

Agreement No. CE 74/2018(CE)

Study of Coastal Hazards under Climate Change and Extreme Weather and Formulation of Improvement Measures – Feasibility Study

Final Report (Final)
(Ref. R17-04)

May 2022



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AECOM ASIA COMPANY LIMITED

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APPENDIX

Abbreviation

The following table lists out the abbreviated titles of Government bureaux, departments, offices, statutory bodies and public organizations mentioned in this report:

Abbreviation	Full title
BD	Buildings Department
CAS	Civil Aid Service
CEDD	Civil Engineering and Development Department
DSD	Drainage Services Department
FSD	Fire Services Department
HAD	Home Affairs Department
HKO	Hong Kong Observatory
HKPF	Hong Kong Police Force
HKSAR	Hong Kong Special Administrative Region
HyD	Highways Department
IPCC	Intergovernmental Panel on Climate Change
LandsD	Lands Department
LCSD	Leisure and Cultural Services Department
MD	Marine Department
NGOs	Non-government organisations
SB	Security Bureau
UNEP	United Nations Environment Programme
WMO	World Meteorological Organization

The following table lists out the abbreviations for expressions adopted in this Report:

Abbreviation	Full title
AR5	The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014)
AR6	The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2021)
CCWGI	Climate Change Working Group on Infrastructure
COP26	The 26th UN Climate Change Conference of the Parties
CPND	Contingency Plan for Natural Disasters
E&M	Electrical and mechanical

Abbreviation	Full title
ENC	Electronic Navigation Chart
GCM	General circulation models / Global climate models
GEBCO	General Bathymetric Chart of the Oceans
GHG	Greenhouse Gas
LiDAR	Light Detection and Ranging
NASDAQ	National Association of Securities Dealers Automated Quotations
RCPs	Representative Concentration Pathways
SLR	Sea Level Rise

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1. INTRODUCTION

1.1 Background of the Study

- 1.1.1 The geographical position of Hong Kong makes it susceptible to adverse weather-related threats such as tropical cyclones, rainstorms, storm surges¹ and overtopping waves². In particular, some coastal low-lying or windy locations are vulnerable to sea water inundation caused by extreme storm surges and/or overtopping waves, and have the facilities situated near the seaside damaged as a result.
- 1.1.2 The Super Typhoons Hato and Mangkhut hit Hong Kong in 2017 and 2018 respectively. Their storm surges and waves caused different extent of damages in some coastal areas of Hong Kong, for instance, some residential areas located in Eastern District of Hong Kong Island, Tseung Kwan O, Lei Yue Mun and Sai Kung. In addition, global warming has led to more frequent and intense extreme weather events around the world.
- 1.1.3 In April 2019, the Civil Engineering and Development Department (CEDD) commissioned AECOM Asia Company Limited (AECOM) to undertake the “Study of Coastal Hazards under Climate Change and Extreme Weather and Formulation of Improvement Measures – Feasibility Study” (“the Study”).

1.2 Objective of the Study

- 1.2.1 The objective of the Study is to comprehensively review the condition of the coastal low-lying and windy locations in Hong Kong and carry out investigation of storm surges and waves in order to assess the impacts under extreme weather, taking into consideration future climate change effects, at these locations. Where appropriate, enhancement measures are formulated to alleviate these coastal hazards as far as practicable with reference to overseas and local practices and experience in climate adaptation and management.
- 1.2.2 The objective of the Study include:
- (a) Review and identification of coastal low-lying and windy locations vulnerable to sea water inundation along the Hong Kong shoreline;
 - (b) Carrying out computer modelling simulations under climate change and extreme weather for assessment of coastal hazards;
 - (c) Review of the adequacy and capacity of the existing coastal protection for the coastal low-lying and windy locations along the Hong Kong shoreline;

¹ Storm surge is a rise of sea level due to the combined effects of low atmospheric pressure and high winds associated with tropical cyclones

² During the passage of tropical cyclones, waves approaching shores may surpass the coping level of seawall forming “overtopping wave”

(d) Formulation of enhancement plans for identified areas vulnerable to potential coastal risks; and

(e) Recommendations on follow-up actions.

Plate 1.1 Damages due to extreme weather observed during Typhoon Mangkhut (2018)

(Left: damage photos; Right: repaired photos)



1.3 Structure of the Final Report

1.3.1 This Final Report presents a summary of the major findings from the Study.

1.3.2 The structure of this Final Report is as follows:

- Section 1 provides a brief introduction of the Study;
- Section 2 presents the approach to deal with coastal hazards;
- Section 3 presents the assessment of the potential coastal risks at Hong Kong shoreline;
- Section 4 presents the formulation of enhancement plans for identified areas vulnerable to potential coastal risks; and
- Section 5 provides a summary of the recommendations on follow-up actions to be taken and way forward for future planning.

2. APPROACH TO DEAL WITH COASTAL HAZARDS

2.1 Hong Kong Shoreline

2.1.1 Given Hong Kong’s geographical location, it has long been vulnerable to impacts from a range of natural disasters, including tropical cyclones, storm surges and overtopping waves. Specifically, some coastal low-lying and windy locations are vulnerable to attacks by extreme storm surges and overtopping waves. These are naturally occurring coastal processes resulting in coastal flooding and facilities damages along the shorelines that are referred to as coastal hazards as they have the potential impact on public safety and development along the shorelines.

2.1.2 Impacts from coastal hazards may have different degree of significance affected by coastal environment, e.g. geographical locations, coastal topography, bathymetry, coastal defence structure, etc. In assessing the capability of a coastal area to cater for storm surges and overtopping waves under climate change effects, we need to get hold of the above aspects as summarized in **Table 2-1** for adoption in subsequent analytical assessment.

Table 2-1: Effects to Coastal Hazards

Aspects	Effects
1. Geographical location	<ul style="list-style-type: none"> • Both regional and local influences, such as variability in geomorphology, will result in local deviations from the generic response, producing variations in localised implications of coastal change. • The local implications of extreme water level and the interrelationship of weather events, coastal geomorphology and coastal processes, will vary from place to place. • Geomorphologic features of the existing coastline should be reviewed accordingly.
2. Coastal topography	<ul style="list-style-type: none"> • Topography and inundation are very closely linked to each other like the two sides of the same coin. Inundation affects topography; on the other hand, topography also affects how inundation occurs. • Topographic information within coastal areas should be collected for assessment.
3. Bathymetry	<ul style="list-style-type: none"> • The measurement of water depth in oceans, seas and rivers, etc. The bathymetry (underwater topography offshore) as well as the shape and character of the shoreline, influence the height and duration of wave.
4. Coastal defence structures	<ul style="list-style-type: none"> • Seawall is primarily to protect a shoreline from erosion against wave and current actions, while secondary function would reduce wave agitation. • The shoreline features and its extent should be reviewed for assessment.

2.1.3 Generally, the south and southeast side of Hong Kong are more exposed to overtopping waves caused by more frequent approach direction of typhoons crossing the South China Sea. In comparison, wave generated from wind is relatively insignificant while storm surges plays more important role in Tolo Harbour, where the coastal geomorphology amplifies surge levels due to the embayment effect, and the north western New Territories due to the flat low-lying topography.

2.1.4 As observed during the Super Typhoon Mangkhut occurring in 2018, significant overtopping waves was experienced at coastal locations such as Tseung Kwan O South. In comparison, storm surge plays an important role in Tolo Harbour, where the coastal geomorphology amplifies surge levels due to the embayment effect, resulting in flooding affecting the Lam Tsuen River in Tai Po.

Plate 2.1 Different coastal hazards observed at different locations during Typhoon Mangkhut (2018)



2.2 Overseas Coastal Resilience Practices

2.2.1 Some countries, such as United States, United Kingdom etc., have been historically hit by severe cyclones and caused severe coastal hazards. In response to their lessons learnt, these places have developed disaster management and adaptation measures. They have formulated guidelines to cope with coastal hazards. The key steps include:

- identifying coastal areas exposed to current and future coastal hazards

- identifying key assets potentially impacted
- assessing the potential risks for the key assets in coastal hazard areas
- identifying practical and feasible options for enhancement

2.2.2 The Study has made reference to their practices in coastal protection, climate vulnerability assessment³ and management to recommend enhancement plans suitable for Hong Kong.

2.3 Climate Change Projection

2.3.1 The Earth's climate has been changing due to variation in sunlight, Earth's orbital changes, volcanic activity, etc. However, their effects have been overshadowed by that of the increasing atmospheric concentration of greenhouse gases (GHG) since the Industrial Revolution. Human-caused climate change has become one of major challenges of mankind.

2.3.2 Extreme weather events are affected by climate change in Hong Kong. According to the HKO's information, extreme precipitation events have become more frequent. The hourly rainfall record at the Hong Kong Observatory Headquarters was broken several times in the last few decades, whereas it used to take several decades to break the record in the past. Over the last hundred years, the number of hot nights and very hot days in Hong Kong has increased while the number of cold days has decreased.

2.3.3 Climate change is one of the factors influencing the coastal processes. Sea level rise (SLR) and intensification of wave and extreme storms exacerbate the effect of the coastal hazards. Increase in GHG concentration causes a reduction in the outgoing infrared radiation, allowing heat energy to accumulate on the Earth and leading to warming of the climate system.

2.3.4 Global climate may continue to change in future. The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for disseminating climate change information, including synthesis of current climate change scientific reports and journal papers. Created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies. The IPCC provides scientific assessments of the scientific basis of climate change, its implications and potential future risks as well as adaptation and mitigation options (IPCC Website, n.d.).

