Geography

Learning and Teaching Resources on Guangdong-Hong Kong-Macao Greater Bay Area (Greater Bay Area)

Water resources in the Greater Bay Area

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1. Overview

China is rich in water resources. Its volume of fresh water occupies 6% of the global total and ranks fifth globally. However, with approximately 20% of the total world population, the water resources per capita in China is low (1,971.85 m^3 per capita recorded in 2018) (National Bureau of Statistics of China, 2019), which is about one-third of the world's average. With rapid urbanisation and industrialisation driven by the reform and opening-up launched in 1978, water scarcity in China has been aggravated by serious water pollution, posing a significant threat to national water security and ecological balance. Thus, great concerns have been raised about the challenges in the pursuit of sustainable development.

The Guangdong-Hong Kong-Macao Greater Bay Area (Greater Bay Area) is located in the Zhujiang Delta in the southern part of China. It is included as an important part in the economic and social planning of the *13th Five-Year Plan 2016-2020*. Water has always been playing a crucial role in economic development. Being close to Zhujiang, the second largest river in China in terms of annual water discharge, water resources in the Greater Bay Area are not scarce but are highly stressed due to continuous socio-economic development. There is an urgent need to strengthen the protection of water security in the area, otherwise the existing water risks will hinder the Greater Bay Area to be the world's largest bay area economy.

2. Hydrological characteristics

The Greater Bay Area has an area of 56,000 km^2, comprising a complex river network (called the Zhujiang River network) with a catchment area of 26,800 km^2. According to the Water Resources Zonation established in 2002 by the Ministry of Water Resources, the Zhujiang Region is one of the ten "first-level" zones in China and is comprised of ten "second-level" areas, among which is the Zhujiang Delta. The Zhujiang comprised of three major tributaries, namely the Xijiang, Beijiang and Dongjiang, as well as minor tributaries, including Tanjiang, Suijiang, Liuxihe, Zhengjiang, Xinxing, Maozhou and Shenzhen River. They finally enter the South China Sea through eight outlets, including four eastern outlets (Humen, Hengmen, Hongqimen and Jiaomen) and four western outlets (Yamen, Hutiaomen, Jitimen and Modaomen) (Mao et al., 2004).

The hydrology of the Greater Bay Area is characterised by (1) high average annual river discharge; (2) frequent and intense flooding and drought. These characteristics are mainly affected by its precipitation, tidal ranges and storm surge.

2.1 River discharge

River discharge in the Greater Bay Area depends on the amount of precipitation. The river discharge in the area is high with an average annual discharge of 336 billion cubic meters, accounting for 12.7% of the national annual average. Since the seasonal river discharge pattern is the same as the precipitation, the discharge in rainy season (between April and September) accounts for 74% to 84% of the total discharge, while the discharge in dry season (between October and March) accounts for only 16% to 26%. As the distribution of discharge is uneven, flooding and inadequate water supply may occur during rainy and dry seasons respectively.

2.2 Floods and droughts

Floods and droughts are the major hydrological hazards in the Greater Bay Area which caused massive economic losses and casualties in the past. Floods in the area are mainly resulted from heavy rains. In case of prolonged and intense rainfall, the river discharge and peak discharge increases which not only affects the livelihoods of people living in the middle and lower courses of Zhujiang but also results in large amount of freshwater running rapidly into the South China Sea, making it unavailable for use. Owing to an uneven seasonal distribution of precipitation, the Greater Bay Area has also suffered from severe drought, mainly in the form of agricultural droughts, during the dry season. More importantly, floods and droughts in the Greater Bay Area have become increasingly common and more severe due to climate change.

Supplementary Information (1):

June 2005: A 50-year flood hit occurred in Xijiang basin

A continuous heavy rainstorm hit the Xijiang basin in June 2005 and caused a 50-year flood, with the Zhujiang Delta being one of the worst-hit areas. Five cities, namely Guangzhou, Foshan, Dongguan, Zhongshan and Zhuhai, were flooded. As reported, at least 536 people were killed and 3.71 million people were affected. The flood also destroyed 31 million hectares of crops and damaged dykes and reservoirs. Roads and railroad lines were cut by rising floodwaters, including the Longchuan-Huzhou section of the Beijing-Hong Kong rail line. The tota l economic losses amounted to at least RMB 20.35 billion.

