standard for routine drinking water quality monitoring. Additionally, two new sets of parameters, namely the Surveillance List and the Watch List, were introduced. The former is used for surveillance monitoring and includes microbial parameters to indicate the sanitary of the drinking water supply system, while the latter is used for reviewing the latest international scientific developments. Aesthetic guidelines have also been added as a water quality indicator.

Summary of Hong Kong Drinking Water Standards Promulgated in April 2021

	Chemical Category	Radiation Category	Microbiological Category	Physical Category
Parameters of HKDWS	57 parameters, including metals, disinfectants, disinfection by-products, pesticides, organic and inorganic chemicals	2 parameters: Gross alpha (α) activity, Gross beta (β) activity	1 parameter: *Escherichia coli*	/
Parameters for the Surveillance List	Total 37 parameters	/	4 parameters: Coliform, Cryptosporidium, Giardia, heterotrophic plate count	/
Parameters for the Watch List	686 parameters	1 parameter: Radon	/	/
Aesthetic Guidelines	5 parameters: aluminium, iron, manganese, zinc, 2-methyl-isoborneol	/	/	5 parameters: colour, odour, pH, taste, turbidity

Drinking Water Safety Advisory Committee

▲ Ir Edmund LEUNG Kwong-ho, Chairman of the Drinking Water Safety Advisory Committee, said that the Committee occasionally raises questions to the WSD on current drinking water safety issues.

In September 2017, the DEVB and WSD launched the "Action Plan for Enhancing Drinking Water Safety in Hong Kong" (Action Plan). Then, the DEVB established the Drinking Water Safety Advisory Committee in January 2018, engaging multi-disciplinary professionals to examine drinking water safety in Hong Kong from different disciplines, including engineering, chemical and medical, as well as drawing from overseas experience. As part of the Action Plan, the HKSAR Government strengthened the monitoring of water safety, the regulation of plumbing materials and the commissioning requirements for new plumbing installations. The HKSAR Government also provides training and support for the industry. According to Ir Edmund LEUNG Kwong-ho, Chairman of the Committee: "The water supply monitoring system has improved over the years. I hope that the public ensures that water tanks in private buildings are kept clean and contractors use appropriate plumbing materials. Hong Kong can then leverage its advantage of having a closed water supply system to maintain drinking water safety."

Appointed to the Committee at the invitation of the DEVB, Ir Edmund LEUNG Kwong-ho is an engineer by profession and Chairman of the Committee. The Committee's duties include reviewing Hong Kong's regulatory regime for drinking water safety, Hong Kong Drinking Water Standards and related policies. They are also tasked with formulating new research directions based on global drinking water safety concerns and to review the work of the WSD in safeguarding and enhancing drinking water safety in Hong Kong. Ir LEUNG explained, "I recognised the significance of drinking water safety upon assuming this public service role and the responsibilities of the Committee. We don't have any preconceptions to examine Hong Kong's drinking water supply system and understand the risks involved and the countermeasures taken. The experts from various disciplines will discuss their areas of expertise and exchange views from different perspectives, such as chemistry, medicine, and engineering. We clarify issues and explore opportunities for improvement of the WSD."

Ir LEUNG says that the dense population in Hong Kong's urban areas facilitated the development of a cost-effective drinking water surveillance system. The closed drinking water supply system that has been in place for years has proven its effectiveness in safeguarding drinking water safety. The Committee has witnessed Hong Kong's drinking water safety system becoming more sophisticated over time, ensuring a high level of safety.

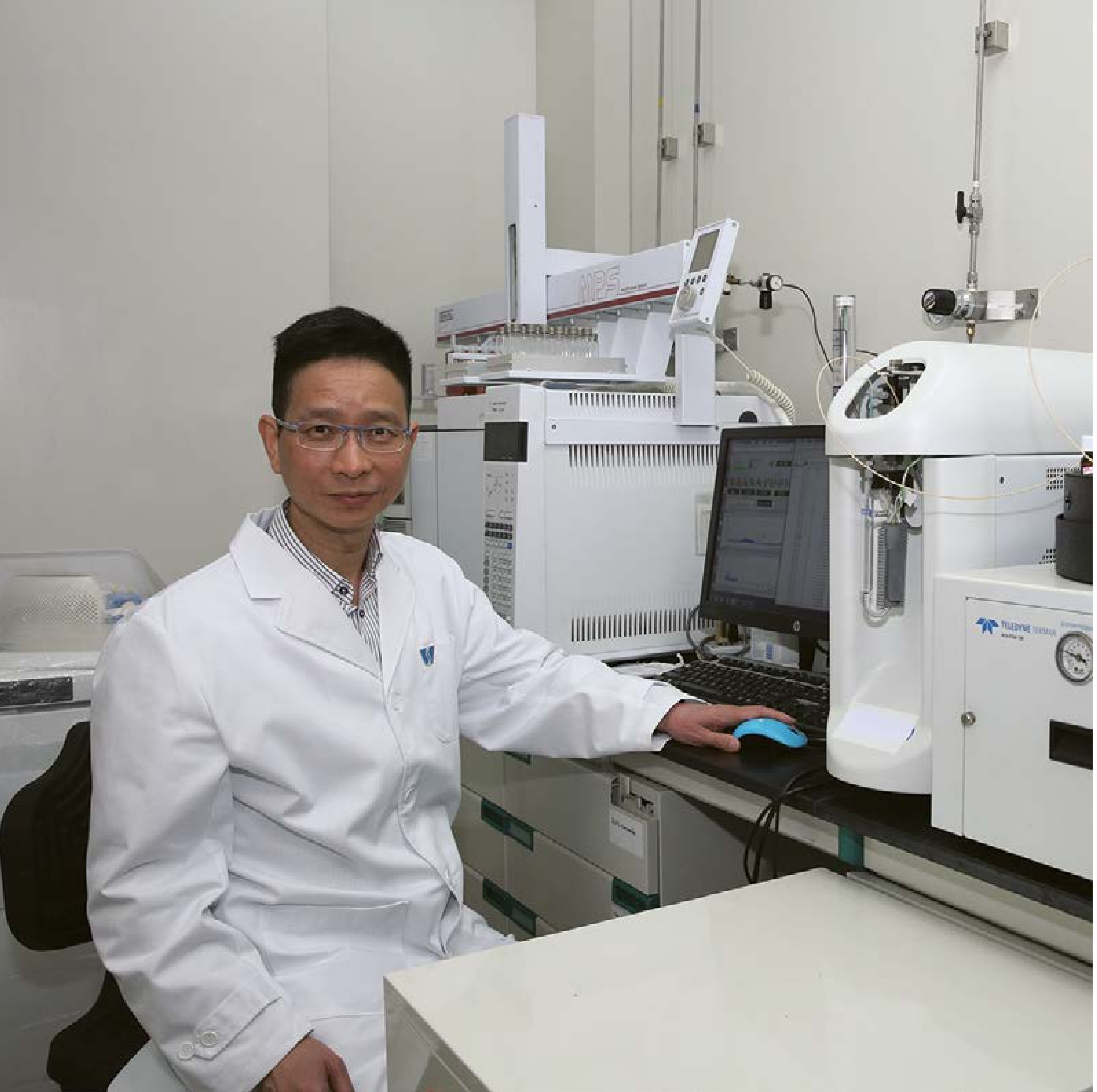
Cooperation Between the Committee and the Water Supplies Department

Ir LEUNG says that while the Committee is autonomous and reports directly to the DEVB, its responsibilities includes reviewing the WSD's efforts towards ensuring water safety. "Based on my project management experience, I believe that communication and collaboration can enhance job performance." He mentioned that the Committee occasionally raises questions with the WSD on current water safety issues. "For instance, we have discussed the effects of the discharge of radioactive wastewater from the Fukushima Daiichi Nuclear Power Plant in Japan into the sea on Hong Kong's drinking water in the aftermath of Fukushima nuclear incident." The committee also questioned WSD staff about the soil samples taken from the top of a service reservoir in Sham Shui Po which tested positive for the bacterium *Burkholderia pseudomallei* (melioidosis). Ir LEUNG explained, "This gave the Committee confidence in the safety of drinking water as the WSD promptly addressed these public concerns by providing specific replies."

Ir LEUNG further explained that radioactive waste water would naturally dilute in the ocean and the WSD has developed radiological monitoring and contingency plans for the desalination plants to ensure that desalinated seawater meets safety standards. "Regarding melioidosis, the Committee understands that there was no evidence linking infection to drinking water. To address our concerns, the WSD has taken additional safety measures including increasing the residual chlorine content in the treated water supply and installing high efficiency particulate air filters at the air vents of the service reservoirs." The Committee members discuss these issues from their professional perspectives and periodically review the measures taken by the WSD to safeguard drinking water safety.

Inside Service Issues of Public Concern

After the water is delivered to private properties through the drinking water supply system, the most critical aspect of drinking water safety is the maintenance of the inside service. According to Ir LEUNG, risks from water filters and dispensers are often overlooked by the public. "So, to ensure safety, water filters should be used in accordance with the manufacturer's guidelines. Components, such as filter cartridges, should be regularly replaced to avoid damage and failure." Not installing a backflow prevention valve or having a clogged water filter can cause contaminants to accumulate in the filter, leading to contamination of the drinking water in an individual unit or even the entire building's inside service. He added, "When purchasing dispensers, ensure that they have safety test certification to avoid the use of leaded solder. Leaded solder has a low melting point and is sometimes used in the construction of non-water supply facilities." Consumers should pay attention to a product's certification to ensure it is safe and of good quality.



Water Safety and Its Monitoring

◄ Chief Waterworks Chemist CHOY Tak-yip says that the WSD's team of chemists is responsible for the important task of ensuring the city's water safety.

"Hong Kong people's recent awareness of water quality issues has encouraged us to improve our various services. For example, we have tried to shorten the duration of water staying in the supply system to be more effective in maintaining the water's residual chlorine levels and prevent the growth of bacteria in the pipes. In other words, Hong Kong's water is generally "fresher" in recent years," says Chief Waterworks Chemist CHOY Tak-yip.

CHOY, who has worked in the WSD for more than 20 years, says a chemist's duties in the WSD seem subtle but every small adjustment in the water treatment process can make a significant difference to the overall water quality. He added, "Chemists are the gatekeepers of the water supply system, ensuring that the quality of Hong Kong's drinking water is maintained at a high standard through testing, research and development, as well as training and monitoring of global trends in water quality requirements and control."

The work of a waterworks chemist includes collecting and testing water samples for monitoring and the control of water quality at various strategic points, from raw water sources, impounding reservoirs to water treatment works, service reservoirs, supply connection points and recently, taps at customers' premises. The number of samples taken each year is approximately 170,000.

The objective is to ensure that at all stages of the water supply system, water quality is normal and safe for consumption. Water quality is measured by being in compliance with the 60 parameters of the Hong Kong Drinking Water Standards (HKDWS) and the 10 parameters of the Aesthetic Guidelines. To this end, the WSD has kept abreast of the latest technologies by using advanced equipment, such as inductively coupled plasma-mass spectrometers and gas chromatograph-mass spectrometers. The equipment is highly sensitive and efficient, which allows the testing of water samples for a wide range of metals and organic compounds to be quickly completed. Chemists are able to promptly verify the safety of drinking water using scientific data from this equipment.

▲ An inductively coupled plasma-mass spectrometer

More Than Laboratory Work

"Apart from routine work, we also carry out independent research and development, such as using unmanned surface vessels (USV) to monitor water quality and take water samples. We also developed a Biosensing Alert System using zebrafish and light-emitting bacteria. These are innovative developments in enhancing water quality control," says CHOY. Waterworks chemists' dedication and their work has been well recognised, for example the Biosensing Alert System won a Silver Prize as a Team Collaboration Award (Internal Service) and a Bronze Prize for the Departmental Service Enhancement Award (Large Department Category) in the Civil Service Outstanding Service Award Scheme 2013; and, the USV system was awarded the Merit Award in the Innovation and Technology Bureau's "Leading Towards Robotics Technologies Innovation Competition" in 2021.

