Flood Management Strategies in Hong Kong: Addressing Climate Change through Progressive Adaptive Approach combining with Adaptation, Resilience, and Management (ARM)

K. W. Yuen[1], C. M. Lee[1], M. Y. Ng[1], Y. F. Wu[2], J. Lai Ng[2] and T. H. Chiu[2]
Land Drainage Division, Drainage Services Department, HKSAR, China[1]
E-mail: cmlee@dsd.gov.hk

AECOM Asia Co. Ltd, 9/F, Tower 2, Grand Central Plaza
138 Shatin Rural Committee Road
Shatin, HKSAR, China[2]
E-mail: alex.yf.wu@aecom.com

ABSTRACT

This paper presents a case study on development of a comprehensive flood management strategy for Hong Kong, a highly urbanized and densely populated megacity. It examines the challenges, investigations, and outcomes associated with establishing strategy to improve flood resilience of the city under climate change.

Hong Kong, located in a subtropical climate with an average annual rainfall of 2,400 mm, faces increasing flood risks due to extreme rainfall, rising sea levels, and storm surges exacerbated by climate change. To address these issues, Drainage Services Department of the Government of the Hong Kong Special Administrative Region of the People's Republic of China commissioned AECOM Asia Co. Ltd to conduct the Strategic Planning Study on Flood Management against Sea Level Rise and Extreme Rainfall (the Study).

Hong Kong has made significant investments in drainage infrastructure. However, under threat of climate change, it might no longer be practical to invest unlimited resources in providing massive drainage infrastructure to withstand very extreme event. Drawing references from international practices, a paradigm shift from focusing on structural measures to striving for a balance mix of structural and non-structural measures is promoted. An Integrated Flood Management Strategy that incorporates Adaptation, Resilience, and Management (ARM) is recommended to address the flood risks associated with climate change.

To address the uncertainties for development of climate change in future, the Study also promotes a Progressive Adaptive Approach which involves progressively enhancing drainage infrastructure with continuous monitoring of the climate change trend for long term planning. This approach helps avoid premature implementation of extensive infrastructure, thus preventing unnecessary construction and operation cost, while ensuring that decision-makers can respond effectively to evolving climate conditions. Together with ARM, the government is committed to protecting public safety while ensuring long-term sustainability.

KEYWORDS: Hong Kong, Climate change, Integrated Flood Management Strategy, Progressive Adaptive Approach, Extreme rainfall, Sea level rise.

1 INTRODUCTION

Hong Kong is one of the most densely populated coastal cities in the world, with over 7.5 million inhabitants occupying about 25 % of its 1,115 km² land area. Urban areas are highly concentrated along coastal areas or close to the steep hillsides. Hong Kong's subtropical climate delivers an average annual rainfall of approximate 2,400 mm, one of the highest in East and Southeast Asia. Rainfall distribution is uneven, with about 80 % concentrated between May and September (Web-1). The city also lies in the regular path of tropical cyclones, making it vulnerable to both intense rainstorms and storm surges brought by tropical cyclones. In recent years, Hong Kong experienced extreme weather events including series of extreme rainstorms necessitated issue of 4 Black Rainstorm Warnings in August 2025, record-breaking rainstorm on 7–8 September 2023 (with hourly rainfall of 158 mm registered at the Hong Kong Observatory Headquarters), Super Typhoons Ragasa (2025) and Mangkhut (2018) resulting significant storm surge along Victoria Harbour.

Global climate is expected to continue changing in the future. The Intergovernmental Panel on Climate Change (IPCC) has identified several critical impacts of climate change that directly affect urban drainage systems worldwide. According to the IPCC (2021), rising global temperatures intensify the hydrological cycle, which results in more frequent and intense precipitation events. This increase in rainfall can overwhelm existing drainage infrastructure, especially in densely populated, low-lying urban areas and coastal cities. Drainage systems, traditionally designed based on historical weather patterns, may be insufficient in coping with these new extremes. Consequently, cities are facing increased flooding risks and infrastructure strain.