2.3.5 In Paris Agreement, in enhancing the implementation of the United Nations Framework Convention on Climate Change, adopted in New York in 1992, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by holding the increase in the global average

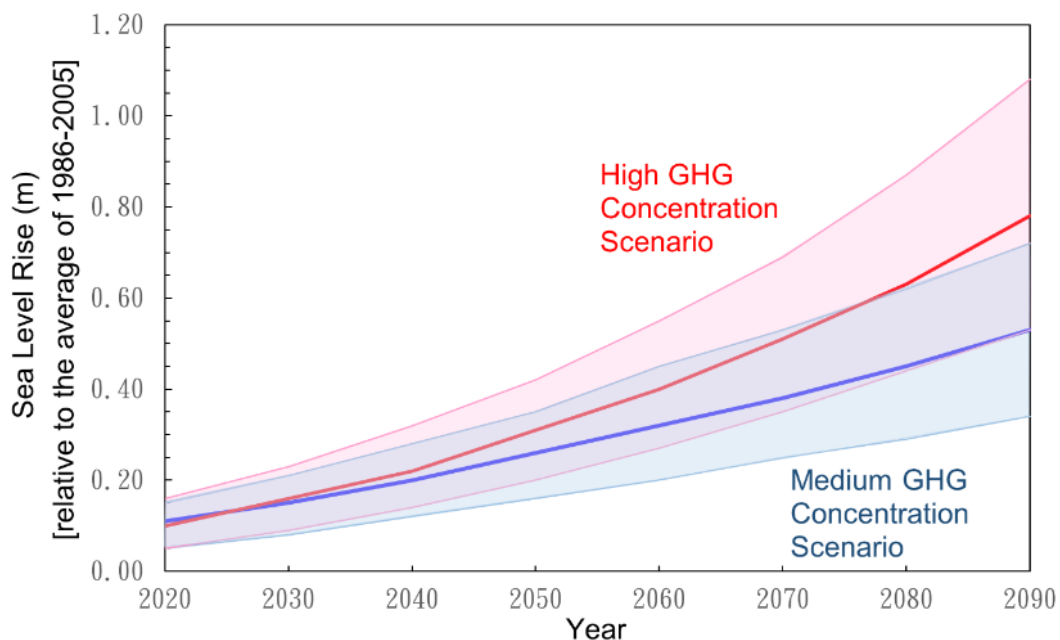
³ The tolerance of potential impacts of wave attack and associated consequence in coastal areas

- temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.
- 2.3.6 Climate change projections are developed based on a range of emissions scenarios. The IPCC Fifth Assessment Report (AR5) has considered four different pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) which referred to as Representative Concentration Pathways (RCPs). RCPs were developed to be 'representative' of possible future GHG emissions and atmospheric concentration scenarios published in the existing literature. They focus on the 'concentrations' of GHG that lead directly to a changed climate and include a 'pathway' – the trajectory of GHG concentrations over time to reach a particular radiative forcing. The pathways RCP2.6, RCP4.5, RCP6.0 and RCP8.5 are represented to low, [medium low, medium high] (medium) and high GHG concentration scenarios respectively. For example, in RCP8.5 the radiative forcing is 8.5 Watts per square metre in 2100. The four RCPs cover a range of emission scenarios with and without climate mitigation policies. For example, RCP8.5 is based on minimal effort to reduce emissions, while RCP2.6 represents strong mitigation efforts with early participation from all emitters followed by active removal of atmospheric carbon dioxide. However, the IPCC does not attribute likelihoods to which scenarios are more likely to occur over time.
- 2.3.7 While climate change has been established among the scientific community to be occurring and the trends are upward, there is great uncertainty about the magnitude of future climate change particularly towards the end of century and beyond. Depending on climate actions taken by global countries to reduce GHG emissions, development of climate change effects may follow different possible pathways in long-term future.
- 2.3.8 In addition, latest scientific research suggests that before 2050, differences in SLR projections under difference GHG concentration scenarios are relatively minor but they diverge significantly past mid-century. After 2050, SLR projections increasingly depend on the trajectory of GHG emissions.
- 2.3.9 The Hong Kong Government also attaches great importance to this issue and established in 2016 the Climate Change Working Group on Infrastructure (CCWGI) under CEDD to coordinate the effort of the works departments on the impact of climate change on public infrastructure in respect of adaptation and resilience.
- 2.3.10 Nations have commented to take actions to reduce carbon emissions and implement climate mitigation as pledged under the Paris Agreement. In April 2021, the United States and China commit to cooperating with each other to tackle the climate crisis and to take further concrete actions to reduce emissions aimed at keeping the Paris Agreement-aligned temperature limit within reach. Subsequently, most nations (including the world's two biggest CO₂ emitters) have pledged to act in a joint declaration to take actions to

reduce the GHG emissions in the 26th UN Climate Change Conference of the Parties (COP26) meeting in United Kingdom.

- 2.3.11 The key climatic variables considered in the Study include SLR and extreme wind, as they contribute the vast majority of Hong Kong’s future exposure to coastal hazards. With reference to AR5 published by IPCC⁴, take SLR as example, there is insignificant difference in SLR projection under medium and high GHG concentration scenario in mid-century whereas the difference is increasing significantly as time towards the end of century (**Diagram 2-1**).

Diagram 2-1: Representation of Climate Change Projections in terms of SLR



Reference: The Fifth Assessment Report of the Intergovernmental Panel on Climate Change

2.4 Strategy for Adapting to Coastal Risks

- 2.4.1 To combat climate change effectively, apart from materializing measures to reduce emission of GHG, we need to formulate strategy on climate change adaptation taking into account the coastal risks with a view to reducing the impacts on coastal and low-lying areas from extreme weather and strengthen the resilience of the community.
- 2.4.2 In view of the considerations in **Section 2.3** above regarding the uncertainties in the range of possible future climate change development and global actions among nations on reducing carbon emissions, this Study recommends to adopt a “progressive adaptive approach” to formulate climate adaptation measures for coastal low-lying and windy locations. This approach is to be flexible and adaptive enough that they can be changed or updated as conditions change or if impacts due to climate change are different from that

⁴ IPCC has released global mean SLR projection in the Sixth Assessment Report (AR6) in August 2021. The global mean SLR at mid-century under the intermediate GHG emissions scenario in AR6 are comparable with the projections under medium GHG concentration scenario in AR5

anticipated.

- 2.4.3 Under the progressive adaptive approach, this Study recommends to adopt medium GHG concentration scenario (assumed scenario) established in IPCC to focus on devising enhancement measures up to mid-century (2050), and closely monitor long-term climate change projection. Planning and management of the implications of climate change on coastal hazards should therefore be carefully considered to appropriately account for the uncertainty.
- 2.4.4 According to the Port Works Design Manual (PWDM), extreme events with return periods of 100 years should be considered in the design of typical coastal structures. Other overseas places, including United Kingdom, Mainland and New York, United States, commonly adopt 100-year return period extreme events for design of coastal structures. Taking into account site constraints and environmental and social impacts, the Study recommends to adopt at least 100-year return period extreme events, as far as practicable, in designing the enhancement for existing typical marine structures with a design life of 50 years in Hong Kong.
- 2.4.5 Where practical, this Study recommends to apply “design allowance”⁵ in design of adaptation measures for coastal structures, with a view to further enhancing their resilience against climate change under different climate change scenarios, including the possible differences in SLR predictions, increase in storm surge and wave height due to increase in wind intensity.
- 2.4.6 As part of progressive adaptive approach, this Study recommends to continuously monitor the climate change and review the measures to cope with coastal risk in a timely manner.
- 2.4.7 For enhancement of existing coastal structures, even if the climate change projection is more severe than the assumed scenario in mid-century (i.e. towards high GHG concentration scenario), the design allowance to be adopted by the Government could enhance the resilience of existing coastal structures.
- 2.4.8 If the long-term climate change to be predicted near mid-century follows the assumed scenario, modification (by means of heightening or strengthening) of the concerned coastal structures in a timely manner could generally enable them to cope with the extreme weather in end of century. If the long-term climate change to be predicted near mid-century is more severe than the assumed scenario, the Government should consider planning for larger-scale coastal protection measures to cater for the coastal risks in end of century. This approach could avoid implementation of large-scale mitigation measures prematurely at unnecessary construction and operation cost.
- 2.4.9 For new coastal structures, this Study recommends to reserve design allowance in design taking into account the life of marine structures to enhance

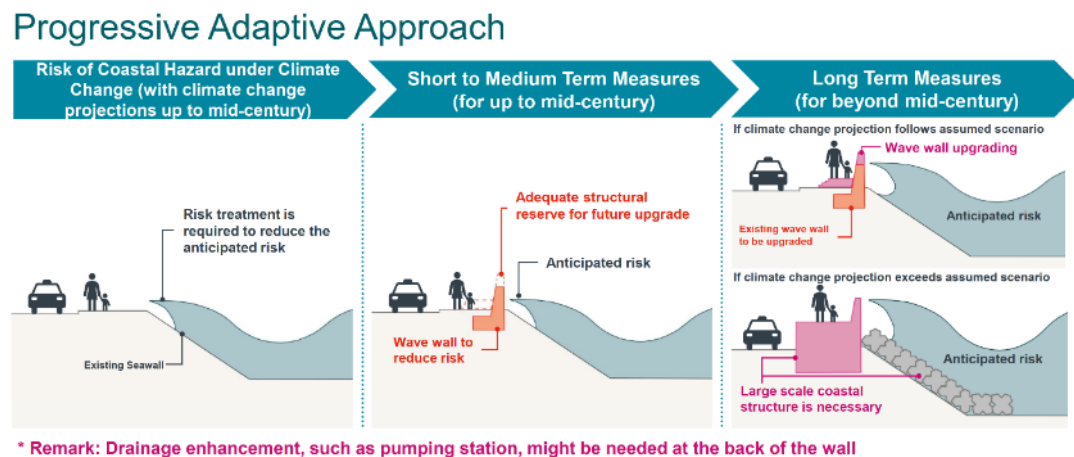
⁵ Design allowance: It reserves as an allowance for modification of design in future, e.g. designing sufficient foundation capacity for further raising height of wave wall, etc., if necessary.

their resilience against possible higher GHG concentration scenario.

2.4.10 The concept of the proposed progressive adaptive approach can be summarized as below and illustrated in **Diagram 2-2**:

- a) to adopt medium concentration scenario to design coastal structure with allowance in the design for enhancement in the future, where practical; and
- b) to continuously monitor the situation of climate change and review the need for the enhancement near mid-century, which may include large scale enhancement, if needed.

Diagram 2-2: Progressive Adaptive Approach for Addressing Uncertainties about Climate Change



2.4.11 Making reference to overseas experience, this Study recommends to providing guidelines on planning and land use as well as formulating the related long-term strategies and defensive measures to enhance the Government and relevant stakeholders' ability to cope with climate change in Hong Kong.