Waterworks chemists also work beyond the laboratory and regularly exchange and collaborate with the academic community to further monitor and enhance the quality of Hong Kong's drinking water. For example, an ecological floating island was set up at Lam Tsuen River on which plants are cultivated to absorb nutrients from the river water, thereby avoiding the proliferation of bacteria and aquatic organisms in the raw water and maintaining water quality.

CHOY highlighted that the "lead in drinking water incident" in 2015 was a significant experience for him. This was especially true when the drinking water in a kindergarten water dispenser was found to contain excessive amounts of lead. This prompted the WSD to step-up testing of all kindergarten water dispensers in Hong Kong. During the incident, the WSD laboratory operated 24 hours a day for three to four weeks, and also mobilised non-WSD laboratories to quickly assist the daily water testing workload. Apart from the workload, CHOY was worried about the impact on children as well as the pressure from teachers, parents and the media. "I reminded myself that we needed to handle the incident carefully, without creating any panic. We also had to deal with it promptly to prevent children from drinking any contaminated water." He explained further, "On the positive side, the incident has greatly raised the public's concern about water quality, especially the maintenance of the inside service in their properties. The WSD has also implemented a series of measures to enhance water safety, which is an opportunity to bring about improvements in society."

Water Safety Plans and its Advancement

In 2004, the WHO introduced a risk-based Water Safety Plan that recommended the world's water suppliers to assess their entire supply chain from source to tap, identify possible risks at each stage, and strengthen monitoring at critical points as early as possible to prevent water quality incidents. The three most important elements of the Water Safety Plan are "system assessment", "monitoring" and "management and communication".

Using the WHO recommendations as reference, the WSD developed and implemented its own departmental Water Safety Plan in 2007 to review its supply processes and ensure Hong Kong's quality of water from source to the distribution system. It also highlighted the regulatory and advisory role of the government towards inside services. In 2017, the WSD further developed an integrated "Drinking Water Quality Management System", which can be regarded as a more advanced version of WSD's Water Safety Plan that included an enhanced risk assessment and monitoring of inside services.

The WSD conducts regular assessments and planning under the Drinking Water Quality Management System to ensure Hong Kong's water safety. It covers five major components, including: Hong Kong's Water Quality Policy, Principles of Water Quality Management, Health-based Targets, WSD's Water Safety Plan and Independent Surveillance. The key points are as follows:

Drinking Water Quality Management System

1 Hong Kong's Water Quality Policy

WSD is committed to providing quality water to its customers, and its effectiveness is verified through a rigorous risk and customer satisfaction assessment mechanism. It also establishes legislation to regulate buildings' inside services and promote stakeholder engagement through public education and the dissemination of water quality data.

2 Principles of Water Quality Management

There are three main elements in establishing the principles of water quality management, which include:

I. To establish **Health-based Targets** for drinking water;
II. To further develop a **Water Safety Plan** using the **risk-based** and **multiple barriers approach** to ensure that the quality of drinking water meets the **Health-based Targets**; and
III. To establish an **Independent Surveillance System** to verify compliance with the **Health-based Targets** and the effective implementation of the **Water Safety Plan** through a **Public Health Context** and **Health Outcomes**.

3 Health-based Targets

According to WHO, water quality should meet local public health requirements and take into account the transmission of diseases through drinking water. As such, water quality objectives can vary from place to place. Hong Kong's drinking water is already of a very high standard, and waterborne diseases have not occurred for many years. Therefore, it is not appropriate to refer to all waterborne diseases for setting local health-based targets. The government promulgated the HKDWS in 2017 and the WSD has adopted it as health-based targets for drinking water. With the revision in April 2021, there are now 60 water quality parameters in the Standards. In addition, the government has established Aesthetic Guidelines for monitoring the aesthetic quality of drinking water (refer to the article "Hong Kong's Drinking Water Standards" in this chapter for more details).

4 Water Safety Plan

The Water Safety Plan is a water quality management tool developed in accordance with the WHO recommendations and the key features include:

I. Establish a dedicated working group comprising staff from various sections of the WSD who are familiar with the operation of the water supply system;
II. The team reviews the entire water supply system to identify potential risks and to develop control measures and improvement plans;
III. Set-up monitoring procedures, frequency and targets, and develop handling procedures if the targets are not met; and
IV. Crisis management plans, emergency response manuals, water quality incident management plans, training programmes and information dissemination mechanisms have been developed to facilitate early preparedness.

WSD undertakes regular water sampling and testing to verify that water quality meets the HKDWS. A steering group under WSD is responsible for monitoring the implementation of the Drinking Water Quality Management System, including regular reviews, revisions and enhancements.

5 Independent Surveillance

Last but not least, the DEVB, together with the Department of Health, conducts independent water quality surveillance of treated water to verify its safety.

Safeguarding Water Safety in Buildings

▲ Water storage tanks on the rooftop of a building

Treated water from the water treatment works is safe for consumption, but there is still a risk of contamination after distribution to buildings' inside service. In 2017, the WSD developed a set of guidelines, the "Water Safety Plan for Buildings" (WSPB), with reference to the WHO's recommendations, that provide advice to owners with a set of guidelines on water quality management in buildings. It comprises a three-step approach of "Risk Assessment → Regular Inspection → Regular Review" for public reference. In addition, the WSD has also launched the "Quality Water Supply Scheme for Buildings - Fresh Water (Management System)" to award certificates to buildings that have implemented the WSPB, and to recognise the efforts of owners and property managers in maintaining water safety.

For the convenience of consumers, the WSD has also established a Voluntary General Acceptance (GA) Product Shop Scheme. This allows the public to identify retailers with a significant number of GA products on sale through a labelling mechanism.

Water Safety Plan for Buildings (WSPB)

The "lead in drinking water incident" in 2015 revealed that there was a problem with the use of leaded solder in the welding of pipe joints. As a result of the review, in addition to proposing amendments to the Waterworks Ordinance to strengthen regulation (see the article "Legislative Amendments and a New Water Supply Era" in this chapter for more details), the WSD has also promoted the WSPB to owners and property management agents to prevent chemical or microbiological contamination of drinking water during the transport and storage within the inside service.

According to the "Guidelines for Drinking Water Safety Plans for Buildings in Hong Kong", the owner or property agent is required to appoint a designated person who is familiar with the operation of the building, and with the assistance of suitable support staff, to jointly develop and implement the plan to facilitate the assessment and improvement of a building's inside service.

Steps to Develop and Implement a WSPB

1 Risk Assessment

- Understand and outline the internal plumbing system of the building
- Assess and identify risk areas for contamination of the internal plumbing system
- Develop and implement control measures to prevent and reduce the occurrence of any associated risks

2 Regular Checking

- Perform periodic checking on the prescribed control measures to ensure that the WSPB is effectively implemented

3 Regular Review

- Thereafter, conduct internal audits and reviews at least once every two years to review the implementation of the WSPB and recommend further improvement measures, if necessary.

The full text of the "Guidelines for Drinking Water Safety Plans for Buildings in Hong Kong":

Quality Water Supply Scheme for Buildings - Fresh Water (Management System) (QMS)

Following the development of the WSPB, the WSD further revised the "Quality Water Supply Scheme for Buildings" and launched the "Quality Water Supply Scheme for Buildings - Fresh Water (Management System)" (QMS) in 2017. This scheme encourages owners and property management agents to implement WSPB and gives recognition on properly managing the water quality in their buildings.

Buildings applying for the scheme are required to meet the following criteria:

- Formulate and implement the WSPB in accordance with the "Guidelines for Drinking Water Safety Plans for Buildings in Hong Kong" and the Drinking Water Safety Plan for Building Template for general buildings and specific buildings.
- Engage a Qualified Person (QP) who has completed the training on WSPB and has passed the assessment to carry out the water safety risk assessments and conduct some of the specific inspections under the WSPB.

The WSD will select 5% of the approved applications for audit by checking their completion of the implementation of the WSPB and the proper documentation.

The applicant must submit the following documents for application for residential or office buildings, which include:

New Application	WSPB, that includes: • A general description of the buildings • A water supply flow diagram • Risk assessment summary table endorsed by the responsible QP • A routine water safety checklist of general buildings or specific facilities which includes the inspection record for items with an inspection frequency of at least once a month
Renewal of Application*	• An internal audit report • A declaration confirming completion of all checking/inspections as set out in the WSPB and the records of checking/inspections by a QP • Latest version of the WSPB

*For all schools that use copper pipes connected by solder and serve students at six years of age or below, e.g. primary or some special schools, but excluding kindergartens, the water quality examination should be carried out at least once a year and the corresponding test reports must be submitted, in addition to the above documents, for the renewal application.

Quality Water Supply Scheme for Buildings - Fresh Water (Management System):

The Voluntary GA Product Shop Scheme

A GA plumbing product is one that has passed the statutory tests to ensure water safety and has been approved by the WSD. The "GA Products Shop Scheme" is a voluntary scheme launched by the WSD to facilitate consumers in identifying GA products and to reduce the chance of using non-compliant plumbing products by the public, thus minimising the risk to water safety. Retail shops who apply for registration must have a significant number of GA products on sale. After approval by the WSD, shops will receive GA Product Shop Labels. These labels should be prominently displayed at shops for easy identification by the public. Additionally, GA labels of the plumbing products should be showcased on shelves and staff should be knowledgeable to actively introduce GA products to customers.

The GA product labels are accompanied by a QR code, which allows consumers to retrieve more information about a product, such as its country of origin and GA expiry date.

Voluntary GA Product Shop Scheme:

GA Product Shop Label

Category: A, B, C, D

Category: A, B, D

Category: A, C

Category: C

#Fun Fact

Plumbing products sold in a GA Product Shop are in four categories:

A. Valves
B. Pipes and Pipe Fittings
C. Taps and Mixers
D. Soldering/Brazing Materials

The Enhanced Water Quality Monitoring Programme

Property owners are responsible for maintenance and management of the inside service of their building to ensure there is no contamination of the system affecting drinking water quality. Since December 2017, the WSD has randomly selected registered consumers and invited them to participate in the "Enhanced Water Quality Monitoring Programme". Each year, drinking water samples from approximately 670 premises are collected from customers' taps for monitoring of the water quality.

Although participating in the programme is voluntary, the WSD encourages consumers to take part. The tests monitor six metals shown in the chart on the right. Since May 2021, two additional tests have been added, covering residual chlorine and *Escherichia coli* (*E.coli*).

The parameters monitored under the "Enhanced Water Quality Monitoring Programme" and their respective standard values are:

Symbol	Parameter	Standard value
Sb	Antimony	≤20 µg/L
Cd	Cadmium	≤3 µg/L
Cr	Chromium	≤ 50 µg/L
Cu	Copper	≤ 2,000 µg/L
Ni	Nickel	≤ 70 µg/L
Pb	Lead	≤ 10 µg/L
	Residual Chlorine	≤ 5 mg/L
	E.coli	0 cfu/100 mL

Follow-up Action after Monitoring

If the test result of a drinking water sample is found to exceed the standard value, the WSD will provide advice and support to the concerned consumers, including:

1. To notify by-hand the concerned occupier (if necessary) and the relevant parties responsible for maintaining and managing the building as soon as possible. Notification will also be sent by mail to the registered consumers and owners of the concerned premises;
2. To provide information on related health risks;
3. To advise on possible mitigation measures;
4. To provide technical information such as the possible source of the water contamination and options to deal with the problem, including engaging of designated person(s) (e.g. licensed plumbers) to rectify the internal plumbing system; and
5. To offer the registered consumer a one-off free investigation into the cause and location of any exceedance.

Publication of Water Quality Statistics

The WSD collects drinking water samples from consumers for testing through this programme and compiles the test results into water quality statistics, published weekly on the WSD's website.

Weekly Report of Water Quality Monitoring Statistics

▲ CHUNG Hon-ming, Water Sampler of the WSD

Water Sampling from Premises

CHUNG Hon-ming has been working in the WSD for four years as a Water Sampler. He is one of the two WSD staff responsible for collecting daily water samples from consumers' premises. As a requirement of his work, he visits all areas of Hong Kong - including some remote locations. During the 30-minute period for collection of water stagnation sample, he often becomes a 'spokesperson' for the WSD. Many elderly residents he meets enjoy talking to him during his sampling visits.