2 CHALLENGES

Hong Kong's steep terrain, high urban density (as shown in Figure 1), and extensive impervious surfaces cause rapid runoff convergence into downstream drainage system, resulting in frequent flash floods. Low-lying coastal areas are simultaneously threatened by storm surges during passage of tropical cyclones and potential high astronomical tides. Sea level exceeding drainage outlets, can create backwater effects, which may result in inland flooding. Climate change exacerbates both threats through higher rainfall intensity and accelerating sea-level rise.

Figure 1: Steep terrain and dense urban setting of Hong Kong (DSD and AECOM, 2025)

Traditional urban flood management in Hong Kong has long relied on constructing large-scale drainage infrastructure to mitigate flood risks. However, with the increasing frequency and intensity of extreme weather events driven by climate change, the adequacy of this approach has come under scrutiny. A central debate has emerged over whether it is justifiable—or even feasible—to continuously invest unlimited resources to reinforce infrastructural capacity against increasingly extreme yet relatively rare events. Moreover, even the most robust designs have inherent limitations and may be exceeded by unforeseen events such as blockages of drains caused by leaves, debris, or waste, which can severely compromise system performance during critical moments.

Furthermore, the construction of large-scale drainage infrastructure is constrained by factors such as limited land availability and complex site conditions common in dense urban environments. In a compact city like Hong Kong, the public is cautious about allocating valuable space primarily for infrastructure intended to address future climate risks that may not yet be imminent. Instead, there is growing preference to use such land for purposes that deliver immediate social or economic benefits. These challenges highlight the need to move beyond purely structural measures toward an adaptive, resilient, and space-efficient approach to flood risk management.

3 INTEGRATED FLOOD MANAGEMENT STRATEGY

With reference to the Integrated Flood Management Concept Paper (the Concept Paper) by World Meteorological Organization and Associated Programme on Flood Management, it highlighted that *"flood management policy had already shifted in various places towards an approach beyond the myth of "absolute safety from flooding" towards a more flexible and adaptive approach of "living with flood risk". Such an approach recognizes the value of flood protection measures, yet also recognizes such residual risks as levee failure. Flood management needs to provide strategies for such eventualities, further strengthening the need for a balanced combination of structural and non-structural approaches."* (World Meteorological Organization. 2009)

A desktop review of global practices in tackling flood risks was conducted under the Study. It revealed that most cities adopt a combination of engineering infrastructure, sustainable drainage systems, floodproofing barriers, emergency preparedness, land use planning, etc, to handle flood risks. Although the extent and implementation details vary across locations, these measures share similar objectives and underlying principles in flood risk management. Drawing references from the Concept Paper and international practices, a paradigm shift from focusing on structural measures to striving for a balance mix of structural and non-structural measures in Hong Kong is promoted. An Integrated Flood Management Strategy that incorporates ARM is recommended to address the flood risks associated with climate change.

3.1 Adaptation

"Adaptation" was defined to suit the local context in Hong Kong. It refers to implementing various drainage improvement works such as constructing drainage tunnels, stormwater storage schemes, widening rivers, etc to enhance the drainage capacity of the drainage systems and hence reduce the flood risks. Given the high rainfall intensity experienced in Hong Kong, continued implementation of drainage infrastructure remains crucial, as extreme rain events are likely to exceed the capacity of other measures such as sustainable drainage systems. Tailored to the steep terrain of Hong Kong, a three-pronged flood prevention approach as illustrated in Figure 2 has been adopted in implementing drainage improvement works to reduce flood risks in various districts:

- Upstream - Interception
  Building drainage tunnels to intercept stormwater from the mid-levels and discharge it directly into the sea or to other channels.
- Midstream - Storage
  Building stormwater storage tanks in the mid-stream for temporary stormwater storage to attenuate the peak runoff and relieve the discharge load of the downstream drainage system.
- Downstream – Drainage Improvement

Carrying out river training works or build new drainage channels and drains to upgrade the capacity of drainage system.