3. IDENTIFICATION OF COASTAL AREAS TO BE ENHANCED

3.1 Review of Hong Kong Shoreline

- 3.1.1 With its longer than 1,000km shore, Hong Kong is one of the major cities in Southeast Asia having longest coastlines. Though many coastal areas in Hong Kong are protected by coastal structures, they are experiencing risks caused by continuous climate change.
- 3.1.2 Given Hong Kong's geographic position, different topography, bathymetry and relevant coastal defence structures, etc., it is currently susceptible to potential weather-related risks, specifically, coastal low-lying and windy areas are vulnerable to sea water inundation and wave attack driven by extreme storm surges and overtopping waves. Records on the damage to coastal structures (e.g. seawalls) and facilities (e.g. pavements, premises near residential units) at coastal areas during past typhoon events and subsequent repairs and enhancements have been reviewed, which indicate that a review of the adequacy and capacity of the existing coastal structures is indispensable for the planning of future enhancement of the coastal structures taking into consideration climate change effects.
- 3.1.3 Hong Kong's existing shoreline comprises a variety of different coastline settings generally including:
- Man-made coastlines protected by rubble mound sloping seawall
 - Man-made coastlines protected by gravity vertical seawall
 - Low-lying coastlines
 - Beaches
 - Natural shorelines
 - Riversides
 - Coastal high grounds
 - Undeveloped shorelines
- 3.1.4 Rubble mound sloping seawall (**Plate 3-1**) are artificial revetments comprised of multiple layers of armour rocks. These armour rocks provide a permeable surface to absorb energy of incident waves and hence reduce overtopping waves and associated risk of damages and floods.

Plate 3-1: Rubble mound sloping seawall



- 3.1.5 Gravity vertical seawall (**Plate 3-2**) are artificial vertical walls usually comprised of concrete blockworks or reinforced concrete caissons. These vertical walls have relatively small land footprints but incident waves may induce up-rushing of sea waters over the walls causing potential overtopping waves.

Plate 3-2: Gravity vertical seawall



- 3.1.6 Low-lying coastlines (**Plate 3-3**) are coastal areas situated near or below the extreme sea levels arising from storm surges. These areas may potentially be subjected to damages by floods due to sea water inundation and overtopping waves.

Plate 3-3a: Low-lying coastlines with stilt houses



Plate 3-3b: Low-lying wetland



- 3.1.7 Beach (**Plate 3-4**) is a landform consist of loose particles such as sand and pebbles. The beach profiles may change over time through natural processes like tidal currents, wave actions and extreme weather events.

Plate 3-4: Beaches



- 3.1.8 Natural shorelines (**Plate 3-5**) refers to non-artificial but naturally consolidated shorelines. Natural shorelines in Hong Kong are commonly comprised of bedrocks, rubbles, muds and mangroves.

Plate 3-5: Natural shorelines



- 3.1.9 Riversides (**Plate 3-6**) refers to the areas of land by the banks of rivers. Riversides are subjected to flooding when the water goes over the riverbank, usually due to the heavy rain and storm surges under extreme weather conditions.

Plate 3-6: Riverside



- 3.1.10 Coastal high ground areas (**Plate 3-7**) are situated significantly higher than expected extreme sea levels under climate change and extreme weather conditions. No potential risk of coastal hazards is therefore anticipated.

Plate 3-7: Coastal high ground



- 3.1.11 Undeveloped shorelines (**Plate 3-8**) are coastal areas without development and therefore, even if subjected to coastal hazards, have insignificant consequences, e.g. no damage to properties and infrastructure, no impact on local economy and no disruption to community.

Plate 3-8: Undeveloped shorelines



- 3.1.12 The Hong Kong shoreline has been comprehensively reviewed in a systematic and analytical manner. Some coastal areas are exposed to coastal hazards in different extent under extreme weather and climate change.
- 3.1.13 In general, overseas coastal protection planning practices are increasingly adopting a “risk management adaptation pathways” approach which is taking into consideration “likelihood of coastal hazards” and “severity of consequence” under climate change and extreme weather to deal with uncertainties associated with long-term climate change for a planning horizon up to end of century.
- 3.1.14 Therefore, it is required to identify those coastal areas susceptible to higher risks primarily based on “likelihood of coastal hazards” and “severity of consequence” and to consider the enhancement measures in priority at those coastal areas where are vulnerable to potential higher coastal risks.
- 3.1.15 For analytical assessment, the relevant coastal topography and bathymetry data as well as coastal defence structures as mentioned in **Section 2** have been collected from the relevant governments and/or organization. During the analytical process, this Study has made reference to the records of damage posed by coastal flooding in past super typhoon attacks.

3.2 Analytical Assessment

- 3.2.1 We have applied computer models to simulate the sea water level and wave height with 100-year return period extreme events taking into consideration climate change projection up to 2050 under medium GHG concentration scenario. These models are developed to cover the water areas within Hong Kong and nearby (South China Sea) and are calibrated and validated in good

agreement with measured data during past typhoon events.

3.2.2 Computer models which have been used to provide the wave climate for the coastal areas across Hong Kong under a 100-year return period event. The Delft3D D-Wave module provides an interface for the SWAN wave model, a state-of-the-art, third generation spectral wind-wave model, which can be applied to simulate the growth, decay and transformation of wind-generated waves and swell. The following main physical processes are included in the model:

- Wave growth by action of wind;
- Non-linear wave-wave interaction;
- Dissipation due to bottom friction;
- Depth-induced wave breaking; and
- Refraction, shoaling and diffraction.

3.2.3 Fully-developed wind-sea conditions have been assumed within the model domain. A constant wind speed and extreme water level based on design parameters in PWD M published by CEDD taking into account the climate change effect have been applied across the whole model domain to generate the nearshore wave climates.

3.2.4 A local wave model has been configured for Hong Kong and surrounding waters to predict nearshore wave conditions. The model domain is open to the South China Sea and provides coverage of all coastal areas and an extensive offshore region (**Figure 3-1**).

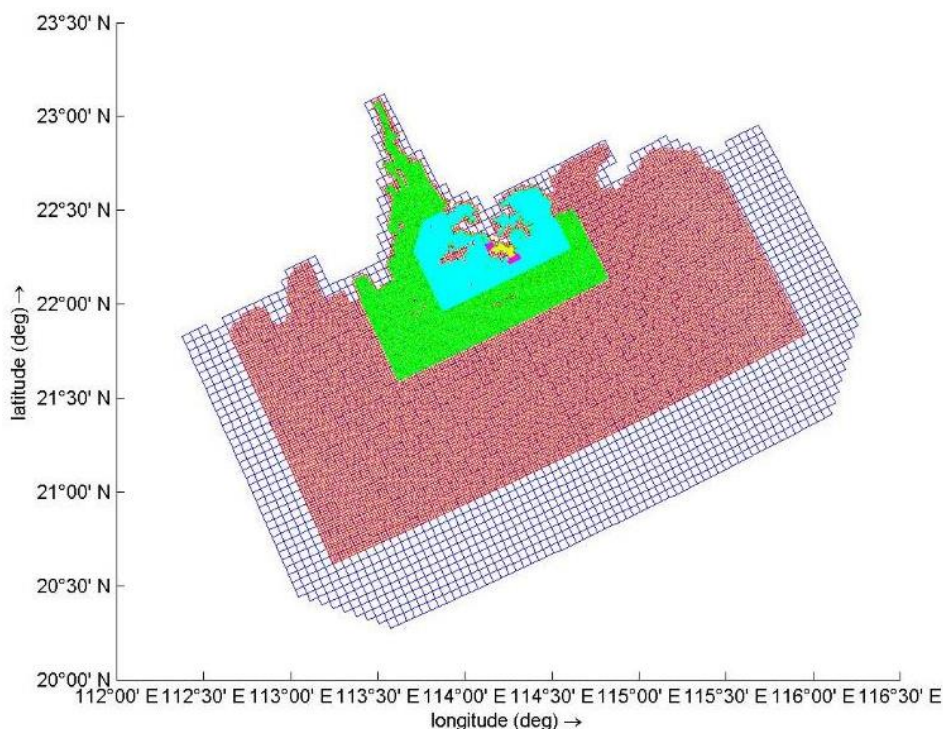


Figure 3-1: Model Set-up

3.2.5 Model input data parameters and information required for assessment is described below:

Table 3-1: Model input data parameters

Data Parameters and Information	Sources of Data
Bathymetry information of surrounding waters	<ul style="list-style-type: none"> • General Bathymetric Chart of the Oceans (GEBCO)
Bathymetry information of Hong Kong Waters	<ul style="list-style-type: none"> • Bathymetric survey data and Electronic Navigation Chart (ENC) provided by MD, Rivers survey data provided by DSD • Topographic survey plan provided by LandsD • Territory-wide Airborne Light Detection and Ranging (LiDAR) data provided by CEDD
A location where wave reflections and transmissions by obstacle such as typhoon shelters, water basins, breakwater	<ul style="list-style-type: none"> • Bathymetry information of Hong Kong Waters • Charts for local vessels by MD
Mean hourly wind speeds for return periods of 10, 50 and 100 years in different wind directions	<ul style="list-style-type: none"> • PWD M Corrigendum (2018) at the three main meteorological stations, namely Kai Tak Airport Southeast Station, Cheung Chau Station and Waglan Island Station
Extreme Water Level for different return periods	<ul style="list-style-type: none"> • PWD M and its Corrigendum (2018) at eight tide gauges including Waglan Island, Quarry Bay/North Point, Ko Lau Wan, Tai Po Kau, Tai O, Tsim Bei Tsui, Lok On Pai, Chi Ma Wan

3.2.6 The model setup has also been calibrated against measured waves at West Lamma Channel (WLC) and Kau Yi Chau (KYC) during Super Typhoon Mangkhut. The modelled and measured maximum significant wave height reached during Super Typhoon Mangkhut at WLC and KYC are compared and found satisfactory. The calibration has demonstrated that the refined model setup is capable to simulate wave conditions at Hong Kong Waters comparing with the real measurements during past typhoon events.

3.2.7 Further to the model calibration, modelling simulations have been performed to simulate the following combinations of wave and sea water level conditions. According to PWD M Part 1 Clause 5.10.2, these conditions refer to storm events with return periods of about 100 years. The projection of climate change effect (SLR & increase in extreme wind speed) are also adopted for the modelling simulation.