3. Factors affecting the hydrological characteristics of the area

3.1 Precipitation

Being a low-lying delta with a humid subtropical climate, the Greater Bay Area has a high annual mean precipitation of 1,700 mm, ranging from 1,200 to 2,500 mm. The high precipitation explains why the annual average discharge of Zhujiang is so high. The area is also characterised by high humidity, high temperature and intense rainstorms in summer due to subtropical monsoon climate. Precipitation varies greatly seasonally. Nearly 80% of the annual precipitation falls during the rainy season from April and September. The total number of days with precipitation ranges from 145 to 151 annually, accounting for approximately 40% of a year. During the rainy season, frontal and monsoon rain are dominant from April to June, while rainfall associated with tropical cyclone and convective storms are dominant from July to September. In addition, the precipitation of the nine Greater Bay Area cities (GBA cities) in the Mainland is slightly different, with the largest and smallest variations of annual mean precipitation found in Shenzhen and Zhaoqing respectively (see Table 1). Heavy rainfall in summer is one of the causes of flooding in the area.

Table 1: Precipitation of the nine Mainland cities of the Greater Bay Area

City	Annual mean precipitation (mm)	Highest annual precipitation		Lowest annual precipitation	
		Annual precipitation (mm)	Year	Annual precipitation (mm)	Year
Dongguan	1,664	2,200	1953	1,051	1963
Foshan	1,557	2,269	1961	1,059	1991
Guangzhou	1,845	2,548	1983	1,253	1991
Huizhou	1,889	2,530	1957	1,023	1963
Jiangmen	2,009	2,865	1973	1,121	1977
Shenzhen	1,906	2,500	1975	901	1963
Zhaoqing	1,649	2,114	1973	1,167	1991
Zhongshan	1,749	2,563	1997	1,124	1963
Zhuhai	2,037	3,150	1973	1,218	1977

Source: 廣東省水文志 (2012)

3.2 Tides and storm surges

Tides are weak in the Zhujiang Estuary. Tides in the estuary belong to irregular semidiurnal with a relatively small tidal range of between 1.0 and 1.7 m. The tidal range in the southern Lingdingyang is the most obvious. Due to the horn-shaped estuary, the tidal wave propagates upstream into the estuary. The tidal wave becomes steeper when moving inland where the tidal energy accumulates. Thus, the tidal range along the eastern coast of the estuary is much greater than the western coast.

Storm surge is a common phenomenon happened in Zhujiang Estuary. Storm surge induced by tropical cyclone poses great threat to the GBA cities. The low pressure created by tropical cyclone and onshore wind cause the abnormal rise in sea level. Water accumulates along the coast leading to coastal and inland flooding. Since 1949, storm surge happens every year in Guangdong Province, and a total of 21 storm surge events were reported in the Zhujiang Delta till 1990 (see Table 2). This is also one of the causes of flooding in the area.

Table 2: Number of storm surges in different seasons in major river deltas of China, 1949–1990

River delta	January–March	April–June	July–September	October–December	Total
Zhujiang Delta	0	2	16	3	21
Changjiang Delta	0	1	18	1	20
Huanghe Delta	20	19	22	35	96

Source: Storm surge disasters in China (Fang et al, 2016, p. 280). In book "Natural Disasters in China" (Shi, 2016)

4. Issues related to water resource

4.1 River water pollution

The remarkable economic growth came at a very high environmental cost. Our country has established a six-class nationwide grading system on surface water quality (i.e., *Surface Water Environment Quality Standards* GB 3838-2002) based on the purpose of use and protection target in 2002 (Table 3), and river water quality is being monitored on a monthly basis. Main indicators for assessment include conductivity, dissolved oxygen (DO), biochemical oxygen demand (BPD5), pH, permanganate index (CODMn) and ammonia nitrogen. Water with a quality standard of Class V and V+ is regarded as "polluted". Being one of the most industrialised and urbanised areas in China, water pollution has become a major environmental problem of the Greater Bay Area. Owing to heavy discharge of untreated domestic and industrial sewage into rivers, parts of Zhujiang are being polluted. Over 17% of its monitored surface water bodies are classified as Class IV or above in 2018 (Figure 1b), which was not suitable for drinking. In addition, its major tributaries, including the Danshui He, Maozhou He, Shima He, Shenzhen He, Lianjiang and Rongjiang were ranked as Class V or above.