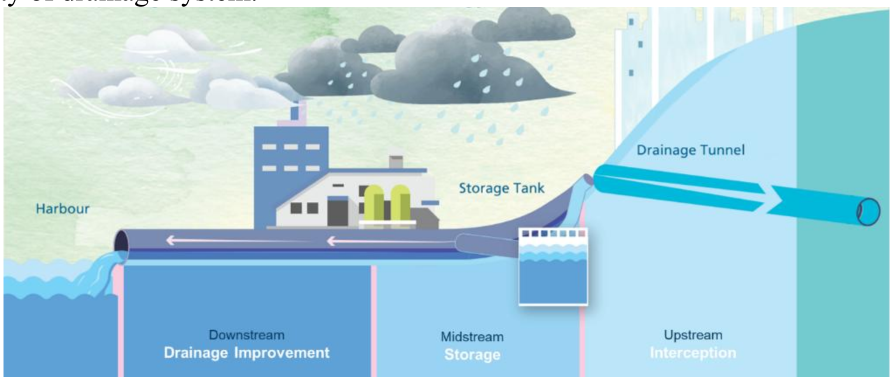

Figure 2: Three-pronged flood prevention approach (DSD and AECOM, 2025)

To effectively adapt to rising sea levels, measures such as smart penstocks/flap valves at drainage outlets to protect low-lying areas against backflow of seawater, barrage schemes at river channels to prevent seawater inundation due to high sea level and pumping systems for floodwater displacement would also be considered depending on the size and characteristic of the catchment to be protected. These measures are essential for safeguarding urban areas against the long-term threats of sea-level rise.

So far, as shown by DSD and AECOM (2025) key drainage infrastructures including four drainage tunnels with a total length of more than 20 km, five underground stormwater storage tanks with a combined capacity of approximately 250,000 m^3, equivalent to 100 standard swimming pools, over 2,400 km stormwater drains and over 370 km engineered channels were built to protect the city from flooding. Meanwhile, 15 drainage improvement projects including 9 stormwater storage schemes (with a total capacity of 320,000 m^3) and a barrage scheme are under construction in Hong Kong (Development Bureau et al., 2025).

3.1.1 Progressive Adaptive Approach

To address the uncertainties surrounding future climate change development and to align with the public expectations for more efficient use of resources in infrastructure implementation amid the evolving challenges, the Study advocates a Progressive Adaptive Approach. This approach, similar to the 'adaptive pathways' adopted in the United Kingdom, involves progressively enhancing drainage infrastructure with continuous monitoring of the climate change trend for long term planning as shown in Figure 3.

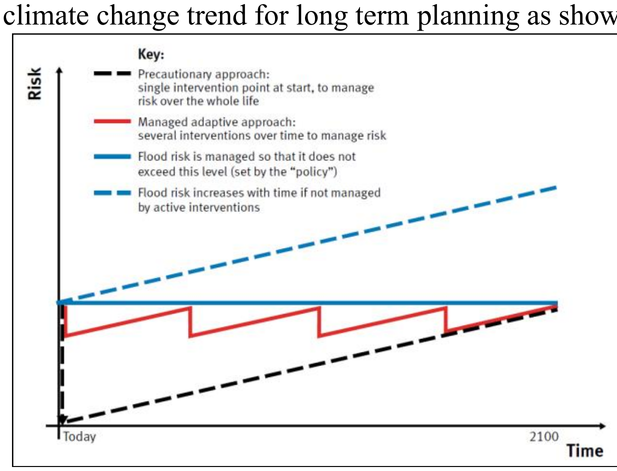

Figure 3: Managing flood risk through the century using the TE2100 managed adaptive approach (Environments Agency, 2012)

With reference to the Figure 3 from Thames Estuary 2100 (TE2100) Plan by the Environment Agency (2012), when compared to the precautionary approach, which relies on a single intervention at the start to manage risk throughout the entire life cycle, the managed adaptive approach—similar to the Progressive Adaptive Approach—involves multiple interventions implemented over time to continuously manage and adjust to evolving risks.