- (i) 100-year return period sea water level & 10-year return period wave
- (ii) 50-year return period sea water level & 50-year return period wave
- (iii) 10-year return period sea water level & 100-year return period wave
- (iv) Mean lower-low water level & 100-year return period wave

3.2.8 Considering the above data and information, we have conducted the following analyses and assessments by means of computer modelling. This facilitates assessment of the potential impacts and severity of consequences for coastal areas exposed to the coastal hazards:

- Stability analysis of existing coastal structures (i.e. seawalls)
- Wave overtopping analysis
- Coastal flood inundation assessment

Stability analysis of existing coastal structures

3.2.9 We have reviewed the existing seawalls susceptible to coastal risks against the design extreme events taking into consideration climate change effects.

3.2.10 Data parameters, information and modelling required for stability analysis is described below:

Table 3-2: Data parameters and information for stability analysis

Data Parameters and Information	Sources of Data
As-built records	<ul style="list-style-type: none"> • Relevant government departments (i.e. CEDD, BD)
Survey record plans	<ul style="list-style-type: none"> • LandsD
Charts for local vessels	<ul style="list-style-type: none"> • MD
Past coastal damage records	<ul style="list-style-type: none"> • Relevant government departments (i.e. CEDD, HAD, DSD, HKO) • Information from public domains
Coastal defence structure	<ul style="list-style-type: none"> • As-built records • site reconnaissance and verification (i.e. manual measurement, provision of wave wall)
Analytical tools	<ul style="list-style-type: none"> • Slope/W computer programme
local and overseas standards and practices	Design manuals, including but not limited to, <ul style="list-style-type: none"> • PWDM • Geoguide • Standards Australia, (i.e. Guidelines for the design maritime structures) • US coastal engineering manual • British Standards (i.e. BS 6349) • EurOtop Manual

3.2.11 In the Study, engineering analysis of the existing coastal structures are conducted with an aim to identify any major stability issues under extreme weather and ongoing climate change effects. With reference to the most recent coastal damage records due to past super typhoons (i.e. Hato and Mangkhut in 2017 and 2018 respectively), in general, only localised damages were recorded at the coastal areas. Repair/recovery was able to be effected in a relatively short period of time. The stability analysis has been taking into account of the repair works and improvement measures already implemented

subsequent to the super typhoon events.

- 3.2.12 The results of analysis have indicated that the existing seawalls could generally be able to withstand the design extreme weather taking into account climate change projections up to 2050.

Wave overtopping analysis and coastal flood inundation assessment

- 3.2.13 Wave overtopping discharge occurs when wave running up the face of a seawall or coastal structure sufficiently to reach the crest elevation. If wave run-up levels are high enough, water will reach and pass over the crest of the structures. For vertical seawalls/coastal structures, the wave may also impact against the wall and send a vertical plume of water over the crest, particularly when blown by wind. These phenomena are defined as wave overtopping. The wave overtopping would estimate the mean rate of wave overtopping water volume over time along the coastline.
- 3.2.14 Coastal flood inundation can occur because of high sea water level during storm event. For low-lying coastal areas where ground level at coastline is below sea water level, coastal flood inundation will occur by direct inundation of sea water. For coastal areas with ground level at coastline higher than sea water level where direct inundation of sea water may not occur, if it is subject to strong wave attack, coastal flood inundation may still occur due to wave overtopping.
- 3.2.15 Data parameter, information, and modelling required for wave overtopping analysis and coastal flood inundation assessment is described below:

Table 3-3: Data parameters and information for wave overtopping analysis and coastal flood inundation assessment

Data Parameters and Information	Sources of Data
Storm data (i.e. sea water level, wave condition)	<ul style="list-style-type: none"> • Modelling simulations results
local and overseas standards and practices	Design manuals, including but not limited to, <ul style="list-style-type: none"> • PWDM • Stormwater Drainage Manual • EurOtop Manual • CIRIA Rock Manual
Coastal defence structures (i.e. seawall types, geometries of seawall structure/coastline)	<ul style="list-style-type: none"> • As-built records • Survey record plan • Charts for local vessels • Site reconnaissance and verification (i.e. manual measurement, provision of wave wall)
Coastal topography (i.e. coastline level, coastal ground level)	<ul style="list-style-type: none"> • LiDAR data from CEDD • Topographic survey map from LandsD • As-built records
Analytical tools	<ul style="list-style-type: none"> • Arc GIS Pro • Infoworks-ICM coupled 2D/1D model

3.2.16 Wave overtopping analysis and coastal flood inundation assessment have been carried out for the design extreme event taking into consideration future climate change projection up to 2050 under medium GHG concentration scenario. These analyses provided the wave overtopping rates and situation of coastal flood inundation for determining the affected assets and likely impacts by coastal flood inundation, and hence in the selection of appropriate type of protective measures for formulation of enhancement plans.

3.2.17 Some of the coastal areas would be vulnerable to the potential coastal risks identified (**Plate 3-9**) as follows:

- Coastal flooding due to spreading of water from overtopping waves
- Damage of waterfront pavement due to overtopping waves
- Sea water inundation at low-lying areas

Plate 3-9: Potential coastal risks at coastal areas of Hong Kong





3.3 Identified Areas Vulnerable to Coastal Risks

- 3.3.1 Based on the analysis above, it should be pointed out that, under normal weather conditions, existing coastal structures along the shoreline of Hong Kong are generally adequate to safeguard coastal areas from coastal flooding at least up to 2050.
- 3.3.2 Following risk management approach, we first deal with those locations susceptible to higher risk with greater consequence. Most people will stay at home when typhoon strikes. Normally in non-residential areas, there will be very few or no activities during extreme weather hence the risk to human safety from coastal hazards is much smaller.
- 3.3.3 To address the prime concern of human safety, coastal areas with residential developments vulnerable to potential coastal risks are identified, where priority should be accorded to formulate enhancement measures to alleviate the implications of extreme weather to the public and to enhance the resilience of the community.
- 3.3.4 26 coastal low-lying and windy residential areas more vulnerable to higher potential risks due to overtopping water or sea inundation in low-lying areas and/or with flood damage record during extreme weather are identified for implementation of improvement works and management measures to safeguard public safety (i.e. identified areas). The existing storm surge spots and overtopping wave spots identified by DSD are included in these areas. The 26 identified areas are shown in the diagram below:

Diagram 3-1: Identified areas for enhancement



4. ENHANCEMENT PLANS

4.1 Major Considerations for Enhancement Options

4.1.1 We have taken major considerations as summarized in **Table 4-1** into account. It is envisaged that these enhancement options will be further developed in future detailed planning when implementing the recommended enhancement measures. The recommendations from the Study will form an informative basis for future reference.

Table 4-1: Major considerations of enhancement plans for identified areas

Aspects	Considerations
1. Coastal hazards extent	<ul style="list-style-type: none"> To identify hazards (e.g. flood inundation or flooding due to overtopping water) with modeled results. To check damage records during Super Typhoon Hato and Super Typhoon Mangkhut.
2. Severity of consequences	<ul style="list-style-type: none"> To assess the severity with modeled results such as flood depth, flood extent, vicinity of properties, etc.
3. Site constraints	<ul style="list-style-type: none"> To identify major site constraints such as availability of access, presence of private lots, limitation of space for construction works, impact on navigation channels, scattering of residential blocks, low-lying areas, stilt house along coastline/river channel, irregularity of coastline with different levels, etc.
4. Enhancement works under construction, investigation and planning	<ul style="list-style-type: none"> To make reference to the enhancement works under construction, recently completed (e.g. construction of wave wall at Tseung Kwan O South), and planning (e.g. Yuen Long barrage scheme) by various government departments or parties.
5. Practicability	<ul style="list-style-type: none"> To assess the structural capability and identify the need of local strengthening work. To take into account the cost effectiveness of enhancement plan and extent of strengthening work. To recommend appropriate measures including resilient and management measures.
6. Adaptability in future	<ul style="list-style-type: none"> To assess the adaptability in future and/or climate change scenarios.
7. Implementation Time	<ul style="list-style-type: none"> To adopt simple measures to avoid lengthy legislative proceedings.
8. Cost Effectiveness	<ul style="list-style-type: none"> To adopt simple measures and assess the cost effectiveness of extensive infrastructure
9. Social and environmental Impact	<ul style="list-style-type: none"> To minimize the social and environmental impact, e.g. transportation, ecological impact for marine works, etc., as far as possible. To use transparent flood wall to preserve the scenic view at locations with low risk of wave attack. To avoid affecting the existing seabed.

4.2 Pragmatic Enhancement Measures

4.2.1 In view of the transient and high consequential nature of extreme weather, the Study has proposed to adopt a pragmatic approach in formulation of cost-effective enhancement plans that strike a right balance between potential coastal risks and practical mitigation solutions. The enhancement plans shall be formulated to relieve the impacts of the major coastal risks under extreme weather conditions. The general approach for the formulation of the enhancement plans are outlined below:

- Review overseas countries' experience of coastal protection strategies and measures for adaptation to climate change; review the relevance / appropriateness of overseas experience in Hong Kong
- Review local practice and experience on enhancement measures against coastal hazards
- Develop the strategies and principles of enhancement plans
- Appraise the coastal hazards and risks and formulate enhancement plans for the identified areas

4.2.2 We need to consider practical and feasible situations to reduce the coastal risks at the coastal areas in priority manner. However, not all coastal areas could be fully 'protected' by engineering approaches of infrastructure enhancement ("Hardware") due to factors including site constraints, consideration of cost-effectiveness, and impact on marine traffic, social activities as well as environment. It is equally important to identify appropriate management measures ("Software"), including early alert system, emergency response, etc., to enhance the level of preparedness, response and resilience of the community to cope with the residual risks after the Hardware is in place.