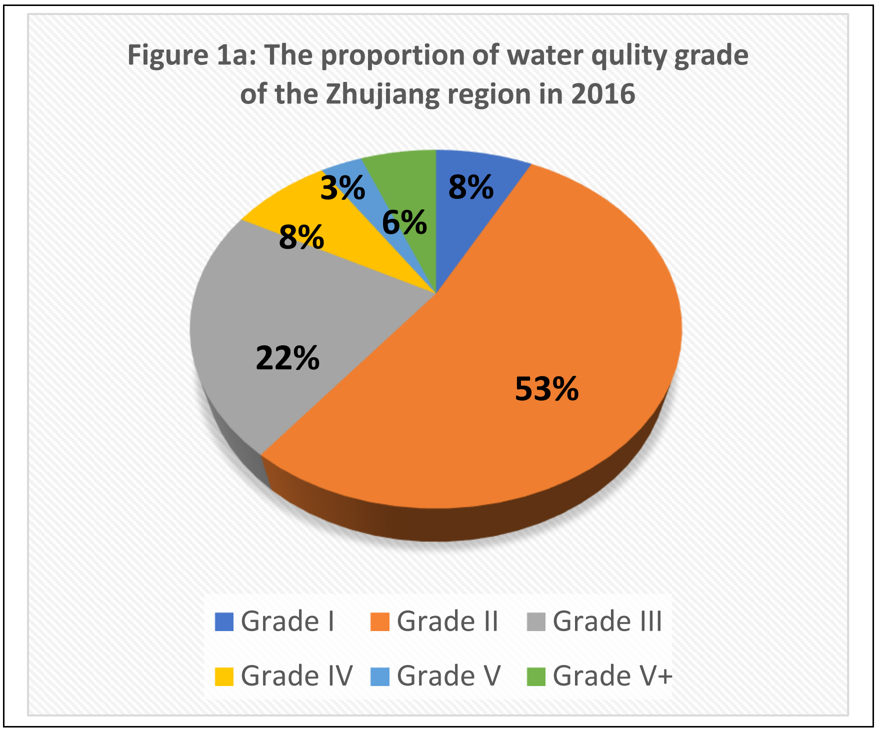
Table 3: Surface Water Quality Standards of the People's Republic of China

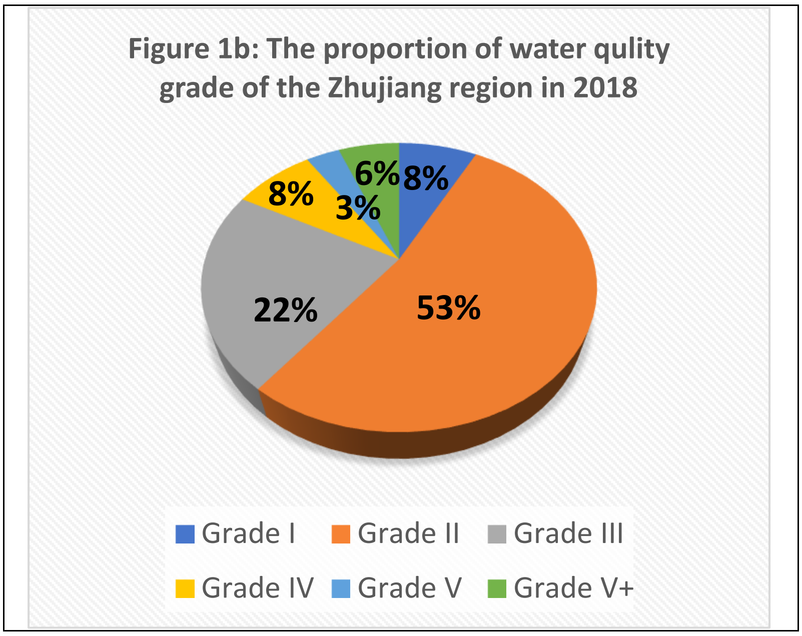
Class	Indicator	Intended purposes
I	Good	Headwater and national natural reserves
II	Relatively clean	Source of drinking water, habitat for rare aquatic species, and nursery ground for fish and shrimps
III	Slightly polluted	Source of drinking water, aquaculture and swimming areas
IV	Moderately polluted	Industrial and noncontact recreational uses
V	Highly polluted	Agricultural irrigation and general landscaping
V+	Extremely polluted	Basically useless

Source: China Water Quality Management: Policy and Institutional Considerations (2006)

Although the Guangzhou Government has put great effort in alleviating pollution, some parts of the river quality still need improvement. During the period between 2016 and 2018, the proportion of Class IV to V water within the Zhujiang region has increased from 9.7% to 11.2%, and that of Class V+ has increased from 3.8% to 6.0% (Figures 1a and 1b), indicating that the water quality still needed to be improved.