As part of the Enhanced Water Quality Monitoring Programme, the WSD has appointed an independent consultant to assist in conducting a random selection of premises around Hong Kong. Two or three of the 18 districts are selected, with one building and a number of consumers selected from each of the districts. The WSD will notify and invite customers to participate two weeks prior to taking water samples. CHUNG explains that he would visit the premises with a licensed plumber when taking water samples. The sampling process typically involves three rounds, starting with a one-litre sample of unflushed water from a drinking water tap, followed by another one-litre water sample after a two-minute flow of flushing. The plumber would inspect the premises' plumbing system and pipework, record the length of the plumbing and the diameter of the pipes. He would then estimate the required number of auxiliary water samples, typically ranging from three to seven one-litre water samples. Before the final round of sampling, the water samples are taken after flushing the tap for five minutes and then stagnating (kept still) for 30 minutes. CHUNG says that the waiting time is not short, and many consumers take this opportunity to enquire him about water supply services and water quality. In preparation, he tries to learn different kinds of waterworks knowledge. In some occasions, the waiting time become the period of the elder's personal story sharing.

CHUNG says that during his work, he has had the chance to visit different areas in Hong Kong, including remote villages in the northern New Territories and many different types of residence. This experience has broadened his horizons and highlighted the extensive reach of the WSD's services throughout Hong Kong.

Water Contamination in a Private Building

▲ Ir TSE Ming-por, Senior Engineer in charge of Customer Services, says that any publicity about water testing in private buildings must strike a balance between public health safety and property owners' privacy.

The WSD has always complied with WHO water safety guidelines and its subsequent Hong Kong Drinking Water Standards (HKDWS). It also conducts reviews of the water quality through sampling at each stage of the supply system to ensure that water safety standards are met. Since 2017, water sampling tests of the city's public water supply system (i.e. water treatment works, service reservoirs, water connections and publicly accessible taps) have been extended to also test the samples collected at the water taps of private properties through the Enhanced Water Quality Monitoring Programme. Samples of fresh water coming from domestic taps are randomly collected throughout Hong Kong on a regular basis to gauge the city's level of water quality. In 2021, the WSD discovered the first exceedance case of lead content in fresh water at a private non-domestic building during a random inspection. A further inspection revealed that the building's water tanks had not been cleaned for a long time. The WSD assisted the owner to quickly make improvements to avoid the public being affected. Senior Engineer Ir TSE Ming-por, who was involved in the work following the incident said, "There was no precedent for this safety breach and striking a balance between public health safety and the privacy of the property owner was a challenge."

Sample Tests Reveal First Case of Excessive Lead in Water

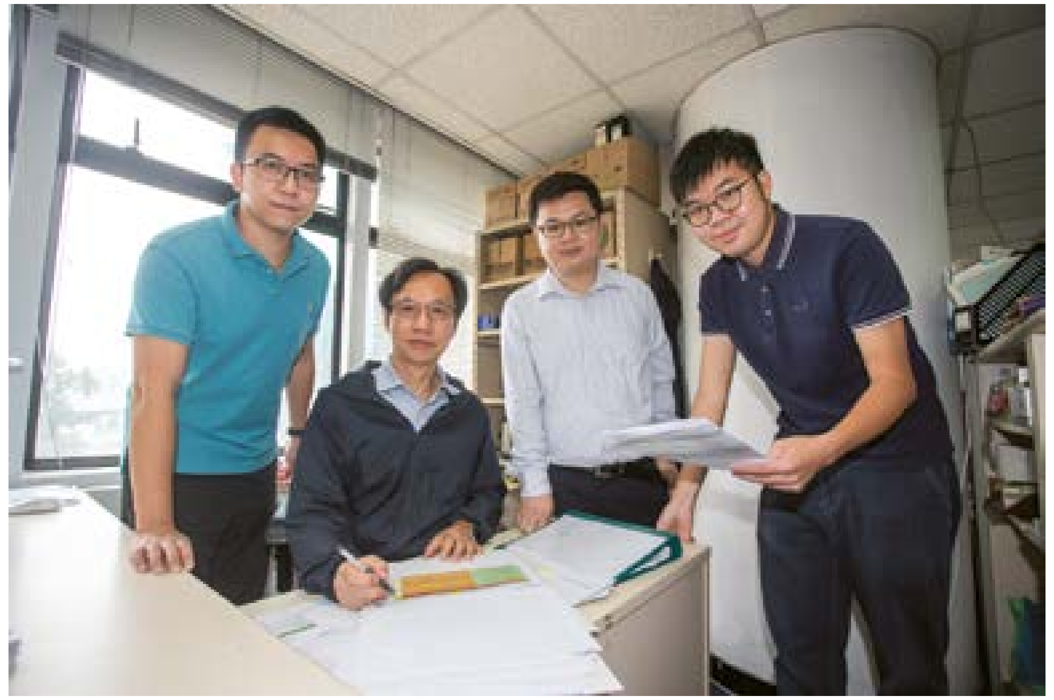
As of October 2021, the WSD has conducted around 2,000 random fresh water sampling tests. One water sample from a private non-domestic premise in Wan Chai was found to contain lead levels exceeding the HKDWS. It was the first exceedance case since the introduction of the updated arrangements under the Scheme. The WSD and the media were greatly concerned about this case.

TSE recalled that the WSD had considered whether the concerned building's location should be disclosed or not. "It wasn't a residential building and most occupants were drinking bottled water. Also, the Enhanced Water Quality Monitoring Programme was a voluntary scheme and not a mandatory initiative. The WSD had to respect the privacy of the participating owners and did not wish to discourage potential participants from joining the programme and undermine its future effectiveness. We decided that the location of the building would not be disclosed, despite media pressure. However, if there had been evidence that a building's water quality posed a direct risk to public health, the WSD would disclose a premise's test results and its address, with or without the consent of the property owners."

Immediate Follow-up of Incident

Immediately upon learning of the test results, the WSD contacted those responsible for the building's maintenance and requested them to inform all users of the building to take appropriate preventive and mitigation measures, including the use of alternative drinking water sources (e.g. distilled water) and post prominent notices. The responsible person of the building then engaged a Qualified Person to conduct inspections and rectify the problem. The investigation found that the building's water tanks had not been cleaned for a long time and contained broken metal parts, which caused exceedance to the lead content of the water samples.

TSE said that the case showed the importance of proper management and maintenance of the inside service and the WSD's monitoring system could also help to improve water quality. He urged the owners and property managers to implement the Water Safety Plans for Buildings and stressed that regular cleaning of water tanks was the key to safeguarding a building's water safety.



▲ Senior Engineer Ir TSE Ming-por (second from left) said that in the face of any water safety incidents encountered without a precedent, it was important for WSD staff to work together to tackle the issue.

Evolution of the Licensing System for Plumbers

▲ A licensed plumber inspects and records whether the pipe materials and connections outside a building comply with water safety standards.

The public has probably heard of the professional designation "Licensed Plumber". The plumbing profession and its work is closely related to the work of the WSD and plays a very important role in construction projects. Plumbers are part of the history and development of the city's entire water supply system and the licensing of plumbers has concurrently evolved over the years. This article will discuss its evolution.

The Emergence of Licensed Plumbers

The government commenced the waterworks project to provide clean potable water to the city of Victoria in 1860 within a budget of £30,000. In 1902, the Waterworks Ordinance was amended, allowing owners or occupants of land lots to install a private water supply system in compliance with the legal requirements under the regulations and receive water supply from the waterworks with the consent of the Water Authority. However, the qualifications of those who could conduct the private plumbing works had not yet been defined.

In 1938, the Waterworks Ordinance first introduced a licensing system for plumbers, specifying that only holders of certificates from the "the Royal Sanitary Institute", "the Institute of Plumbers", "the City and Guilds of London", or other similarly qualified persons (or the firms employing them) recognised by the Water Authority, were eligible to be licensed. Licensed plumbers could provide their services either as individuals or on behalf of their organisations.

Since then, the profession of licensed plumbing has been established in Hong Kong, with the continuing mission to exert plumbing craft expertise to connect water supplies to buildings. In 1939, there were only 14 licensed plumbers gazetted in Hong Kong. Currently, Hong Kong has about 4,000 licensed plumbers.

▲ Publication of the names and addresses of Hong Kong's first 14 licensed plumbers in the *Government Gazette*, 4 January 1939

Apprenticeship before Examinations

The training of plumbers initially began through an apprenticeship system. Later on, the WSD assessed the professional qualifications of plumbers through an examination system and increasingly recognised those with academic qualifications. In the 1970s and 1980s, the WSD regularly reviewed the licensing system, including amendment of Regulation 34 of the Waterworks Regulations in 1974 to require applicants wishing to apply for a plumber's licence not only to have plumbing craft skills, but also adequate knowledge of the inside service and fire service under the Waterworks Ordinance. A point penalty system was introduced in 1985 to assess the performance of licensed plumbers during the inspection of plumbing works. Under certain circumstances, a plumber's licence could be cancelled or temporarily suspended.

CHENG Wai-cheong, Chairman of the Hong Kong Water Works Professionals Association, obtained his plumber's licence in the early 1980s. After submitting his application, he received the syllabus and the date of a written examination from the WSD. With his written examination passed afterword, a separate interview was required. "The written examination involved drawing a sketch of a plumbing layout design, such as the meter position or the location of a water heater in a centralised system. The interview required meeting four examiners, two expatriates and two locals. He had answered questions, which included the method of water supply application and about my apprenticeship." recalled CHENG.

▲ CHENG Wai-cheong, Chairman of the Hong Kong Water Works Professionals Association, has been working in Hong Kong's plumbing industry for decades and witnessed the changes in the licensing system for plumbers.

The Need for Professionalism and Strength

CHENG added that as there were no textbooks nor examination guidelines, it was mainly left to the apprentices to learn on-the-job. "It was really difficult to pass the examination," said CHENG. He pointed out that plumbers in those early days not only required professional qualifications, but also needed physical strength. "At that time, plumbing materials were so heavy. We had to carry many pipes and over ten kilograms of tools for our daily work. We also had to screw the threaded pipe couplings by hand. We had to eat a lot to gain strength!" said CHENG.

The Introduction of Academic Professional Qualifications

As Hong Kong's economy rapidly grew in the 1980s, applications for a plumber's licence mushroomed. During the emigration wave before 1997, a plumber’s licence became a means of earning a living overseas and attracted people from all walks of life wishing to enter the field. "Even doctors and accountants took the examinations to obtain licences before their emigration," recalled MA Yuk-ying, Life Honorary Chairman of the Hong Kong Institution of Plumbing and Drainage.

MA obtained his plumber’s licence in the 1990s. He said he had to take a written test and a test for design drawing after being interviewed by three examiners. "At that time, the licence needed to be renewed annually and was issued as a printed document," said MA. Subsequently, the examination was extended to cover trade tests, legislation and management.


GRADE I
PLUMBER'S LICENCE
2000- A 34924
[redacted]
[redacted]
$67.00

▲ A renewed licence issued in 1999 was a printed document showing a renewal fee of HK$67.

▲ MA Yuk-ying, Life Honorary Chairman of the Hong Kong Institution of Plumbing and Drainage, explains how the requirements for a plumber's licence changed over time.

Continuous Development for Quality Improvement

At the same time, local technical institutes began to offer a range of widely recognised plumbing craft courses and relevant academic qualifications were generally valued by employers. The WSD reviewed the inclusion of accredited academic qualifications and held discussions with relevant trade unions about the transitional arrangements. In 1992, a Craft Certificate in Plumbing and Pipefitting and a Certificate in Plumbing Services (Hong Kong) issued by the Vocational Training Council were confirmed as prerequisites to apply for a plumber’s licence. This system has been in place ever since and marks the transition towards academic and standardised professional qualifications for licensed plumbers, with stringent technical requirements. "Licensed plumbers are required to be equipped with knowledge of all aspects of waterworks; perhaps they should be called waterworks engineers," said POON Wai-yee, Former President of the Hong Kong Licensed Plumbing Professionals Association.

Licensed plumbers have been serving the Hong Kong community for more than 80 years.