As the pathway of climate change development depends on global commitments toward carbon neutrality, Progressive Adaptive Approach provides flexibility to accommodate evolving needs over time. It enables drainage system to be designed, implemented, and adjusted progressively in response to changing climatic, technological, and societal conditions. At the same time, it would help avoiding the premature implementation of extensive drainage infrastructure, thus preventing unnecessary construction, operation and maintenance costs. Meanwhile, it would ensure the decision maker to plan ahead following the latest climate change development.

According to the climate change projections in various time horizons and greenhouse gas emissions scenarios for Hong Kong based on the "Sixth Assessment Report" (AR6) published by the IPCC (2021) and other related studies, the difference in the climate change impacts for Hong Kong between the intermediate and very high greenhouse gas emissions scenarios at mid-century is insignificant. Depending on the effectiveness of decarbonisation efforts by various nations, there are considerable uncertainties in the climate change impacts at the end of the century. The difference between intermediate and very high greenhouse gas emissions scenarios is more prominent. Table 1 (Web-2 and Web-3) below refers.

Table 1 Climate Change Projections in Hong Kong

	Rainfall Increase		**Mean Sea Level Rise (m)**	
	Intermediate Greenhouse Gas Emissions Scenario (SSP2-4.5)	Very High Greenhouse Gas Emissions Scenario (SSP5-8.5)	Intermediate Greenhouse Gas Emissions Scenario (SSP2-4.5)	Very High Greenhouse Gas Emissions Scenario (SSP5-8.5)
Mid 21st century	11.1%	10.6%	0.20	0.23
End of 21st century	16.0%	28.1%	0.47	0.64

Notes: The projections are relative to the average of 1995-2014. Median projection values are adopted for mean sea level rise and mean projection values are adopted for rainfall increase. Mid 21st century refers to years 2041 – 2060 and end of 21st century refers to years 2081 – 2100.

According to the Emissions Gap Report 2025 (United Nations Environment Programme, 2025), the latest trend of climate change is more likely to follow the intermediate greenhouse gas emissions scenario. For the scenario of Unconditional Nationally Determined Contributions, global temperature will increase below 2.5 ℃ with about a 66% chance and below 2.9℃ with about a 90% chance by 2100, which falls within the intermediate greenhouse gas emissions scenario (SSP2-4.5) with best estimate of 2.7℃ and very likely range from 2.1℃ - 3.5℃ by end of 21st century from IPCC AR6 (IPCC, 2021). Intermediate greenhouse gas emissions scenario at mid-century was taken as the design basis, where practically feasible, design provisions shall be included to enable timely upgrade of infrastructure in the future as needed, up to the climate change effects under the very high greenhouse gas emissions scenarios at the end of the century. As there exist considerable uncertainties in the impacts of climate change near the end of the century, the Progress Adaptive Approach provides sufficient flexibility and adaptability so that we can have sufficient time to develop effective and cost-efficient measures according to the actual situation.

An illustrative example of the application of Progressive Adaptive Approach is shown in Figure 4 below. For an area prone to potential flood risk under the current situation, the underground space beneath the recreational area can facilitate the "Single Site, Multiple Use" initiative to implement measures to mitigate possible flood risks up to mid-century. In the short and medium-term (up to mid-century), a stormwater storage scheme can be constructed underneath the recreational area, with space reserved for future expansion of the stormwater storage tank where practically feasible based on the anticipated climate scenario by the end of the century.