Figure 1a and 1b: The proportion of the different class of water quality in Zhujiang region in 2016 and 2018





Source: National Surface Water Quality Reports 2016 and 2018

With rising economic development and living standards, large quantity of sewage containing different types of pollutants was discharged into the rivers of the Greater Bay Area. This poses great effects on the quality of the surface waters. On average, an annual amount of approximately 202.5 million tonnes of industrial sewage was discharged with 45,750 and 3,025 tonnes of chemical oxygen demand (COD) and ammonia nitrogen respectively, in Guangzhou from 2014 to 2017 (Table 4). Also, the discharge of municipal sewage into rivers showed an increasing trend, aggravating the problem of surface water pollution. Major pollutants being discharged into the water bodies include heavy metals, nitrate, ammonia, phosphorus and oils.

Table 4: The amount of sewage and pollutants discharged from Guangzhou

	2014	2015	2016	2017
Industrial wastewater discharged (100 million tonnes)	2.2	1.9	1.9	2.1
Domestic sewage discharged (100 million tonnes)	14.2	14.3	14.2	15.2
Emission of COD in industrial sewage (1000 tonnes)	23.3	141.5	9.4	8.8
Emission of COD in domestic sewage (1000 tonnes)	104.2	106.3	106.4	105.4
Emission of ammonia nitrogen in industrial sewage (1000 tonnes)	1.6	9.4	0.6	0.5
Emission of ammonia nitrogen in domestic sewage (1000 tonnes)	17.4	17.5	19.2	19.1

Source: China Statistical Yearbooks 2015-2018

Additionally, being an important agricultural country, various agricultural activities also contributed to water pollution. The excessive consumption of chemical fertilisers and pesticides, as well as the discharge of livestock manure, have contributed positively to water pollution and resulted in algal bloom and eutrophication. Apart from the above-mentioned sources of water pollutant, other human activities, including toxic waste deposition, lumbering, mining-related erosion, shipping and land exploitation have also led to water pollution.

4.2. Rapid increase in water demand

In recent years, with an increase in population, the demand for residential water in Guangdong Province has also increased. Despite the decrease in total volume of water use in the province, there has been a clear upward trend of residential water demand since 2011 and it reached 10.09 billion m^3 in 2017, with an average annual growth rate of 1.26% (Table 5). In addition, there have been conflicts over water use between agriculture and industry in the Greater Bay Area. As traditional agriculture has progressively given way to both manufacturing and service sectors, industry has become the largest water user in terms of volume in the Greater Bay Area, accounting for 37% of the total water use.

Table 5: Water demand and water resources per capita in Guangdong Province between 2011 and 2017

Year	Water resources demand (billion m^3)	Residential water demand (billion m^3)	Water resources per capita (m^3)
2011	46.90	9.42	456.0
2012	45.10	9.54	427.5
2013	44.32	9.48	417.3
2014	44.25	9.61	414.2
2015	44.31	9.83	410.8
2016	43.50	9.99	398.2
2017	43.35	10.09	391.1

Source: China Statistical Yearbooks 2012-2018.

4.3 Severe saltwater intrusion

Due to a climate change-driven sea level rise and intensive human activities, the Greater Bay Area has been suffering from increasingly frequent and severe saltwater intrusion in the Modaomen Waterway (one of the eight major river outlets of Zhujiang) in recent years, threatening the freshwater supply of nearby cities. The Modaomen Waterway is the main source of freshwater in Zhujiang Delta as its discharge contributes to one-third of the total discharge of Zhujiang. However, the situation of saltwater intrusion in the waterway has worsened with a prolonged duration and a considerable increase in salinity which exceeds the national standard in drinking water (250 mg/L). Intense saltwater intrusion can significantly degrade water quality, affect agricultural irrigation and reduce drinking water availability in the area, which in turn, causing great economic losses. Cities such as Zhongshan, Zhuhai and Dongguan have been tremendously affected by saltwater intrusion, particularly in dry seasons between November to February. For example, during late 2003 to early 2004, saltwater intrusion lasted for several months which affected more than 5 million inhabitants in the area. Besides, an intense saltwater intrusion also happened in the dry season in mid-2005. To ensure freshwater supply, the first water transfer project was launched by the Guangdong Government to transfer river water from the upstream of Zhujiang (Liu et al., 2019).