"Water is very important as Hong Kong people are accustomed to have washing water and clean portable water after their back to home. Since inferior work can lead to serious consequences, licensed plumbers and the WSD have been working closely together to ensure the city has a safe and reliable water supply." POON continued.

The WSD monitors the performance of licensed plumbers through licensing and by reviewing the licensing system. The WSD's Technical Support Division maintains close liaison with the plumbing trade. “We issue circular letters from time to time to inform licensed plumbers of any updated technical guidelines, waterworks standards requirements, details on application for water supply and approved pipe fittings. These communications assist plumbers in constructing water supply systems in accordance with the latest guidelines and ensuring water safety and an enhanced water supply service.”

In 2016, the WSD launched the “Voluntary Continuing Professional Development Scheme for Licensed Plumbers” to encourage licensed plumbers to pursue further studies to acquire new technological skills, knowledge and techniques, and to continuously improve the quality of their work.

▲ POON Wai-yee, Former President of the Hong Kong Licensed Plumbing Professionals Association, says that licensed plumbers should be knowledgeable in all aspects of waterworks.

Legislative Amendments and a New Water Supply Era

▲ Waterworks Ordinance have been amended in recent years to dovetail with the needs and development of society

Hong Kong's water supply and facilities are governed by the Waterworks Ordinance (WWO) and Waterworks Regulations (WWR) (Cap. 102 and 102A). Most provisions and the latest versions of the WWO and WWR came into force in 1975, with the former substituting the Waterworks Ordinance of 1938 and the latter regulating inside service. The WSD is thus empowered to be responsible for exploring and conserving water resources, as well as maintaining and managing public water supply facilities throughout Hong Kong. The WSD also regulates the construction and maintenance of inside service in individual properties. The two main objectives of the legislation are to safeguard water safety and to ensure water use efficiency. In recent years, the WSD plans to introduce legislative amendments to meet the current needs of the community.

The 2015 "lead in drinking water incident" highlighted the potential risks to water quality posed by inside service, raising concerns about water safety from source to tap. This led to enhanced monitoring and regulation of personnel and materials used in the plumbing work for a building's inside service (see the article, "A Lead-free Water Supply System" in this chapter). The incident prompted a holistic review of the WWO and WWR to enhance water safety and efficiency for the future development of the city. The government has been conducting public consultation exercises on the proposed legislative amendments in phases since 2016.

Added Oversight for a New Era of Water Supply

The WSD has developed a management strategy to optimise the use and development of water resources in response to global climate change (see the article, "Planning a Sustainable Water Strategy for the Future" in Chapter 1). This strategy includes developing recycled water as a "new water resource", and reducing water consumption while promoting water efficiency. The WSD proposes to set efficiency targets for plumbing fixtures and water-consuming devices (see the article, "WELS - The Water Efficiency Labelling Scheme" in Chapter 6). It also requires a building's responsible parties to properly maintain the inside service, especially for communal services in private properties, where leakage leads to wastage. The clear demarcation of the rights and responsibilities of owners and the introduction of a "communal water loss charge" will help to encourage proper management of the communal services by property owners. In addition, grassroots tenants in subdivided units of a building suffer from landlords overcharging for water. This is contrary to the original intention of Hong Kong's public water supply services and there is an urgent need to introduce clear provisions in the law to prohibit this practice.

Proposed amendments to the WWO and WWR have been made in recent years. One of the amendments passed by the Legislative Council in 2018 was related to the control of plumbing works. This amendment specifies who is allowed to carry out certain plumbing works and prescribes the relevant responsibilities of these individuals and of licensed plumbers. The legislation also specifies time limits for prosecution by the Water Authority and empowers the authority to enter premises where plumbing works are being carried out and exercise the power of inspection and questioning.

Summary of Recent Proposed Amendments to the Waterworks Ordinance and Waterworks Regulations

[Objective 1: Safeguard Water Safety]

- Enhancing the power vested in the Water Authority.
- Strengthening the regulation of trade practitioners for plumbing works, plumbing materials and drinking water dispensers.
- Introduction of the Registered Plumbing Contractor system.
- Mandatory continuing professional development for Licensed Plumbers.
- Raising penalties for contamination of inside service.

[Objective 2: Ensure Water Efficiency]

- Introducing provisions in the legislation to expand the local development of recycled water as a new water resource for non-potable use.
- Requiring owners to take responsibility for the proper maintenance of communal water pipes and the repair of water loss.
- Requiring major water consuming devices sold on the local market to be registered under the Water Efficiency Labelling Scheme, in line with the policy and regulations to "reduce water consumption" and "water leakage free" under the "water conservation" strategy.
- Raising charge of fresh water flushing on customers who fail to convert to seawater flushing within a reasonable time.

In 2021, the Legislative Council passed legislation to regulate overcharging for water by landlords of subdivided flat tenants. The law specifies that registered consumers can only recover the actual water charges (i.e. the water charges collected by the WSD) from the tenant of the premises and contravening such requirement would be an offence. The WSD established a Scheme for Installation of Separate Water Meters for Subdivided Units to assist tenants of such units to install individual water meters and establish corresponding accounts. This provides tenants in subdivided units with a clear and accurate account of their water consumption.

6

WATER CONSERVATION

▲ Tai Lam Chung Reservoir

Cherish Water Through a Better Understanding

The Water Supplies Department (WSD) has been providing safe water supplies in Hong Kong for over 100 years and is one of the few publicly operated water suppliers in the world that delivers water to almost 100% of its respective population. It might be taken for granted, but tremendous work lies behind every single drop that comes from our taps.

Over recent years, the WSD has strengthened public education and publicity to raise awareness on water security, including water resources protection, improvements of the inside service to avoid leakages and promoting water-saving habits. An added goal of this publicity is to enhance public understanding of the department's work and services as well as its challenges.

In this chapter a better understanding of the value of water resources will be outlined by presenting statistical figures about the city's waterworks and water resources. Also explained the work will be undertaken in recent years to promote water conservation through the WSD's Water Efficiency Labelling Scheme, an initiative to improve water efficiency using better hardware and technical approaches to encourage the industry and public to support water conservation by using water saving devices. The WSD has also initiated an accessible and professional public education programme, which cover telling stories through social media, organising educational and entertaining guided tours, establishing a water resources education centre and producing education materials on water conservation for kindergartens, primary and secondary school students.

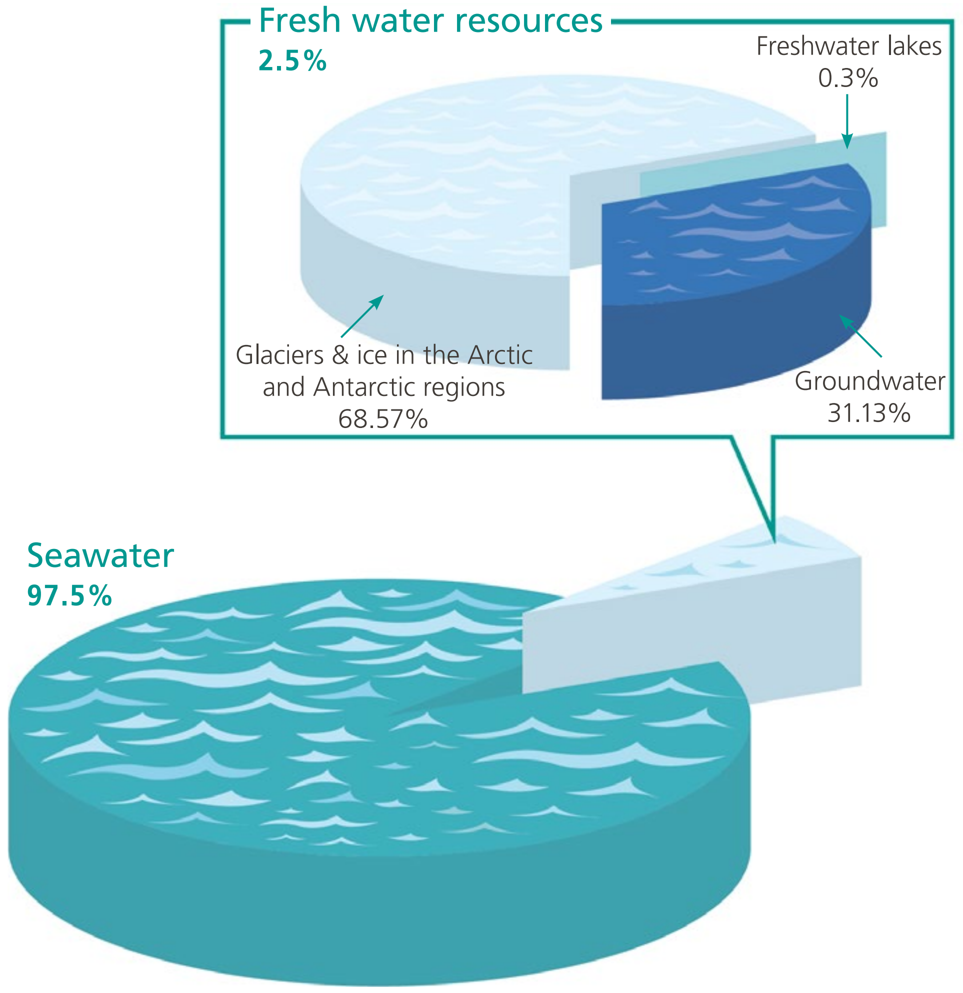
As we come to the final chapter, readers will have a better understanding of the importance of cherishing water after learning about the principles and history of waterworks, and emerging technology for new water resources to cope with climate change, outlined in the previous sections.

Saving the Water We Have

There is possibly a strong impression that the world's water resources appear abundant and inexhaustible, as nearly 70% of the earth's surface is covered by water. However, 97% of the 1.4 billion cubic kilometres of earth's water is seawater, which is highly saline and therefore non-potable. Of the remaining fresh water, nearly 70% is difficult to access as it is contained in glaciers and in the permanent snow and ice of the Arctic and Antarctic regions. Furthermore, around 30% of the world's fresh water is stored as groundwater. It is the remaining - less than 1% - in the form of surface water such as freshwater lakes and rivers that is available worldwide as fresh water resources.

The geographical distribution of water is highly uneven, with more than half of the world's fresh water concentrated in nine countries: Russia, China, India, Indonesia, Peru, Brazil, Colombia, the United States and Canada. According to the United Nations World Water Development Report 2018, more than half of the world's population (between 4.8 to 5.7 billion people) will live in water-scarce areas by 2050. Facing climate change and increasing water demand, water scarcity will be a serious challenge for the world; neither will Hong Kong escape this issue.