4.2.3 Making reference to overseas and local experience and approaches, this Study recommends to adopt multi-layered enhancement measures to cope with extreme weather, which take, including but not limited to, the following advantages:

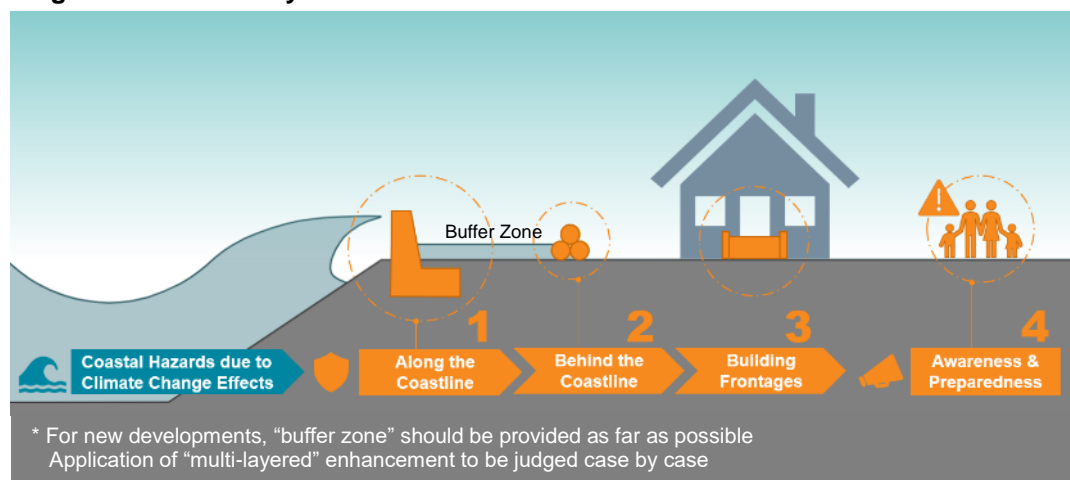
- More cost-effective and environmental friendly as compared with construction of mega infrastructure;
- Minimizing social impact;
- Making use of space near seafront, if available, as buffer zones; and
- Allowing flexibility for raising of wave walls later, if necessary.

4.2.4 **Diagram 4-1** illustrates this concept of "multi-layered" enhancement, which generally comprises:

- (1) Constructing or raising wave walls along the coastline to reduce coastal hazards; and/or

- (2) Installing fixed and/or demountable flood barrier at suitable places behind the coastline to cut off water pathway towards inland; and/or
- (3) Installing demountable flood barrier and providing sandbags at building frontages.
- (4) Adopting management measures to work with (2) and/or (3) above to enhance the awareness and preparedness of the public against extreme storm events, e.g. formulation of action plans on early alert system and emergency preparedness, provision of staff gauge, placement of water pump and warning signs.

Diagram 4-1: “Multi-layered” enhancement



4.2.5 Coastal flooding problem cannot be solely resolved by layers (1) and (2) above in some coastal areas, in particular at low-lying areas. Residential units scattered along irregular low-lying coastline or riverside at different levels, or stilt houses abutting sea render construction of wave wall or installation of demountable flood barriers along the coastline (layers (1) and (2) above) not cost-effective nor practically feasible, or posing impact on public’s activities. It is more practical to provide demountable flood barriers for self-protection of building frontages (layer (3) above) to alleviate the risk to public safety and their property loss against coastal flooding. Relevant stakeholders should also consider to improve drainage system (e.g. pumping facilities, backflow preventers, etc.) at suitable locations. This Study also recommends to continuously monitor and review the development of climate change and conduct further studies for enhancement measures in a timely manner.

4.3 Summary of Recommended Enhancement Measures for Identified Existing Residential Areas

- 4.3.1 Enhancement plans for mitigation of potential impacts due to coastal hazards to the population and asset along the coastlines of the identified areas (presented in **Section 3**), taking into account of the overseas/local experience and major considerations (presented in **Section 4.1** and **4.2**) are prepared for relevant Government departments' reference. The proposed enhancement plans are schematic in nature and are subject to further development and consultations with relevant stakeholders.
- 4.3.2 To mitigate the coastal flood risk, it is recommended to construct or raise the wave wall along the coastline at first to reduce coastal hazards as far as practicable. For areas with severe overtopping waves, provision of buffer zone at suitable places behind the coastline by installing fixed and/or demountable flood barriers could be considered to cut off sea water pathway towards inland. These measures are commonly adopted and cost-effective provided that site constraint and social impact are minimal. For example, Tseung Kwan O South have constructed a wave wall along the coastline to reduce overtopping waves, it is recommended to erect fixed/demountable flood barriers (i.e. flood wall/gates) at public place (i.e. Tseung Kwan O waterfront park) to form a buffer zone to cut off sea water pathway towards inland.
- 4.3.3 Residential units scattered along irregular low-lying coastline or riverside at different levels, or stilt houses abutting sea render construction of wave wall or installation of demountable flood barriers along the coastline not cost-effective nor practically feasible, or posing impact on public's activities. It is more practical to provide demountable flood barriers for self-protection of building frontages to alleviate the risk to public safety and their property loss against coastal flooding. For example, Tung Chung Bay is a low-lying coastal area which is consisted of a long and irregular coastline with scatter development and stilt houses close to sea. In addition, it is recommended to continuously monitor and review the development of climate change and review the effectiveness of the enhancement measures in a timely manner.
- 4.3.4 Apart from the fixed measures, it is recommended to incorporate the management measures serving as alert system, to work with demountable measures including flood barriers and flood gates installation to improve the awareness and preparedness of the public for extreme storm event. Contingency Plan for Natural Disasters which are currently adopted in Hong Kong to further improve the awareness and preparedness of residents for extreme weather events and also provide another layer of protection to the residents against uncertainties during extreme weather. These management measures include but not limited to self-protection, warning sign, staff gauge, promotion of public awareness/preparedness, establishing early alert system, formulation of emergency and evacuation plans, etc. To enhance the early alert system, real-time monitoring device (e.g. water level sensors) should be considered to collect data for further analysis and study.

- 4.3.5 Whilst enhancement measures (comprising seafront interception and confinement of flooding) are proposed to alleviate the coastal flooding during extreme conditions, rise in sea water level due to storm surges and SLR will affect the efficiency of the existing drainage system or even cause back flow of sea water. Coastal flooding problem may not be solely resolved by upgrading the downstream drainage system, in particular at low-lying areas. Relevant stakeholders should also consider to improve drainage system, such as provision of pumping facilities, intercepting drains, stormwater pumping stations or storage tanks, backflow preventers, etc., at suitable locations.
- 4.3.6 Backflow preventers, i.e. flap valves, are recommended to be installed at the weepholes of wave walls / flood walls and drainage outlets at river banks or seawalls as far as practicable to prevent possible sea water back flow during storm tide.
- 4.3.7 For installations or facilities which are sensitive or vulnerable to flooding and may lead to suspension in operation and long recovery time, such as E&M equipment elevators, pillar boxes, underground car park, pavement, etc., it is recommended that suitable protection be provided by the relevant stakeholders of the facilities to reduce the risk of facilities damage.
- 4.3.8 In summary, the recommended enhancement measures comprise a combination of fixed measures and management measures to achieve the following enhancement principles against the potential coastal risks:
- Reduce overtopping waves / inundation by raising the edge of the existing coastline (e.g. with wave wall / flood wall); and / or
 - Stop spreading of flood water by blocking the pathway of water flow (e.g. with demountable flood barriers); and / or
 - Accommodate residual coastal flooding by flood-proofing affected buildings/facilities; and / or
 - Impose management measures (e.g. early alert system, action plans, warning signs) to enhance public awareness and preparedness.
- 4.3.9 The recommended enhancement plans for the 26 identified areas are summarized in **Table 4-2**.
- 4.3.10 Whilst the progressive adaptive approach for coastal enhancement is recommended to cater for the uncertainty about future climate change, continuous monitoring and review of the magnitude and rate of climate change effects should be necessary to anticipate how the future actually unfolds in long-term so that the adaptation measures in place can be reassessed for making further decisions on the subsequent steps of the adaptation pathway.
- 4.3.11 To formulate a long-term appropriate adaptation and protective measures, it is recommended to providing guidelines on planning and land use as well as formulating long-term strategies and defensive measures to enhance the Government and relevant stakeholders' ability to cope with climate change in

Hong Kong with reference to relevant overseas experience.

Table 4-2: Summary of recommended enhancement measures for identified existing residential areas

Identified Areas		Adaptation Measures			Management Measures
		Construct or raise the wave wall	Install flood barriers behind the coastline	Install flood barrier at building frontages	
1	Kennedy Town, Sai Ying Pun and Sheung Wan	✓	✓	-	✓
2	Heng Fa Chuen	✓	✓	-	✓
3	Shek O Village	-	✓	✓	✓
4	Pak Kan, Stanley	✓	-	-	-
5	South Horizons	-	-	-	✓
6	Tung Chung Bay (Ma Wan Chung Village, Sha Tsui Tau, Sha Lo Wan)	-	-	✓	✓
7	Tai O	✓	✓	✓	✓
8	Shap Long and Cheung Sha Lower Village, Lantau Island	✓	-	-	-
9	Ma Po Tsuen and Chung Hau, Mui Wo	✓	✓	✓	✓
10	Peng Chau West Areas (Nam Wan San Tsuen)	✓	✓	-	✓
11	Cheung Chau West Areas	✓	-	-	-
12	Yung Shue Wan, Lamma Island	✓	✓	-	-
13	Lei Yue Mun (Ma Wan Tsuen, Sam Ka Tsuen)	✓	✓	✓	✓
14	Sha Tau Kok Town (Chung Ying Street, Kong Ha)	-	✓	✓	✓
15	Kat O West Low-lying Areas (Kat O Fisherman Village)	-	-	✓	✓
16	Sam Mun Tsai New Village, Tai Po	-	-	✓	✓
17	Tai Po Market (near Lam Tsuen River)	-	✓	-	✓
18	To Tau Wan Village, Ma On Shan	-	-	✓	✓
19	Sai Kung Town Centre and Tui Min Hoi	✓	✓	✓	✓
20	Nam Wai / Heung Chung, Sai Kung	-	-	✓	✓
21	Tseung Kwan O South (Tseung Kwan O Waterfront Park)	-	✓	-	✓
22	Yuen Long Central Low-lying Areas (Tai Tseng Wai, Chung Hau Yu Man San Tsuen, Shan Pui Tsuen, Wang Chau, Yuen Long Town Centre)*	-	-	✓	✓
23	Yuen Long North West Low-lying Coastal Areas (Sha Kiu Tsuen, Fu Tso Tsuen, Lau Fau Shan, Hang Hau Tsuen, Sheung Pak Nai, Ha Pak Nai)	-	-	✓	✓
24	Luen On San Tsuen, Tai Lam	-	-	✓	✓
25	Kar Wo Lei, Tuen Mun	-	-	✓	✓
26	Sham Tseng San Tsuen	-	-	✓	✓

Remark:

- Enhancement measures for 26 areas to be implemented in batches.
- Design details to be formulated for each area case by case.
- The global mean SLR at mid-century under the intermediate GHG emissions scenario in AR6 are comparable with the projections under medium GHG concentration scenario in AR5, for which the proposed enhancement plans are still considered to be applicable under AR6.
- * Yuen Long Barrage Scheme under planning and design has been considered. It will ease the flooding situation at the residential areas in Yuen Long Town Centre.