5. Water resource management

Under the 13th Five-Year Plan for environmental protection, numerous legislations and policies which aimed at establishing integrated management have been launched to protect the water resources in the Greater Bay Area, particularly water pollution control and urban water quality monitoring. It is stated that the percentage of the national surface water reaching Grade III or equivalent must be increased from 66% to more than 70% by 2020. Besides, the percentage of surface water reaching Grade V, which is highly polluted, is aimed to be declined from 9.7% to not more than 5% by 2020. To fulfil this target, integrated prevention and control of water quality is promoted. By early 2017, every province should disclose the management of water quality to the public regularly for better monitoring (State Council of the People's Republic of China, 2016). Furthermore, the central government replaced the pollutant discharge fee system with a newly implemented Environmental Protection Tax in order to reduce the discharge of industrial pollutants into the rivers. Under the original pollutant discharge fee system, producers normally had no incentives to reduce industrial sewage as they were only required to pay a uniform fee. However, according to the newly established Environmental Protection Tax, the amount of charges depends on the types, amount, degree of concentration and harm of the pollutants. In other words, more charges should be paid by heavy polluters. Failure to pay the tax can have serious consequences, including a payment of a fine up to five times of the tax and criminal penalties (Cicenia, 2018). This tax system can help reduce people's incentive to discharge pollutants.

Supplementary Information (II)

Chinese institutions responsible for water resources management

Owing to fragmented roles and overlapped responsibilities among different ministries (this phenomenon was termed as "nine dragons rule the waters" in the past) in environmental management, President Xi Jinping announced the establishment of two new ministries, i.e. the Ministry of Ecology and Environment (MEE) and the Ministry of Natural Resources (MNR), in 2018 to take on the responsibilities of following nine ministries for a more efficient environmental protection:

(1) Ministry of Water Resources (MWR);
(2) Ministry of Land and Resources (MLR);
(3) Ministry of Housing and Urban-Rural Development (MoHURD);
(4) National Development and Reform Commission (NDRC);
(5) Ministry of Environmental Protection (MEP);
(6) Ministry of Agriculture (MOA);
(7) State Forestry Administration (SFA):
(8) State Oceanic Administration (SOA); and
(9) National Administration of Surveying Mapping and Geoinformation (NASG).

Key duties of the Ministry of Ecology and Environment (MEE) and the Ministry of Natural Resources (MNR) on water resources management

Institution	Key duties
MEE	Pollution regulation: ➢ Water pollution control ➢ Agricultural non-point source pollution control ➢ River basin management ➢ Water function area planning ➢ Wastewater discharge point management ➢ Environmental protection project areas
MNR	Resources management: ➢ Urban management of water supply, water conservation, drainage and sewage treatment ➢ Water resource monitoring ➢ Registration rights management

5.1 Pollution control

Cities within the Greater Bay Area have put a lot of investments on upgrading and building sewage treatment plants and cleaning up the polluted riverbeds. For example, the Zhen'an Sewage Treatment Plant in Foshan was expanded and the treatment capacity has been increased from 200,000 to 250,000 cubic meters per day. As a result, the wastewater collection and treatment rate increased from 55% in 2005 to 88% in 2013. Besides, sludge is properly and safely treated and disposed by the usage of four newly built sludge treatment facilities with a total capacity of 220 tons per day. This can help prevent water contamination and protect the water quality in the Greater Bay Area. Moreover, the sewage is being transferred to the wastewater treatment plant and properly treated before entering into the river. Embankments along the Fenjiang River in Foshan were improved by prohibiting the direct discharge of untreated sewage. Four automatic water quality monitoring stations and water environmental management information system were developed to control the discharge of wastewater into the river.