Global Distribution of Water Resources

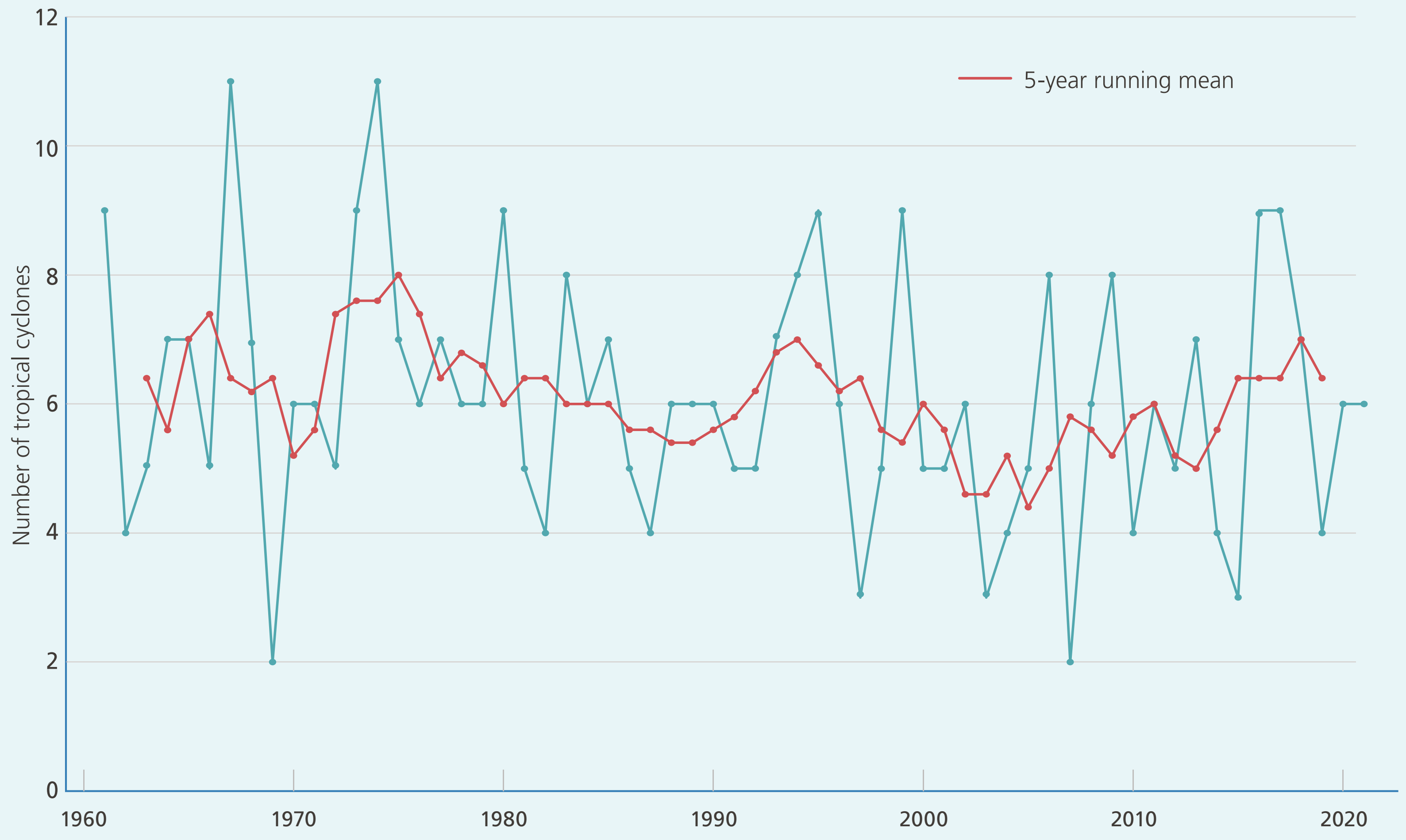


Source: United Nations Environment Programme

Climate Change

Hong Kong's fresh water supply is mainly sourced from rainwater, both from Dongjiang water and local yields. So, any change in rainfall patterns due to climate change may affect the supply of fresh water in Hong Kong and neighbouring areas. Since the 19th century, human activity, especially the use of fossil fuels, has been the primary cause of climate change - which is defined as long-term changes in temperature and weather patterns. This activity has led to an increase in the concentration of greenhouse gases in the atmosphere, increasingly trapping heat. Consequently, global warming has weakened the region's cold fronts blowing south from the north. Some Taiwanese meteorologists have found that over the past 30 years, the East Asian Monsoon - or plum rain - in Southeast Asia has shifted northwards from its original 20 to 30 degrees north latitude to a latitude more northward of 30 degrees north latitude. Located at 22.3 degrees north latitude, Hong Kong may experience a significant future reduction in rainfall during the traditionally rainy months of May and June due to this shift. Also, the number of tropical cyclones within 500 km of Hong Kong has been declining over the 50-year period between 1961 and 2009. Therefore, the amount of rainfall accompanying tropical cyclones is likely to decrease in the future, suggesting that Hong Kong will likely experience significant changes in its future rainfall patterns.

Number of tropical cyclones within 500 km of Hong Kong between 1960 and 2020



Source: Hong Kong Observatory

Increases in Water Consumption

As a result of world population and economic growth, the global demand for water has also been trending upward. According to the United Nations World Water Development Report 2018, the world's population is expected to increase from 7.7 billion in 2017 to between 9.4 and 10.2 billion by 2050. Global Gross Domestic Product (GDP) is expected to increase by 2.5 times over the same period. The report estimates that global water demand will increase by 20% to 30%, from about 46 trillion cubic metres (tcm) per year in 2017 to 55 tcm to 60 tcm in 2050.

Dongjiang water supplies 70% to 80% of Hong Kong's fresh water and is also a major source of fresh water for southern China. As the Pearl River Delta further develops as a processing and export base, the region faces the challenge of competing water resources, creating uncertainties over future water supply. At the same time, water consumption in Hong Kong has increased significantly. The population of Hong Kong has increased from 5.52 million in 1986 to over 7.42 million in 2020, and its GDP has increased almost nine-fold from $31,256.1 billion to $271,073 billion over the same period. Due to population and economic growth, the total water consumption in Hong Kong has significantly increased, from 935 million cubic metres (mcm) in 2012 to 1,055 mcm in 2021. In recent years, Hong Kong's average daily fresh water consumption per capita has been around 130 litres, with bathing and laundry accounting for about 40% and 10% of water consumption respectively. Cooking and other purposes account for the remaining 50%. There has been no significant changes in these water consumption proportions over the years.

▲ Director of Water Supplies delivering a speech at the ECH_2O Award Ceremony on 22 March 2023

Hong Kong's Water Saving Target: Reduce Water Consumption by 10%

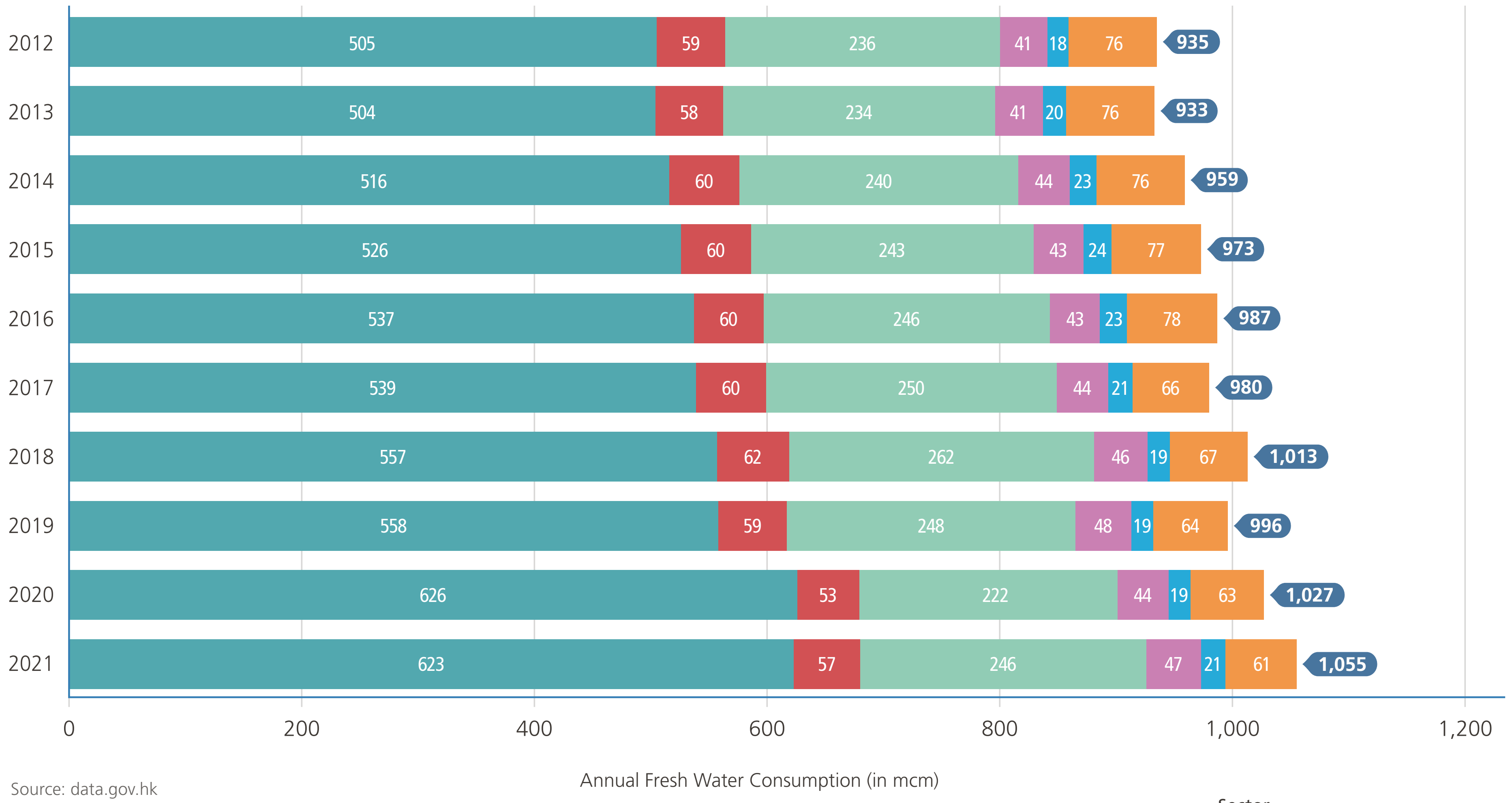
The government's 2017 policy agenda proposed for the first time a target for reducing Hong Kong's fresh water consumption by 10% per capita by 2030 at the earliest[1]. The preceding chapters outlined a series of measures introduced by the WSD in recent years for the sustainable development of water resources. These measures include expanding the use of lower grade water, reducing water losses from distribution networks, regulating water leakage in private properties and ensuring water efficiency. Apart from these practical measures to exploit new water resources and reduce water consumption, it is also important to intensify public education and publicity to build up awareness and encourage better water conservation habits.

The chart on the right illustrates that domestic water is the primary source of water consumption in Hong Kong, accounting for about 55% of the total water consumed. The industrial, commercial and service sectors follow closely behind. In 2016, the WSD introduced the Best Practice Guidelines for Water Usage for the catering and hotel industries, two of the city's largest water-consuming industries.

ECH_2O 「商約」惜水運動 Enterprises Cherish Water Campaign

Further initiatives to improve water efficiency among non-domestic users include the first "ECH_2O - Enterprises Cherish Water Campaign" organised by the WSD in 2021. This campaign aims to create a collaborative platform for the industrial and commercial sectors to promote water conservation through initiatives such as: signing the ECH_2O Charter, appointing ECH_2O managers, education and promotion, equipment improvement and recognition programmes.

Annual Fresh Water Consumption (by Sector) 2012 - 2021



Source: data.gov.hk

1 Using 2016 as the base year

ECH$_2$O Charter Signing

- Support the ECH$_2$O - Enterprises Cherish Water Campaign to cherish water
- Appoint staff as ECH$_2$O manager to manage water consumption
- Promote practices and behavioural changes to cherish water
- Participate in Water Efficiency Benchmarking
- Set water saving targets
- Promote and adopt efficient water consuming devices

▲ Workshops for the business sector have been organised to introduce the current water consumption situation in Hong Kong and water conservation measures.

ECH$_2$O Manager

Appointed staff will help promote the campaign on his/ her responsible premises, duties include:

- Arrange the installation of flow controllers supplied by the WSD in premises under their management
- Monitor water consumption and update on the water cherishing progress of the premises
- Promote the adoption of water-consuming devices with the Grades 1 or 2 "Water Efficiency Labelling Scheme (WELS)"
- Assist in providing data (e.g. flow of people) to calculate the Water Efficiency Index
- Provide venues for exhibitions or promotions for water cherishing
- Attend workshops to learn the latest water cherishing knowledge
- Share successful cases of water cherishing with other ECH$_2$O managers

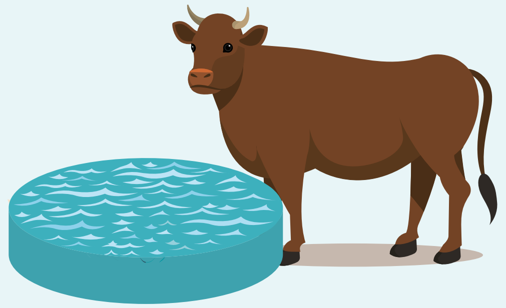
▲ WSD staff explaining the Water Efficiency Labelling Scheme (WELS)

▲ ECH$_2$O Award Ceremony on 22 March 2023

The Concept of Virtual Water

Water is not only used for direct consumption but also in many economic activities, particularly in food production. "Virtual water" is the amount of water used in the production and/or transportation of products and quantifies water consumption that is not visible. For instance, producing one kilogram (kg) of wheat requires about 1,000 litres of water. Therefore, one kg of wheat requires 1,000 litres of virtual water. The diagram on the right provides a concise overview of the virtual water used to produce one kg of beef:

What is the virtual water cost of producing one kilogram (kg) of beef?