4.4 Possible Options for Enhancement Measures

4.4.1 In view of the above recommended enhancement measures by the concept of multi-layered enhancement as presented in **Section 4.3**, with reference to overseas and local experience, it is recommended to consider different kinds of enhancement measures and management measures to heighten the public awareness of potential coastal hazards and flood prevention, enhancing the resilience of community and coastal areas. The possible options for enhancement measures are listed out below for consideration.

Overseas Experience of Enhancement Measures

4.4.2 A technical visit to New York City, the United States was conducted to gain understanding on their advanced coastal protection and climate adaptation technologies and experience. The main objectives of the technical visit are:

- to observe construction and operation of overseas coastal protection infrastructures;
- to understand from the relevant overseas authorities how the coastal protection infrastructures, strategies and measures are implemented to provide protection from coastal hazards; and
- to gain a better understanding on how overseas authorities are approaching climate change and associated extreme weather events in the short, medium and long-term.

4.4.3 Hong Kong bears a number of similarities to New York City in respect of being a significant overseas city with long coastline, containing densely populated areas with commercial and industrial development exposed to coastal hazards, extensive transportation infrastructure and important financial hubs; and with a population having expectations of leadership from Government on climate change and coastal resiliency and emergency management. During normal days, the existing coastal structures are in general adequate to safeguard the above coastal development. The coastal hazards during extreme weather are acute, such as storm surges and overtopping waves derived from cyclone events, and chronic such as sea water inundation derived from SLR. Given the above similarities, New York City is considered a suitable and valuable reference of adaptation to coastal hazards for Hong Kong.

4.4.4 The climate resilience of New York City has largely focused on the district of Lower Manhattan, where the over 400 years historic identity of the city has been rooted in. In recent decades the Lower Manhattan district has transformed into a global economic and financial capital, holding immense importance to the city and regional economies. The impact of Hurricane Sandy (2012) on Lower Manhattan was extreme, causing casualties and affecting thousands of homes. Wall Street was closed for two days after the storm event, completely suspending trading at the two largest stock exchanges in the world by market capitalization, the New York Stock Exchange and NASDAQ.

- 4.4.5 In the seven years since Hurricane Sandy, hundreds of millions of dollars in federal funding have been spent to assist the recovery of communities across the state. Private sectors, including many building owners in the Financial District, have also implemented protective measures in individual buildings. The Lower Manhattan communities have been engaged in thoughtful climate planning and have been deeply involved and invested in the development of near-term (i.e. 2050) improvement measures to enhance the resilience of the city.
- 4.4.6 The guiding objectives of their climate resilience planning is to identify the extent of climate hazards and exposure in Lower Manhattan in the 2050s and 2100, i.e. within the average adult and a young New Yorker's lifetimes respectively. Different climate resilience projects in New York City have been conducted to formulate resilience strategies and climate adaptation measures for the district to cope with 100-year storm event in the 2050s.
- 4.4.7 For those climate resilience projects in New York City, they will be implemented from planning to construction stage by stage at different areas of Lower Manhattan due to large area extent, difficulty of works and resource allocation after Hurricane Sandy in 2012. For example, Battery Park City which kicked off design in 2018, East Side which began the construction in 2020, Financial District and the Seaport which is only released the climate resilience master plan in end 2021, Two Bridges Neighbourhood which will begin the construction in 2022,.
- 4.4.8 Making reference to overseas experience, an inventory of coastal adaptation options has been established including (1) hard engineering structures (wave walls, flood walls and flood barriers) to reduce the extent and degree of coastal impacts; and (2) management measures, such as establishment of early alert system, formulation of emergency and evacuation plans, drill on emergency, enhancement of publicity and public education to heighten the public awareness of potential coastal hazards and flood prevention, enhancing the resilience of community and coastal areas. Some examples are shown in **Plate 4-1**.

Plate 4-1: Overseas examples of enhancement measures

Enhancement Measures



Wave wall



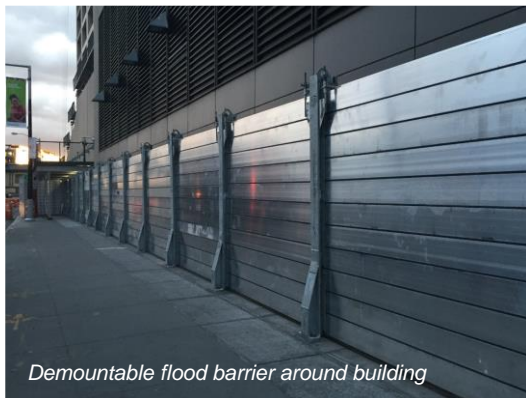
Flood wall



Swing gate



Sliding gate



Demountable flood barrier around building



Demountable flood barrier at entrance/exit



Water-filled tube barrier



Demountable flood barrier at open area



Demountable flood barrier at ground opening



Demountable flood barrier

Emergency Plan

The image shows the cover of the 'READY NEW YORK MY EMERGENCY PLAN' document. The top half features a yellow background with the text 'READY NEW YORK' in large black letters. Below this is a photograph of a car completely covered in snow. Overlaid on the right side of the snow image are three colored boxes containing the words 'MY' (purple), 'EMERGENCY' (orange), and 'PLAN' (green) in white capital letters. The bottom half of the cover is a collage of three images: a street scene with a large pile of rubble and debris, a flooded street with a person wading through the water, and a street sign for a 30 mph zone. At the bottom left, the 'NYC' logo is displayed. To its right are the logos for 'Emergency Management', 'Department for the Aging', and 'Mayor's Office for People with Disabilities'. At the bottom right is a circular 'READY' logo with a checkmark.

READY NEW YORK

MY

EMERGENCY

PLAN

COVID-19 CONSIDERATIONS INCLUDED

NYC Emergency Management | Department for the Aging | Mayor's Office for People with Disabilities

READY

Local Experience in Enhancement Measures

4.4.9 Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement/upgrading measures have been completed at coastal areas in Hong Kong where damages and coastal flooding occurred. These implemented measures are taken into consideration for formulation of further enhancement measures, where applicable.

Enhancement Measures

4.4.10 Wave walls have been constructed along the seafront of coastal structures at coastal areas susceptible to severe overtopping waves. These are examples of enhancement measures which enhances the coastline by reducing the effect of overtopping waves.

4.4.11 For riverside/water course, flood walls have been constructed along the riverside susceptible to river flooding. These are examples of enhancement measures which enhances the riverside by stopping the raised water from flowing into the riverside areas.

4.4.12 Flood walls / planter walls behind the coastline have been constructed at coastal areas susceptible to coastal flooding. These are examples of enhancement measures which prevent sea water from flowing towards inland and hence limit the extent of coastal flooding.

4.4.13 Flap valves have been installed at drainage outfalls along river channels or at seawalls. These are examples of enhancement measures which mitigate the risk of flooding (in particular for low-lying areas) due to backflow of sea water through drainage outfalls during high sea level.

4.4.14 Demountable flood barriers have been installed in front of entrance of buildings, carpark and village houses. These are examples of enhancement measures which protect the coastal assets from flooding and hence reduce the potential damages to the assets inside or interior of the individual premises.

4.4.15 Some examples of the enhancement measures are shown in **Plate 4-2**.

Plate 4-2: Local examples of enhancement measures

Wave wall constructed along coastline



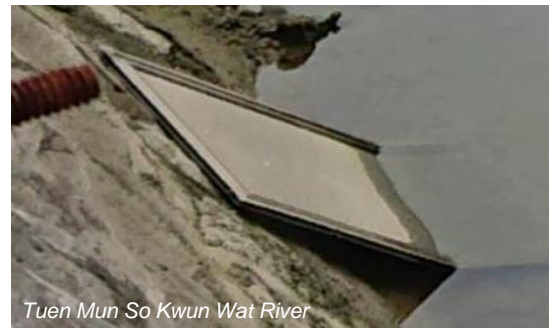
Flood wall constructed along riverside/small water course



Flood wall / planter wall constructed behind coastline



Flap valves / flood panels installed at drainage outfalls



Demountable flood barriers at Public Areas



Demountable flood barriers at entrance of assets



Management Measures

Contingency Plan for Natural Disasters in Hong Kong

- 4.4.16 With the natural disaster experience accumulated by the HKSAR Government, it is found that the natural disasters occurred in Hong Kong are generally the result of severe weather conditions such as heavy rain, storm surges, thunderstorms and tropical cyclones. The HKSAR Government has developed and maintains “Contingency Plan for Natural Disasters” to cater the emergency situation under extreme weather, which also includes warnings and actions to be taken to alleviate the impact of coastal flooding on local residents due to storm surges and wave.

Emergency Preparedness

- 4.4.17 In Hong Kong, Government advice is for the population to stay away from the shoreline when Tropical Cyclone Warning Signal No.3 or above is in force as below:

No.3 Signal: *“Stay away from the shoreline and not to engage in water sports.”*

No.8 Signal: *“Avoid staying in the street. Return home as soon as possible if conditions so permit.”*

(if forecasted): *“Owing to storm surge, low-lying areas may have serious flooding or backflow of sea water. Avoid going to likely affected low-lying areas and stay away from dangerous places.”*

No.9/10 Signal: *“Stay indoors. If you are reasonably protected, stay where you are.”*

(Reference: <https://www.hko.gov.hk/en/informtc/precaution.htm>)

- 4.4.18 Relevant departments and public organizations conduct pre-disaster risk assessment and risk reduction control measures under their respective purview to minimize the potential threats to the community and city infrastructure.
- 4.4.19 Relevant departments and organizations also conduct drills to test the adequacy and effectiveness of their contingency plans before typhoon seasons to enhance their preparedness in the event of serious flooding, as well as to familiarize the residents with the government emergency response plans.