On the other hand, similar measures were also launched in Jiangmen. Expansion of the capacity of Wen Chang Sha Sewage Treatment Plant from 50,000 to 200,000 cubic meters per day has increased the wastewater treatment capacity from 22% in 2005 to 70% in 2013 (World Bank, 2016). In other words, a larger amount of wastewater is treated with upgraded sewage treatment plants, which help reduce the amount of pollutants being emitted into the rivers. This greatly improves the water quality in Greater Bay Area.

5.2 Stabilisation of water supply

Apart from water pollution, an increased water demand is another problem faced by the Greater Bay Area. As the volume of water resources in Xijiang is 10 times more than that of Dongjiang and the utilisation rate is only 1.2% (the utilisation rate of Dongjiang is 38.3% which closely reaches the international standard rate of 40%), to increase water supply in the area, a giant pipeline with a total length of 113 km was built to transport over an annual amount of 1.7 billion cubic meters of water from Foshan to Guangzhou, Shenzhen and Dongguan. This is the longest water diversion line with the largest amount of investment put in the province. Therefore, by transferring water from Xijiang to other cities, water supply in the Greater Bay Area is guaranteed. This project can alleviate the water shortage problem and work as a backup water resources for Hong Kong (Greater Bay insight, 2019).

5.3 Cross-boundary water management

The governments of Hong Kong and Guangdong jointly work together for an action programme to protect the quality of the water bodies nearby, which includes Deep Bay (Shenzhen Bay) and Mirs Bay. Hong Kong and Shenzhen are separated by Shenzhen

River and they share the same water bodies. Under rapid urbanisation and livestock rearing activities, these water bodies have been seriously polluted by the sewage and waste produced. As a result, Deep Bay and Mirs Bay were declared as a priority area for protection and conservation by the governments of Hong Kong and Guangdong in 1990 and 1994 respectively. In 2000, the *Mirs Bay and Deep Bay Areas Environmental Management Special Panel* was established under the *Hong Kong-Guangdong Joint Working Group on Sustainable Development and Environmental Protection* in order to increase protection on the water quality of both Deep Bay and Mirs Bay. The focus was to build and enhance the sewage infrastructure in order to limit the amount of pollutants into the waters.

Noticeable improvement of the water quality of both Deep Bay and Mirs Bay is shown. E. coli is one of the indicator for water quality. According to Hong Kong standard, less than 24 E.coli per 100 ml is regarded as “Good” water quality while more than 610 E. coli per 100 ml is regarded as “Very Poor”. In the case of Mirs Bay, the median E. coli content was 1 per 100 ml which implied that Mirs Bay was very good and was suitable for swimming. However, the median E. coli content in Deep Bay was 515 per 100 ml which was not up to standard (Environmental Protection Department, 2009), implying that improvements were needed for the water quality of the Deep Bay. Hence, Hong Kong and Guangdong will continue to cooperate together to enhance the water quality in the Greater Bay Area (Environmental Protection Department, 2018).

Furthermore, the *Pearl River Delta Water Quality Protection Special Panel* was established by the governments of Hong Kong and Guangdong under the *Hong Kong-Guangdong Joint Working Group on Sustainable Development and Environmental Protection*. It aimed to strengthen cooperation on protecting the water environment at the Zhujiang Estuary. In 2008, a computer water quality model for the Zhujiang Estuary region was developed which could not only help to understand the flow distribution and changes in water quality in the river network but also to assess the pollution carrying capacity of the estuary. Although the study found that the organic pollution level in the Zhujiang Estuary met the sea water standards, the eutrophication levels still did not meet the standard. Therefore, the governments of both Hong Kong and Guangdong will continuously enhance the water quality in the Greater Bay Area with different measures (Environmental Protection Department, 2018).

6. Conclusion

The Greater Bay Area has one of the most complex and special river networks in the world, with high annual and uneven seasonal precipitation, abundant annual discharge and small tidal ranges. Under rapid urbanisation and economic growth, water bodies in the Greater Bay Area have been seriously polluted by active industrial and agricultural activities and increased discharge of untreated domestic sewage. With a recently reformed water management system, improved water infrastructures and cross-boundary water management, many efforts have been made to alleviate different issues related to water resource, and rivers in the area have shown signs of improvement. It is believed that the management of water resources can be further strengthened with a collaborative effort from different stakeholders of the Greater Bay Area in the coming future.

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