Cattle feed
Approximately 6.5 kg of grain (e.g. oats)

Cattle roughages
Approximately 36 kg of roughage
(e.g. pasture grass, dry hay)

Producing this volume of feed requires about **15,300 litres** of water on average.

+

Drinking water for cattle

Water for cattle/ cattle stalls cleaning

Drinking and cleaning require about **155 litres** of water on average.

The virtual water cost for producing one kg of beef requires approximately 15,455 litres of water.

Virtual Water Consumed in the Production of Different Food, Drinks and Consumer Goods

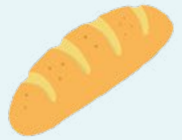
24,000 litres of water per kg of chocolate

18,900 litres of water per kg of coffee beans

15,455 litres of water per kg of beef

3,900 litres of water per kg of chicken

3,400 litres of water per kg of rice



1,300 litres of water per kg of bread

1,120 litres of water per litre of coffee

1,000 litres of water per litre of milk

860 litres of water per kg of bananas

700 litres of water per kg of apples

130 litres of water per kg of lettuce

151,416 litres of water per car

2,900 litres of water per cotton shirt

8,000 litres of water per pair of leather shoes

10,000 litres of water per pair of jeans

12,760 litres of water per smartphone

Individuals can reduce their virtual water consumption in their daily lives by wisely shopping, spending and choosing environment-friendly transportation means.

To learn more about the virtual water consumption of different consumer products, please use the water footprint calculator website on the right:

Water Footprint Calculator of Jockey Club Water Initiative on Sustainability and Engagement (JC-WISE) Project

WELS - The Water Efficiency Labelling Scheme

▲ The Water Efficiency Labelling Scheme (WELS) logo

Waste is when we consume more than we need. What can we do to avoid waste in our daily lives?

The WSD engaged consultants to conduct Domestic Water Consumption Surveys in 2011 and 2015. The 2011 survey found that for the 1,028 households that take showers for bathing, the average frequency of having a shower was 1.04 times per day per person, the average shower time was 6.7 minutes, and the average water consumed was 55.2 litres each time. Showers for bathing account for the highest water consumption for individuals, while the most water-consuming domestic activity was using a washing machine. For each household, the average per capita daily water consumption for laundry by a washing machine is 13 litres. Conducted four years apart, the two surveys found that the smaller the household size, the higher their per capita daily water consumption. In addition, the average per capita daily domestic fresh water consumption of the surveyed households increased slightly from 124.7 to 126.9 litres per person. This is a small but significant increase for a community of about 7 million people.

Since the introduction of the "Total Water Management Strategy" in 2008, Hong Kong has implemented a number of measures to exploit new water supply resources and reduce consumption. One such measure is the launching of the Water Efficiency Labelling Scheme (WELS). The scheme addresses the water efficiency of plumbing fixtures and water-consuming devices by establishing standards for water efficiency through grading. Consumers can select products with reference to its grade. By raising awareness of these products, the community is encouraged to reduce water consumption.

Water Efficiency Grading and Its Calculation

The scheme currently covers six types of plumbing fixtures and water-consuming devices, including showers for bathing[1], water taps[2], washing machines[3], flow controllers[4], urinal equipment[5] and water closets[6]. Their water efficiency is rated under a grading system according to their flow rates, water consumption or flush volumes (as appropriate). The WELS labels show four grades, ranging from Grades 1 to 4. Grade 1 is marked by one water droplet; Grade 2 by two water droplets, and so on. Fewer water droplets indicate less water is consumed by using that product, hence the higher its water efficiency.

▲ Water Efficiency Labels, Grades 1 to 4

1 Covering shower heads installed to fixed arms/concealed pipes in a wall or ceiling, shower heads installed to pivot arms and hand-held showers.
2 Covering water taps of hot and cold water mixing (mixing) or non-mixing types installed in bathrooms/toilets, washing basins and pantry/kitchen sinks. Those water taps equipped with automatic sensing open/close devices or automatic closing mechanism are also included. However the water taps installed in bath tub/shower, any system, machinery and devices such as irrigation systems, washing machines, water dispensers, etc. which serve for bathing/operational uses, are excluded.
3 Covering washing machines that have a washing capacity not normally exceeding 10kg for household use. Washing machines that have a larger capacity or for industrial use or have no spin extraction capability or use non-electric energy sources are excluded.
4 Covering flow controllers used with water taps or showers for bathing.
5 Covering urinals with traps and automatic/manual urinal flushing valves. Urinals with traps coupled with urinal flushing valves to form a combination or urinal suite (urinals with traps equipped with integrated sensing-type flushing valves) are also included.
6 Covering toilet suites (one-piece water closet pan), water closet pan only, water closet cistern only, and a combination of a water closet pan and cistern (close-coupled suite).

Example of Grading Calculation

As an example, showers for bathing are tested in accordance with a set of criteria outlined in the scheme document. The water efficiency of a shower is then rated to different grades according to its nominal flow rate. Grading is tested in a shower test rig by measuring water as it passes through the shower at dynamic flow pressures. When a flow rate stabilises, these pressures are recorded at the ambient water temperature. The resulting average flow rate is the nominal flow rate. If the nominal flow rate of the shower for bathing is equal to or less than nine litres per minute, a Grade 1 rating is given. The nominal flow rates for other grades is given in the table on the right.

Different plumbing fixtures and water-consuming devices are graded based on their nominal flow rates, water consumption or flush volumes (as appropriate). Details are available on the WSD website:

Water Efficiency Labelling Scheme (WELS)

Register of WELS Products

Showers for Bathing

Water Efficiency Grade	Nominal Flow Rate (f = litres/minute)	Droplet Symbols Shown on the Water Efficiency Label
Grade 1	f ≤ 9.0	1 water droplet
Grade 2	9.0 < f ≤ 12.0	2 water droplets
Grade 3	12.0 < f ≤ 16.0	3 water droplets
Grade 4	f > 16.0	4 water droplets

Non-mixing-type Water Taps

Water Efficiency Grade	Nominal flow rate (f = litre/ minute)
Grade 1	f ≤ 2.0
Grade 2	2.0 < f ≤ 4.0
Grade 3	4.0 < f ≤ 6.0
Grade 4	f > 6.0

Horizontal Drum-type Washing Machines

Water Efficiency Grade	Water consumption (W) = litre/ kg/ cycle
Grade 1	w ≤ 9.0
Grade 2	9.0 < w ≤ 11.0
Grade 3	11.0 < w ≤13.0
Grade 4	w > 13.0

Legislation of Water Efficiency Labelling Scheme (WELS)

Water efficiency labelling schemes have been implemented in many countries, in various ways, and at different stages of development. Some countries have made it mandatory for certain plumbing fixtures and appliances to carry a water efficiency label before being sold in the market. Others have introduced water efficiency labelling schemes on a voluntary basis. In Hong Kong, WELS has been implemented progressively since 2009 on a voluntary basis. Manufacturers are encouraged to apply for registration under WELS and conduct tests according to the scheme. This helps consumers make informed choices while allowing time for the market to switch to higher water efficient products. Currently, the WSD is working to amend the legislation requiring the supply of prescribed WELS types of products in Hong Kong to be registered and labelled under the Scheme to support long-term water resource management.

New Ways to Reach Out to the Public

Hong Kong people have a great affection for their country parks. However, they may not realise their close relationship with local reservoirs and water gathering grounds. There may be a lack of understanding to the water supply system developed over the last century, despite its enormous scale and continued services served unnoticeably by the public. The WSD has taken the initiative in recent years to reach out to the public by sharing the history of water supply in Hong Kong, so the public can better appreciate the efforts of the WSD and its pioneering predecessors, as well as the importance of precious water resources. The WSD now regularly organises open days and guided tours at various waterworks facilities. There has also been great effort to produce promotional publications and reach out to the public through various social media platforms. The WSD also took the opportunity to address public concerns about the Ex-Sham Shui Po Service Reservoir incident by organising virtual and guided tours, which have now become popular with the public.

▲ Ir LAW Wai-ho, Senior Engineer of the Public Relations Unit, says that enhancing public awareness of water supply services is the best way to promote water conservation.

Ir LAW Wai-ho, Senior Engineer of the Public Relations Unit, has been involved in the WSD's public relations work in the past few years. "I have worked with my colleagues to reach out to the public. Some retired colleagues also offered assistance and shared their experience during our large-scale publicity events. The public can learn more about the water supply profession through interacting with us and thus building both internal and external public relations," he says.

Leisure as Public Education

Ir LAW says the WSD had been operating in the shadows and out of the public eye since its beginnings. The recent increase in public concern about water safety has led to a number of improvements to its monitoring systems. He added, "We have also stepped-up our outreach efforts by providing the public with information about water supply and conservation. The public guided tours and regular liaison with stakeholders have been implemented. By improving the transparency of information, the WSD aims to increase public confidence in its work."

The WSD launched the "Excursion with Water Save Dave" visiting programme since 2019, which provides guided visits to waterworks facilities, including reservoirs and water treatment works. The guided tours cover three main themes:

▲ Guided tours of the waterworks are effective to increase public understanding of the WSD's work and raise awareness about water conservation.

▲ One of the itineraries of the "Excursion with Water Save Dave" visiting programme includes the scenic East Dam of High Island Reservoir, which is surrounded by eye-catching anchor-shaped dolosse.

(1) Our water resources and nature: visits to the two largest reservoirs, High Island Reservoir and Plover Cove Reservoir;
(2) Waterworks heritage trails: visits to the Tai Tam Waterworks Heritage Trail and the Kowloon Waterworks Heritage Trail; and
(3) Fresh water treatment and quality control: visits to three water treatment works at Ma On Shan, Ngau Tam Mei and Tai Po.

Rich in content, the guided visiting programme explains Hong Kong's water resources and introduces the waterworks facilities. It also covers the history of water supply in Hong Kong and details of the water treatment processes. The programme promotes ecological conservation, enhances public confidence in water safety and improves the image of the WSD. Although the campaign was suspended due to the COVID pandemic, public interest in the programme remains unaffected. By the end of 2022, the WSD had organised over 300 guided tours with approximately 7,000 participants.

According to the event survey findings taken between 2019 to 2022, around 95% of tour participants had a positive view towards WSD. Many agreed that the programme had raised their awareness of personal attitudes to water conservation and of the importance of water conservation.

Regular Open Days

Ir LAW states that despite round-the-clock operations at waterworks facilities, regular openings are arranged for the public. To celebrate the 25th anniversary of the establishment of the Hong Kong Special Administrative Region in 2022, the WSD held a two-day open day at the Ma On Shan Water Treatment Works in early October to give the public an opportunity to understand the WSD's work. During the event, various parts of the plant including the raw water inlet chamber, flocculation and sedimentation tanks, filter beds, sludge filter press and the central control room were shown to the public. The open day in 2022 attracted over 2,700 visitors.

▲ Students visiting the open day's thematic exhibition

The public may realise the WSD's strong work culture while participation in our event upon colleageus' willing to go the extra mile. "In preparation for this event, the WSD mobilised over 450 serving and retired staff to participate. Our colleagues are like a big family. Retired staff actively shared their work experience to their juniors, especially in the organisation of large-scale events requiring extensive planning. For instance, traffic arrangements for visitors, crowd control and safety at the water treatment works are tedious but crucial tasks that cannot be overlooked." Ir LAW says.

▲ The Water Treatment Works Open Day attracted large crowds. This photograph was taken in the sludge filter press plant room.