Establishment of Early Alert System and Action Plans

- 4.4.20 In Hong Kong, DSD, HAD, HKO and other relevant Government departments have jointly established an early alert system to alleviate the impact of flooding on local residents in the low-lying areas vulnerable to flooding or sea water inundation (e.g. Tai O and Lei Yue Mun) and some locations prone to wave impact (i.e. Heng Fa Chuen, South Horizons and Tseung Kwan O South).

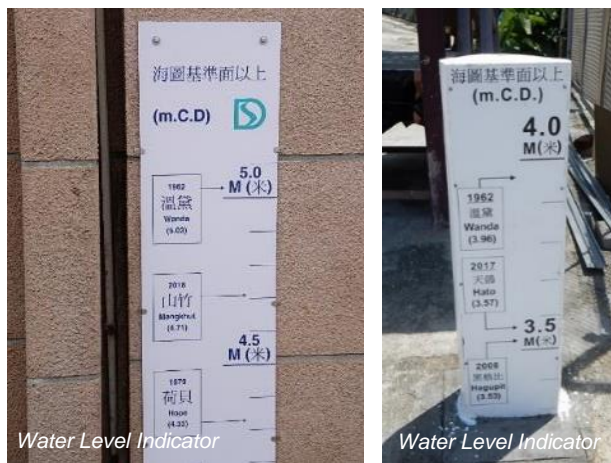
Actions plans, which set out the responsibilities of various departments and parties that are expected to carry out emergency flood relief measures and executing the evacuation plan (when sea level is expected to reach the alert level specified in action plan), have been devised jointly by relevant departments to alleviate the impact of flooding in the above-mentioned locations.

Enhancement of Public Awareness and Preparedness

- 4.4.21 Through the publicity and public education, public awareness with respect to disasters preparedness knowledge, as well as self-help tips for natural disasters, could be strengthened. With these self-help tips, the public could avoid casualties when a disaster comes, and so could wait for rescue. This, in turn, enhances community resilience against natural disasters.
- 4.4.22 Warning signs and water level indicators have been installed at locations where susceptible to severe flood risk (**Plate 4-3**) to alert the public to stay away from coastal risks.

Plate 4-3: Warning signs and water level indicators

Water level indicators installed at flood risk locations



Warning signs at flood risk locations



4.4.23 Some examples of the above management measures are shown in **Plate 4-4**. These measures enhance emergency preparedness and public awareness of the potential risks of coastal hazards by providing relevant information of storm events to the public so that precautionary actions can be taken to reduce potential damage/loss.

Plate 4-4: Local examples of management measures

Emergency drills



Tai O – Annual Emergency Drill



Tai O – Annual Emergency Drill

Early alert system



Public awareness programme



4.5 Recommended Implementation Strategy

- 4.5.1 Successful overseas experience in handling coastal hazards have demonstrated that mitigation of coastal hazards is not simply the government's responsibility but also requires preparedness by coastal residents, property owners and communities. This Study provides the relevant stakeholders with the information of the dynamic nature of their environment, the coastal hazards that they are experiencing or will experience in future, and measures available to reduce vulnerability and maintain our future options for further enhancement. This information will be helpful for the relevant stakeholders to consider the required resources in deciding enhancement and management measures.
- 4.5.2 The coastal areas vulnerable to potential coastal risks identified under the Study cover a large extent of coastal areas with a long stretch of coastline. The general implementation arrangement is to engage relevant stakeholders formulating the enhancement plans, especially in formulating the details of the management measures, i.e. early alert system, to alleviate the impact due to the coastal hazards.
- 4.5.3 Taking into account the collaboration effort between relevant stakeholders, and requirements of statutory procedures in implementing the proposed enhancement measures, this Study expects that these measures could be implemented within 5 years in batches, alleviating coastal risks of the identified existing residential areas.
- 4.5.4 However, more complicated is the mix of public and private developments situated at the coastal areas, which would require collaboration between the Government, private property owners and citizens to achieve the common goal: alleviating the impact due to the coastal hazards.

5. RECOMMENDATIONS AND WAY FORWARD

5.1 Recommended Approach and Enhancement Measures to deal with Coastal Hazards

- 5.1.1 To enhance the existing coastal areas against potential coastal hazards, this Study recommends to cater for 100-year return period extreme event, as far as practicable, with climate change projection up to 2050 under medium GHG concentration scenario.
- 5.1.2 Considering the uncertainties in the range of possible future climate change development and global actions among nations on reducing carbon emission, this Study recommends to adopt a “progressive adaptive approach” to formulate climate adaptation measures for coastal low-lying and windy locations. This approach is to be flexible and adaptive enough that they can be changed or updated as conditions change or if impacts due to climate change are different from that anticipated.
- 5.1.3 Where practical, this Study recommends “design allowance” to apply in design of adaptation measures for coastal structures, with a view to further enhancing their resilience against climate change under different climate change scenarios, including the differences in SLR predictions, increase in storm surge and wave height due to increase in wind intensity
- 5.1.4 As part of progressive adaptive approach, this Study recommends to continuously monitor the climate change and review the measures to cope with coastal risk in a timely manner.
- 5.1.5 This Study recommends multi-layered enhancement measures to adopt cope with extreme weather which comprise constructing or raising wave walls along the coastline; and/or installing fixed and/or demountable flood barriers at suitable places behind the coastline; and/or installing demountable flood barriers or provide sandbags at building frontages and adopting management measures.

5.2 Recommendation on Follow-up Actions to be Taken

- 5.2.1 In the Study, the Hong Kong shoreline has been reviewed holistically to assess the potential major coastal risks at coastal areas of Hong Kong. Based on analytical assessments, coastal areas vulnerable to the potential coastal risks have been identified, for which enhancement plans have been recommended with an aim to alleviate the coastal risks through comprising seafront interception, confinement of flooding, protection of individual assets and improvement of public awareness and preparedness.
- 5.2.2 Nevertheless, the recommended enhancement plans are schematic in nature and provide necessary information for further consideration by relevant stakeholders. To take forward for implementation, these recommended schemes shall be further reviewed and refined with additional investigation

and/or detailed design, where appropriate.

- 5.2.3 Some of the recommended enhancement plans involve implementation of demountable and management measures, which shall be accomplished by carefully planned action plans, which set out the details, timing and demarcated responsibilities of relevant stakeholders of the actions to be taken before, during and after an extreme event.
- 5.2.4 Liaison and coordination among relevant stakeholders including relevant government departments, private sectors and local residents etc. is essential for the implementation of enhancement plans. For example, enhancement measures proposed along waterfront private developments would require the contributions of private land owners; whilst management measures at low-lying villages would require collaborated efforts of villagers and relevant government departments. The general implementation strategy recommended under the Study shall be further developed for future implementation on a case-by-case basis.

5.3 Recommendation for Further Planning Required in Future

- 5.3.1 Whilst the progressive adaptive approach for coastal enhancement is recommended to cater for the uncertainty about future climate change, continuous monitoring and review of the magnitude and rate of climate change effects should be necessary to anticipate how the future actually unfolds in long-term so that the adaptation measures in place can be reassessed for making further decisions on the subsequent steps of the adaptation pathway.
- 5.3.2 Currently, Hong Kong lacks a clear framework for coastal zone planning and management. To formulate a long-term appropriate adaptation and protective measures, it is recommended to providing guidelines on planning and land use as well as formulating the related long-term strategies and defensive measures to enhance the Government and relevant stakeholders' ability to cope with climate change in Hong Kong with reference to relevant overseas experience (e.g. Shoreline Management Plan implemented in UK).
- 5.3.3 The relevant design standards and practices for coastal protection shall be reviewed and updated taking into consideration development of future climate change in a timely manner. This may include, but not limited to, review and update of design extreme events, climate change projections, provisions of coastal structures for future upgrades, specific design criteria for different coastal land uses, etc.
- 5.3.4 The global scientific community is expected to continue providing updated development in climate change effect from time to time. It is therefore recommended to carry out further related studies to keep the city in line with global trend of climate change projections, coastal developments, protections and managements.

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Appendix

Recommended Enhancement Plans

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APPENDIX – PREAMBLE

1. INTRODUCTION

1.1. General

- 1.1.1 Coastal residential developments which exposed to relatively higher coastal risk during extreme weather with climate change projection up to 2050 have been identified. In response, corresponding enhancement plans for mitigating such risks are prepared accordingly for relevant Government departments' reference. However, the proposed enhancement plans are schematic in nature and are subject to further development and consultations with relevant stakeholders.
- 1.1.2 To mitigate the coastal flood risk, it is recommended to construct or raise the wave wall along the coastline at first to reduce coastal hazards as far as practicable. For areas with severe overtopping waves, provision of buffer zone at suitable places behind the coastline by installing fixed and/or demountable flood barriers could be considered to cut off sea water pathway towards inland. These measures are commonly adopted and cost-effective provided that site constraint and social impact are minimal.
- 1.1.3 Residential units scattered along irregular low-lying coastline or riverside at different levels, or stilt houses abutting sea render construction of wave wall or installation of demountable flood barriers along the coastline not cost-effective nor practically feasible, or posing impact on public's activities. It is more practical to provide demountable flood barriers for self-protection of building frontages to alleviate the risk to public safety and their property loss against coastal flooding.
- 1.1.4 Apart from the fixed measures, it is recommended to incorporate the management measures serving as alert system, to work with demountable measures including flood barriers and flood gates installation to improve the awareness and preparedness of the public for extreme storm event. These management measures include but not limited to self-protection, warning sign, staff gauge, promotion of public awareness/preparedness, establishing early alert system, formulation of emergency and evacuation plans, etc.
- 1.1.5 Whilst enhancement measures (comprising seafront interception and confinement of flooding) are proposed to alleviate the coastal flooding during extreme conditions, rise in sea water level due to storm surge and sea level rise will affect the efficiency of the existing drainage system or even cause back flow of seawater. Coastal flooding problem may not be solely resolved by upgrading the downstream drainage system, in particular at low-lying areas. Relevant stakeholders should also consider to improve drainage system, such

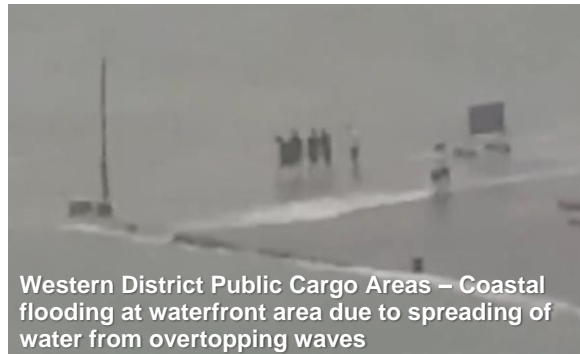
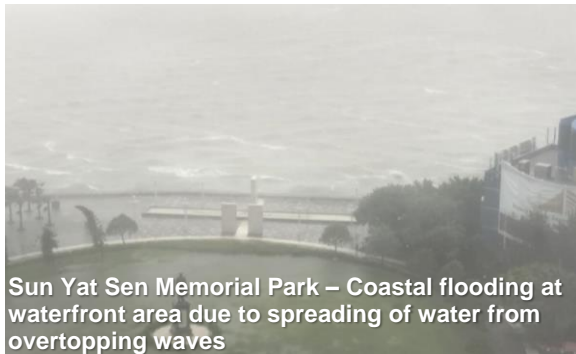
as provision of pumping facilities, intercepting drains, stormwater pumping stations or storage tanks, backflow preventers, etc., at suitable locations.