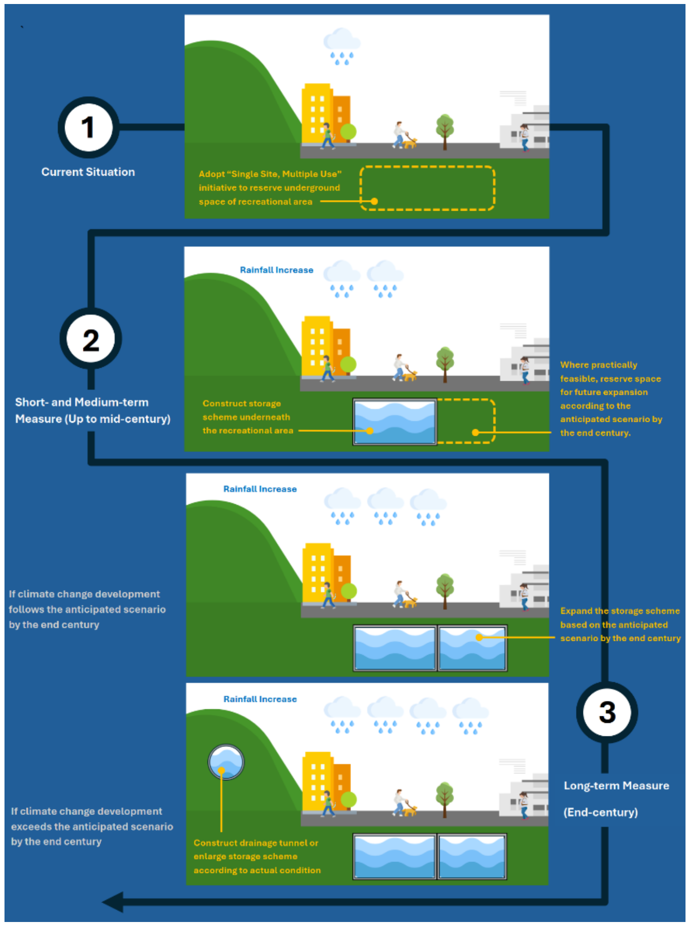

Figure 4: Illustrative Example of Progressive Adaptive Approach (DSD and AECOM, 2025)

The development of climate change will be under close monitoring. If the climate change trend aligns with the anticipated scenario, the remaining reserved space can be utilized to expand the stormwater storage scheme, accommodating the additional flood risk from climate change at the end of the century. If the climate change trend exceeds the anticipated scenario, additional measures such as constructing a drainage tunnel or further enlarging the stormwater storage scheme may be required based on the actual conditions.

3.2 Resilience

"Resilience" was defined to suit the local context in Hong Kong. It refers to adopting temporary or non-structural measures to control flood risks or reduce flooding impact for speedy society recovery. It creates a line of defence to form a buffer zone or limit the extent of flooding. It mainly includes blue-green drainage infrastructure and floodproofing measures.

Blue-green drainage infrastructure resembles other similar concepts, such as the "Sponge City", the "Active, Beautiful, Clean Waters", the "Sustainable Drainage System" and the "Low Impact Development" being adopted in the Mainland China, Singapore, the United Kingdom and the United States respectively. Blue-green drainage infrastructure emphasizes the importance of ecosystems and improvement of water resources such as water quality, climate regulation and habitat provision, as well as enhancing the city's flood adaptive capacity through promoting infiltration, storage, purification, reuse and discharge. Although blue-green drainage infrastructure alone cannot fully manage extreme rainfall events in Hong Kong, it can effectively handle a portion of the rain load and help reduce pressure on the conventional drainage system. Beyond its hydraulic benefits, it provides multiple co-benefits, including enhanced urban greening, improved environmental quality, and opportunities for land co-use. These features contribute to creating a more liveable cityscape and are widely appreciated and supported by the public.

Blue-green elements including revitalised river channel, bioretention system, green roof, porous paving system and water harvesting are commonly utilized to reduce surface runoff entering into the drainage system under normal rainfall events, hence improving the tolerability of the drainage system and reducing the risk of flooding. Another key blue-green element - floodable area, is used as recreational facility such as basketball courts, sports fields, and green parks during normal days and can be transformed into temporary flood storage facility under extreme rainfall events for benefits of land co-use.

As mentioned previously, even the most robust drainage designs have inherent limitations and may be exceeded under unforeseen extreme events, potentially resulting in flooding. In such cases, floodproofing measures, such as various types of flood barriers, can effectively minimize flood impacts by preventing floodwater intrusion into properties and enabling swift post-event recovery. In addition, when social impacts limit the full adoption of adaptation measures, resilience measures can serve as effective supplements. For instance, high flood walls may obstruct scenic views or reduce public interaction with water bodies. Therefore, a balanced approach integrating adaptation and resilience measures—such as constructing permanent flood walls at balustrade height with demountable barriers installed during extreme weather—may offer effective flood protection while preserving social and aesthetic values.