Turning a Crisis into an Opportunity

The historic Ex-Sham Shui Po Service Reservoir has now been preserved due to concerns from various sectors of the community. The near-demolition of the reservoir's buildings was a critical incident that revealed the true extent of the hidden waterworks' heritage, which had rarely been seen by the public in the past. In response, the WSD addressed the incident and quickly compiled information about the historic structures by creating a 360-degree virtual tour of the service reservoir. This allowed the public to appreciate the interior of the building ahead of its necessary stabilisation and renovation work. To provide the public with an opportunity to view the service reservoir and offer advice on its long-term conservation plans, the WSD put together guided tours in a short period of time by completing accommodation facilities, a thematic website and a visitor enrolment system. The online registration for the guided tours was opened in mid-December 2021, gauged with demand reaching the allowable quotas promptly. Due to COVID restrictions, the WSD introduced self-guided tours in October 2022 for the public to visit the service reservoir by using an on-site audio-guide system. This greatly increased the opportunities for public's visit.

"Although we had to address the public's expectations in a very short time, the visit details were arranged with due care. For instance, we worked with colleagues to ascertain the participants' ability to handle the uphill trail by climbing up over 300 stairs, and estimated it to be around a 15-minute walk at an average pace. This facilitated public to manage expectation and assess the situation." Ir LAW explains. The roll-out of these new activities has been well received by the public, which he sees as a reward for his colleagues' hard work.

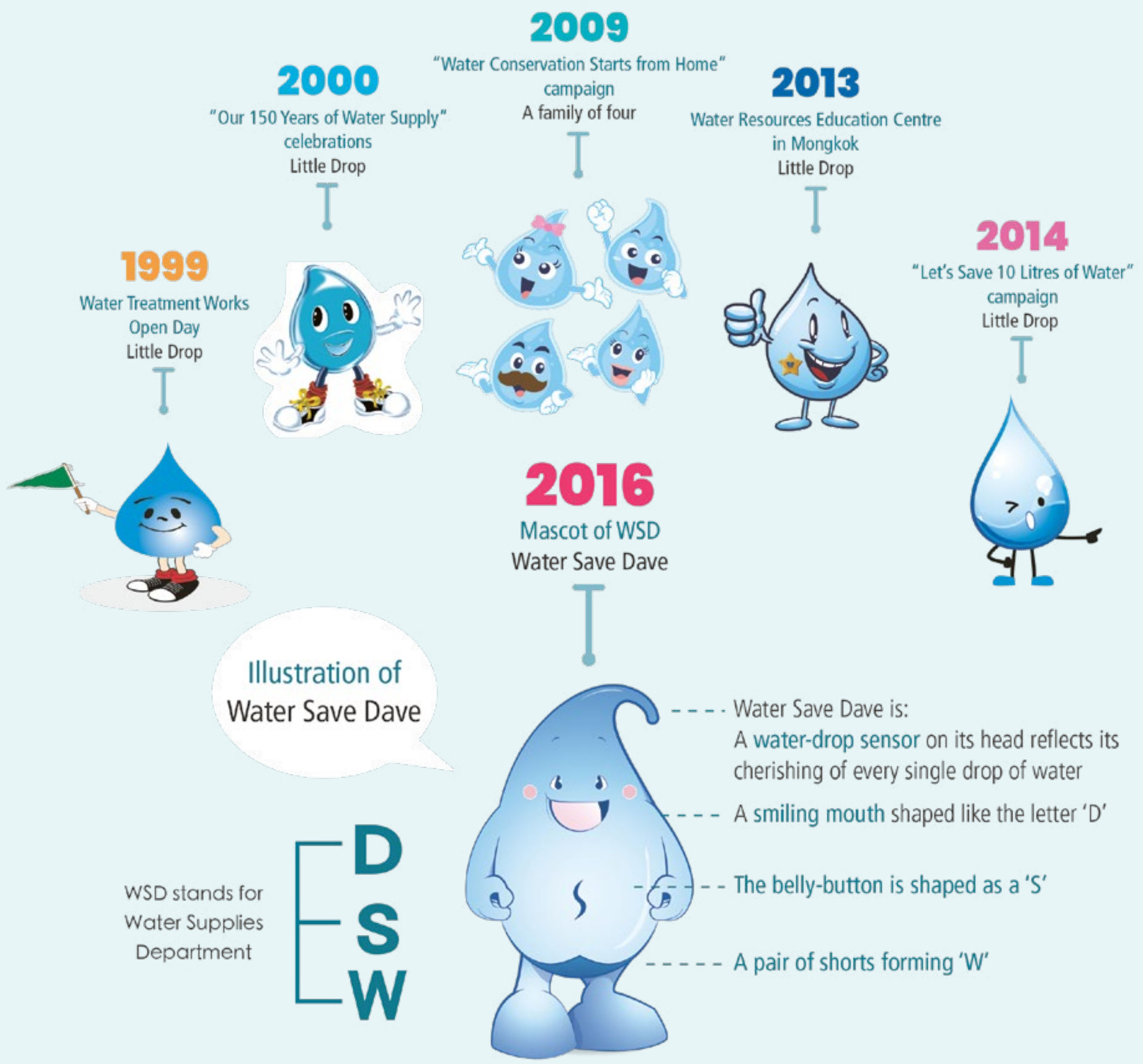
▲ Temporary strengthening and tidying works using reinforced-glass roofing for natural lighting

Mascot for the Water Supplies Department - Water Save Dave

In an era in which social media is closely intertwined with people's daily lives, the WSD introduced a mascot named "Water Save Dave" in March 2016 to promote the importance of cherishing water resources and water conservation. The design of the mascot has undergone several changes over the years. The mascot made its debut at the Water Treatment Works Open Day in 1999. It was later showcased at the "Our 150 Years of Water Supply" celebration activities and given the name "Little Drop" by a primary school student. Little Drop later expanded to become a family of four and participated in the "Water Conservation Starts from Home" campaign. A special "Droplet" figure bearing the WSD badge was also later displayed at the Water Resources Education Centre in Mongkok. The "Sporty Droplet" was served as the mascot of the "Let's Save 10 Litres of Water" campaign.

Now officially named Water Save Dave, the WSD's mascot has been featured on social media and in various promotional publications to make campaigns more vivid and intimate. The number of followers on Water Save Dave's Facebook social media account has increased from around 21,000 in early 2020 to 36,000 by the end of 2022 in just three years. An Instagram account also opened in late 2021, which has gained over 3,000 followers by the end of 2022. In view of the rise in the number of followers, Ir LAW believes this confirms efforts to raise public awareness of the WSD's work and its reputation as a reliable and safe water supplier.

The Evolution of Water Save Dave - the WSD Mascot



The Water Resources Education Centre - The H_2OPE Centre

Hong Kong has a vast and complex water supply system. To help the public understand the city's water resources, the WSD set-up a water resources education centre named "H_2OPE Centre" in 2019. The centre has had 80,000 visitors by April 2023 and provides comprehensive information on water resources through exhibits, demonstrations and interactive games.

Previously located in the WSD's Mong Kok office, the Water Resources Education Centre opened in 2013 and was a temporary exhibition centre mainly visited by primary school students; six-and-a-half years after its launch it had received nearly 70,000 visitors. The Water Resources Education Centre later moved to Tin Shui Wai with the relocation of the Mong Kok office. With a change of name, the H_2OPE Centre now occupies a much larger space: from 300 m² to 720 m²; an increase of 1.4 times.

The two-storey H_2OPE Centre features 12 exhibition zones with 54 exhibits and interactive facilities. Closely following people's daily life, the displays cover a wide range of topics, including the city's water supply history, water ecology, water reclamation, water recycling and waterworks projects. It is now Hong Kong's most comprehensive exhibition about the city's water resources.

During the planning stages for the exhibits, the WSD set-up an internal staff advisory team from different divisions to map the way forward for the development of the centre. The team adopted "SO WE AIM" as an acronym to represent the seven key design objectives for exhibits, using it as a design direction for the exhibition's themes and format - as outlined.

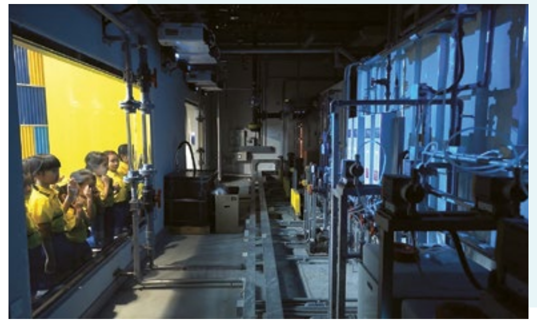
◄ The H_2OPE Centre in Tin Shui Wai

SO WE AIM

S

Sustainable:
Showcasing Hong Kong's Vision for Sustainable Water Use

Grey water recycling and rainwater harvesting are key water resources that have been developed in Hong Kong. A projected animation seen through a glass display window, the **Water+Recycling** exhibition zone presents the process of water recycling, purification and reuse of grey water and rainwater. The WSD Tin Shui Wai building housing the H_2OPE Centre, is actually built with a grey water recycling and rainwater harvesting system with a daily treatment capacity of 19 m³ and 9 m³ respectively. The water collected is treated and reused for the building's toilet flushing.



▲ Water+Recycling exhibition zone

O

Organic:
Responding to the Environmental Changes and Visitors' Interest

The **Water+Show** exhibition zone showcases a changing range of displays, including experiments and competitions on water conservation. The visitor seating is designed as benches made from pre-used water meters.

▲ Water+Show exhibition zone

A

Actionable:
Raising Awareness and Knowledge of Water Conservation

The use of plumbing fixtures and appliances that consume less water is another way to save additional water. To raise public awareness of the WSD's Water Efficiency labels, **Water+Efficiency** exhibition zone is designed to be a shopping mall, where visitors simulate making purchases and learn about products with different water efficiency grades and the difference it can make to water consumption.

◀ Water+Efficiency exhibition zone

I

Interactive:
A Fun and Interactive Learning Environment for Everyone

Water+Sources features a series of interactive exhibits in which visitors play games, such as simulated fishing in reservoirs and acting as a waterworks inspector. Using technology and visual effects, students and the public are introduced to the city's water catchment facilities and gathering ground ecology.

▲ Water+Sources exhibition zone

W

Worldwide:
Presenting Worldwide Issues on Water Resources

Water scarcity as a result of climate change is a future global issue, of which Hong Kong is also facing. The **Water+Climate** exhibition zone gives a global perspective using a spherical-globe projector to display images and videos about climate change and water issues.

▲ Water+Climate exhibition zone

E

Educational:
The Exhibition is linked to the School Curriculum and Educational Activities

The exhibits in H_2OPE Centre are designed for the learning needs of a range of students. The **Water+Cycle** zone is a popular interactive area for children that realistically simulates the water cycle, showing various processes, from water yielding to waterworks facilities. Children can control rainfall, turn dams and gates on-and-off, play-act as engineers who build a network of water pipes, and experiment with new and old pumping methods.

The **Water+Engineering** zone is particularly suitable for older students and profiles water-related science and principles, including interactive exhibits showing the relationship between water pressure and water depth, as well as changes in piping and equipment.

▲ Water+Cycle exhibition zone

▲ Water+Engineering exhibition zone

M

Memorable:
Creating a Memorable Experience

The interior of the **Water+Theatre** zone features a rarely-seen dome-shaped theatre screen showing three-dimensional movies that educate the audience about water resources.

◀ Water+Theatre exhibition zone

Nurturing a Water Caring Culture from a Young Age

CHAN Sin-yan, a H_2OPE Centre docent, says tours of the centre are often given to primary school and kindergarten students, "Children come to the H_2OPE Centre on a field trip, and they are usually very excited." Unlike classroom learning, the H_2OPE Centre emphasises interaction and a sensory experience. The tour is specifically designed to be interactive and students are impressed when trying it themselves. "Nowadays, children think that just by turning-on a tap they will get water. But they never think of where water comes from. The tour starts with historical stories of people fetching water using a carrying-pole. In the video, elderly residents talk about how they had to queue to fetch water when water rationing was in place. This is something students have never heard of," says CHAN. After this introduction, children move through different exhibition zones to learn about methods of water yielding, reservoirs, ecology and the principles of water treatment. When they reach the "Water+Cycle" exhibition zone, the interactive features and games summarise what they have already learnt.