3.3 Management

"Management" refers to enhancements aimed at improving emergency response/preparedness for flooding through Just-in-time Clearance, adoption of innovative technologies, and effective information dissemination. It also covers updating standards and guidelines for flood management.

The Just-in-time Clearance focuses on addressing blockages in drainage systems caused by leaves, debris, or waste. Upon the issuance of rainstorm warnings by the Hong Kong Observatory, maintenance staff are immediately deployed to inspect drainage spots known to be prone to blockage, ensuring timely clearance and minimizing the risk of localized flooding.

The adoption of innovative technologies is essential for strengthening emergency response against flooding. For instance, installing Flood Monitoring Device along road kerbs at locations prone to blockages enables the collection of real-time water level data, supporting timely clearance operations. The application of artificial intelligence (AI) for real-time flood monitoring further enhances response efficiency by enabling automated detection and continuous assessment of flood severity. The use of "Mosaic Model Map" (M^3), a platform that integrates short-term precipitation and tidal forecasts with hydraulic model simulation results for prediction of flood risk across districts, facilitates advance planning for emergency preparedness. The deployment of powerful pumping robots can significantly strengthen emergency response by efficiently removing floodwater, thereby shortening flood duration and expediting society recovery.

Effective information dissemination on potential flood risk to the public is essential for enhancing preparedness, enabling timely protective actions and minimizing potential losses for the society. With the disclosure of the list of flood-prone areas, which includes Locations Prone to Blockage, Locations with Drainage Improvement Works in Progress and Coastal Low-lying or Windy Areas, the public are informed with areas with potential flood risks. In addition, water level sensors have been deployed along major rivers in Hong Kong to support digital transformation. Allowing public access to real-time water level information via a dedicated website can alert the community on potential flooding areas and make informed preparations, thereby facilitating safer travel and enhancing overall transparency of information.

Updating standards and guidelines for flood management is essential to adapt to climate change, incorporate new technologies, and reflect current best practices. As flooding events become more frequent and severe, revised standards ensure that flood management strategies remain effective and efficient. They enhance community resilience by integrating flood preparedness into urban planning, promote regulatory compliance, and improve coordination among stakeholders.

4 STRATEGIC APPLICATION OF ADAPTATION, RESILIENCE AND MANAGEMENT MEASURES FOR FLOOD EVENTS

In flood management, determining when to adopt structural (adaptation) measures versus non-structural (resilience and management) strategies depends largely on the predictability and characteristics of the flooding event. In Hong Kong, flooding can result from either extreme rainfall or during passage of tropical cyclones. Extreme rainfall events are highly unpredictable under current technology, offering very limited lead time for preparation. Consequently, structural measures are crucial to mitigate flooding impacts, particularly under normal societal operations when daily activities continue. In contrast, tropical cyclones related flooding is generally more predictable, with higher forecasting confidence and longer lead times for advance preparation. In addition, Hong Kong's established emergency mechanism—where the hoisting of Typhoon Signal No. 8 or above suspends schools and most work activities—ensures the majority of the population remains safely at home. Under such conditions, non-structural measures have greater room for effective implementation, as advance planning is essential to maximize their operational efficiency. Therefore, while adaptation measures play a vital role in responding to sudden extreme rainfall, resilience and management approaches are better suited to manage typhoon-induced flooding, where early warnings and organized societal responses can be leveraged to minimize risks and enhance overall preparedness.

5 CONCLUSION

Hong Kong faces intensifying flood risks from climate-driven extreme rainfall and sea-level rise. The Study provides a robust response through two interconnected frameworks: the Progressive Adaptive Approach, which phases investment according to evolving climate projections, and an Integrated Flood Management Strategy built on ARM pillars.

By combining flexible structural upgrades with enhanced resilience and management measures, Hong Kong can protect lives, critical infrastructure, and economic activity while optimising public resources. Continuous monitoring, periodic review aligned with IPCC assessment cycles, and active stakeholder collaboration will ensure the strategy remains effective against an uncertain climate future.

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