Now, understanding that water is not easy to come by, students visit the second floor of the exhibition, where the exhibits focus on the domestic use of water. By getting to know more about waterworks and water-saving appliances, they learn to cherish water. "I am impressed by the students' reaction to the exhibition. Sometimes, I test them on what I have explained earlier. They remember and answer correctly! I find it very fulfilling," says CHAN.

▲ CHAN Sin-yan, H_2OPE Centre docent

The H_2OPE Mobile App

The WSD launched the H_2OPE mobile app in 2021, to provide tour reservations as well as virtual tours. Visitors can join the centre's activities and receive a wide-range of water conservation information through the app.

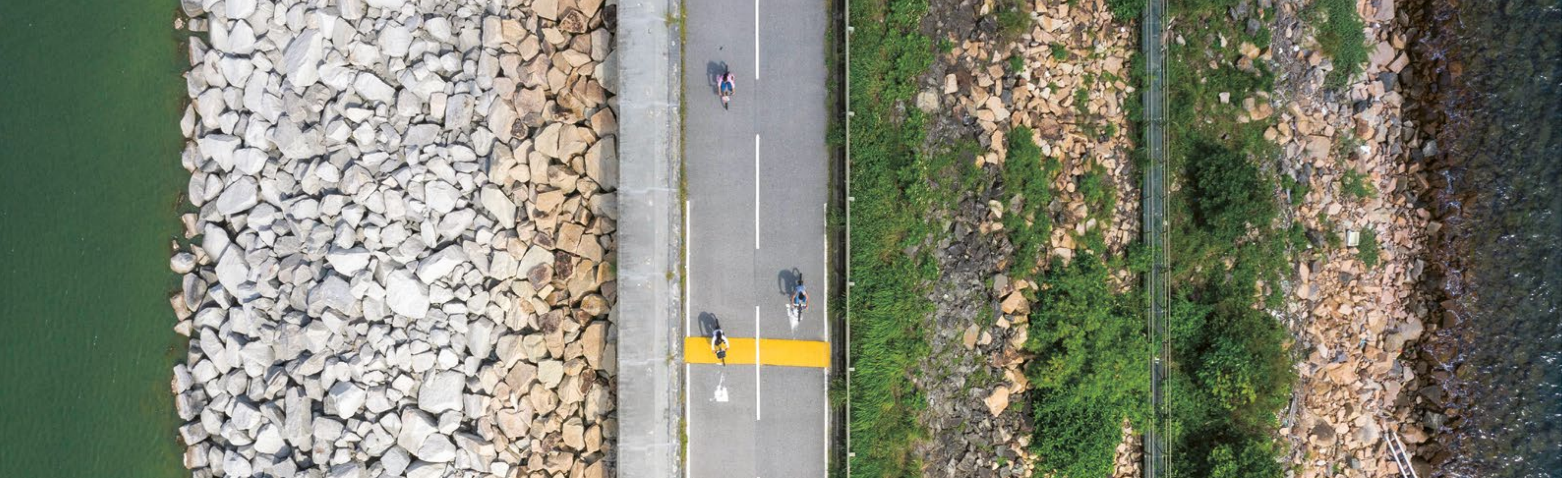
水知園
H_2OPE CENTRE

iOS

▲ The Water+Sustainability exhibition zone

Virtual Tour

Official website of the H_2OPE Centre

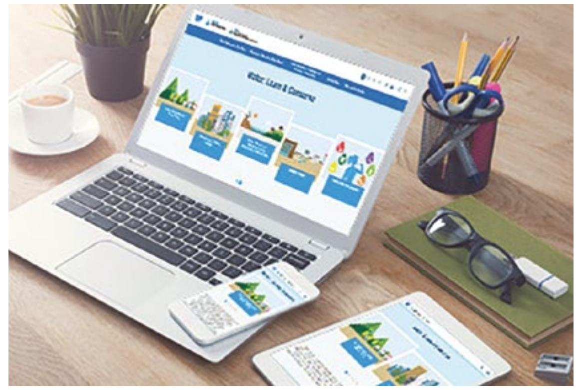


Initiating Water-Saving Habits at a Young Age

The WSD is dedicated to promote water conservation among the city's younger generation. In addition to organising school talks, visits and waterworks facilities tours, the WSD has recently deepened its collaboration with schools by launching educational programmes that combine knowledge with practice. It has also developed teaching materials for teachers to educate students about water conservation.

"Water: Learn and Conserve" Online Teaching Kit

Keeping abreast with recent online teaching and curriculum reform developments, the WSD has updated its teaching Kit for Liberal Studies, including "Water Resources in Hong Kong", "Milestones of Water Supply", "Water Resources: Challenges and Initiatives in Hong Kong", "Quality Water" and "Water and the Society". Each topic includes discussion questions and STEAM activities. These new materials were published alongside the launch of the "Water: Learn and Conserve" e-learning platform in September 2021 and its content is also applicable to science, geography and civic and social development education.



▲ "Water: Learn and Conserve" e-learning teaching materials

"Water: Learn and Conserve" e-learning Platform

"Cherish Water Campus" – Integrated Education Programme for Primary Schools

For primary school students, the WSD launched the "Cherish Water Campus" Integrated Education Programme - Primary School in the 2015/16 school year. Through a series of water audit activities, lesson plans, worksheets, educational videos and games, these teaching kits enable students to collaboratively implement water-saving tasks and increase their awareness and concern for water resource issues in Hong Kong and globally.

In August 2020, the WSD launched a section of the "Cherish Water Campus" teaching resources for teachers to download worksheets and activity kits. In addition, an award scheme has been launched to recognise schools and teachers for their active participation in water conservation activities, with the aim of exchanging and sustaining a culture of water conservation in schools. More than 400 primary schools have participated in the programme by December 2022.

▲ The WSD provides game booths borrowing service to schools and other organisations

"Cherish Water Campus - Primary School" Integrated Education Programme – Primary School:

"Cherish Water Campus" - Integrated Education Programme for Kindergartens

The WSD extended the "Cherish Water Campus" education programme to all of the city's kindergartens from the 2018/19 school year. The programme targets five and six-year-old children in upper-kindergarten classes. The fun-to-do teaching materials are designed to incorporate storybooks, sing-along activities and colouring to educate children about the importance of water-saving. As of December 2022, over 420 kindergartens have joined the programme.

▲ The front cover of "Cherish Water Campus" - the Integrated Education Programme for Kindergartens' teaching material.

"Cherish Water Campus" Integrated Education Programme - Kindergarten

The Cherish Water Ambassador Scheme

First launched in 2018, the WSD's "Cherish Water Ambassador Scheme" promotes water conservation by encouraging young people to become ambassadors. Being an ambassador helps to foster one's awareness and encourages the habit of conserving water resources and to actively promote saving water. The programme has recruited over 200 secondary school and tertiary students to become ambassadors. Activities, such as guided tours of water treatment works, exchange sessions, video production workshops and training camps, have been organised for the ambassadors, who were encouraged to use their creativity, through video-making and other in-school promotional activities, to promote the message of water conservation.

Due to the programme's popularity, the WSD launched the "Cherish Water Ambassador Scheme 2021-22" KOL (i.e. Key Opinion Leader) Incubation Programme for secondary school students in the 2021/22 school year. The programme involves partnering with internet celebrities to organise online workshops that help participants themselves become water-saving KOLs. The Cherish Water Ambassadors were tasked with creating a one-month promotion project centred around the theme of water conservation. Finalist teams were awarded sponsorship to implement their online advertising strategies to increase exposure. The scheme attracted over 360 secondary school students as participants.

▲ The poster for the "Cherish Water Ambassador Scheme 2021-22" KOL Incubation Programme

"Let's Save 10L Water 2.0" Campaign

The WSD launched the "Let's Save 10L Water" campaign in 2014 as a call for the public to save at least 10 litres of water a day as one of the responses to climate change. Riding on the back of this successful initiative, the WSD launched the "Let's Save 10L Water 2.0" campaign in 2019. A series of activities, including a "Free installation of flow controllers at private housing estates and private schools", the "Innovative water efficient showerhead design competition" and the "4-minute shower challenge" were organised. The campaign aims to promote water conservation across various sectors to encourage people to save water in their daily lives and curb the increasing demand for water in Hong Kong.

▲ The award ceremony for the "Water Speaks - Video Competition" and "In-School Promotional Activities"

▲ The poster for the "Let's Save 10L Water 2.0" campaign

▲ The award ceremony for the "Innovative water efficient showerhead design competition"

Conclusion:
Innovation, Foresight and Vision of the Water Supplies Department

Water Matters provides an overview of the Water Supplies Department (WSD) in Hong Kong over the past 170 years. We have proactively developed waterworks to meet the growing demand for water, and have led the way in the operation of waterworks to secure efficient and reliable water supply services.

Despite being surrounded by the sea on three sides, Hong Kong has always been shortage of potable fresh water resources. Nonetheless, Hong Kong has been a pioneer in supplying water to meet the needs of the society in changing times. In addition to implementing state-of-the-art technology and management systems, we have been able to improve the quality and quantity of water supply by applying innovative technologies and overcoming the constraints imposed by physical conditions.

The Shek Lei Pui Water Treatment Works - built in the 1920s and decommissioned after almost a century of use - used the most advanced rapid gravity filtration method available at the time. In the late 1950s, Hong Kong pioneered the use of seawater for flushing in order to reduce potable water consumption. Half a century later, this flushing system was the first system outside Europe to win the "Year 2001 Chris Binnie Award for Sustainable Water Management" from The Chartered Institution of Water and Environmental Management in the United Kingdom. As land area for constructing reservoirs became scarce, the WSD built dams and drained the seawater to create the world's first in-sea-built reservoir, the Plover Cove Reservoir. With Dongjiang water supply from the mainland in the 1960s, Hong Kong entered into a stable water supply regime. The WSD has invested additional resources in research and development of applications for efficiency enhancement, water safety and water quality monitoring. It has formulated a series of advanced computer management systems such as the Supervisory Control and Data Acquisition (SCADA), Distributed Control Systems (DCS), Digital Mapping System (DMS), Maintenance Works Management System (MWMS), Customer Care and Billing System (CCBS), to enhance the waterworks operation, asset management and customer service.

The WSD will enter a new era in the coming years. A number of major waterworks projects and programmes will be built: the soon-to-be-completed of the first stage of the Tseung Kwan O Desalination Plant is the initial step towards sustainable water use; the district-based grey water recycling system in the Anderson Road Quarry site; and the Shek Wu Hui Water Reclamation Plant will also be milestones in realising the development of new water sources. These initiatives will help reduce water consumption for non-drinking purposes while reducing wastewater discharge, thereby promoting sustainability. As for the operation of the waterworks, the use of intelligent technologies, such as the gradual expansion and enhancement of the water intelligent network (WIN), along with the establishment and application of the digital twin of the distribution network and water treatment processes, will help us to efficiently monitor, manage and optimise the entire water supply process and laying the foundation to create a future smart water city.

In the future, the WSD will devise a plan for the implementation of intelligent waterworks in Hong Kong, supported by the rapid development of digital technology and artificial intelligence. It will also lead the way in establishing the WSD Central Operations Management Centre (COMC), and develop an Internet of Things (IoT) platform. This will enable comprehensive online monitoring and improving the management of the water supply system, while ensuring the safe and uninterrupted operation of the waterworks facilities. The WSD is building the Cloud Data Centre to develop and exploit data resources by integrating the latest technology with the water supply industry. The aim is to assist the WSD analyse and make decisions at all levels and in all areas. Through an intelligent control system with decision-making and AI-driven customer services, the WSD will assure water safety, provide quality services and a reliable water supply.

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Acknowledgments

The Board of Advisory Committee would like to express gratitude to the following parties for the support including photos in the making of this book:

Hong Kong Institution of Plumbing and Drainage Limited
Hong Kong Licensed Plumbing Professionals Association Limited
Hong Kong Museum of History
Hong Kong Public Libraries
Hong Kong Water Works Professionals Association Limited
Information Services Department
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Public Records Office, Government Records Service

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Publication Details

Title: Water Matters
Publisher: Water Supplies Department of the Government of Hong Kong Special Administrative Region
Publication Date: October 2023
Writing and Photography: SEE Network Limited
Book and Digital Design: Wiseman International Digitech Limited
Printing: Champion Design and Production Company Limited