- 1.1.6 Backflow preventers are recommended to be installed at the weepholes of wave walls / flood walls and drainage outlets at river banks or seawalls as far as practicable to prevent possible sea water back flow during storm tide.
- 1.1.7 For installations or facilities which are sensitive or vulnerable to flooding and may lead to suspension in operation and long recovery time, such as E&M equipment elevators, pillar boxes, underground car park, pavement, etc., it is recommended that suitable protection be provided by the relevant stakeholders of the facilities to reduce the risk of facilities damage.
- 1.1.8 The recommended enhancement plans, which comprise combinations of quickly implementable and cost-effective enhancement works with an aim to withstand the design scenario of a design extreme storm event with climate change projections up to mid-century, are presented in this appendix. As a progressive adaptive approach, these recommendations may be further upgraded/extended to cater for climate change projections beyond the mid-century.

1. KENNEDY TOWN, SAI YIN PUN AND SHEUNG WAN

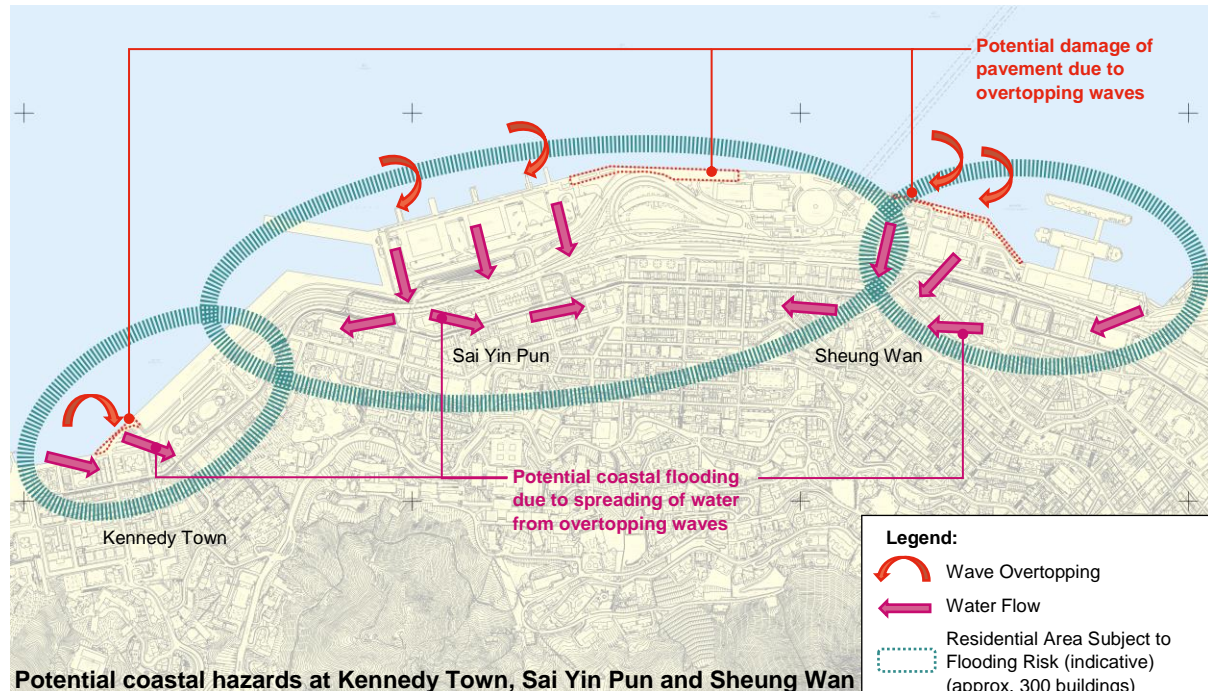
SITE DESCRIPTION

Kennedy Town, Sai Yin Pun and Sheung Wan is located at Western Hong Kong Island with a shoreline facing Western Victoria Harbour. The site is exposed to waves and swells propagating through West Lamma Channel and was subjected to local overtopping waves and associated flooding at some waterfront areas during past typhoon events. Specific observation around the site includes:



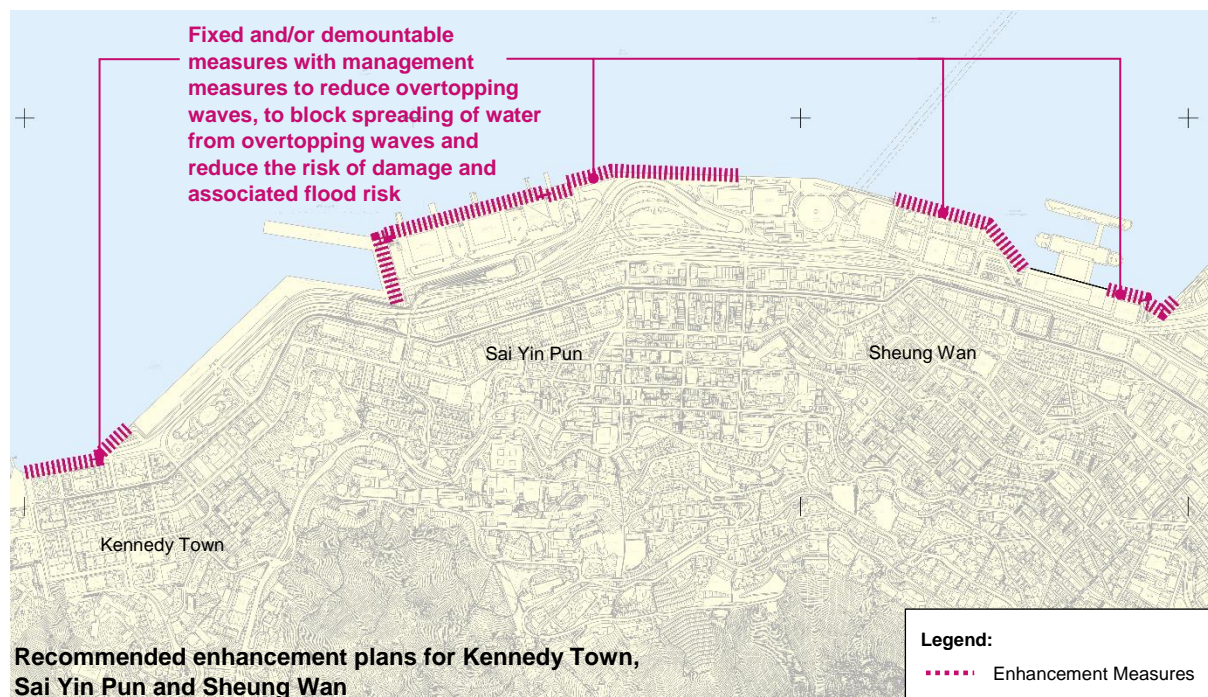
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Kennedy Town, Sai Yin Pun and Sheung Wan with climate change projections up to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



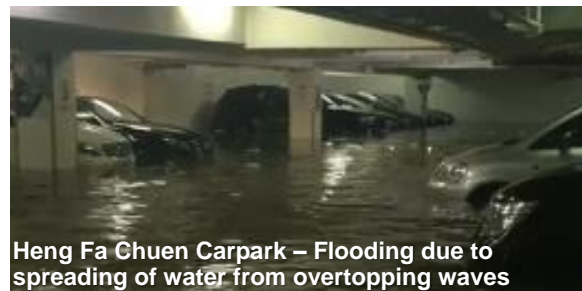
Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

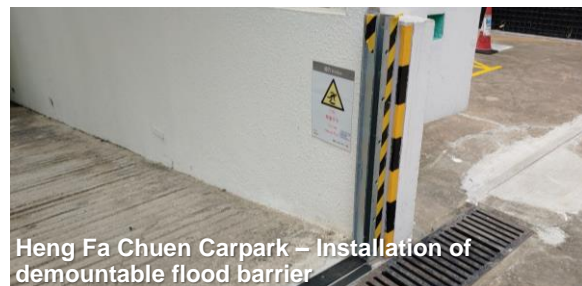
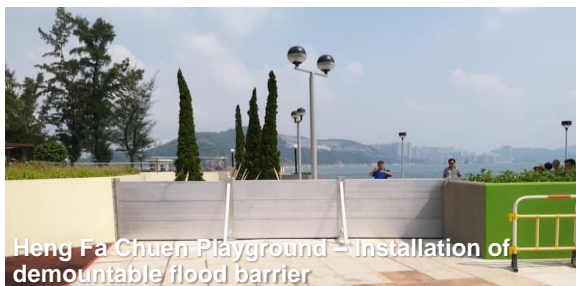
2. HENG FA CHUEN

SITE DESCRIPTION

Heng Fa Chuen is located at Eastern Hong Kong Island with a shoreline facing Junk Bay. The site is exposed to waves and swells propagating through Tathong Channel and was subjected to overtopping waves and associated flooding / damages during past typhoon events. Specific observation around / near the site includes:

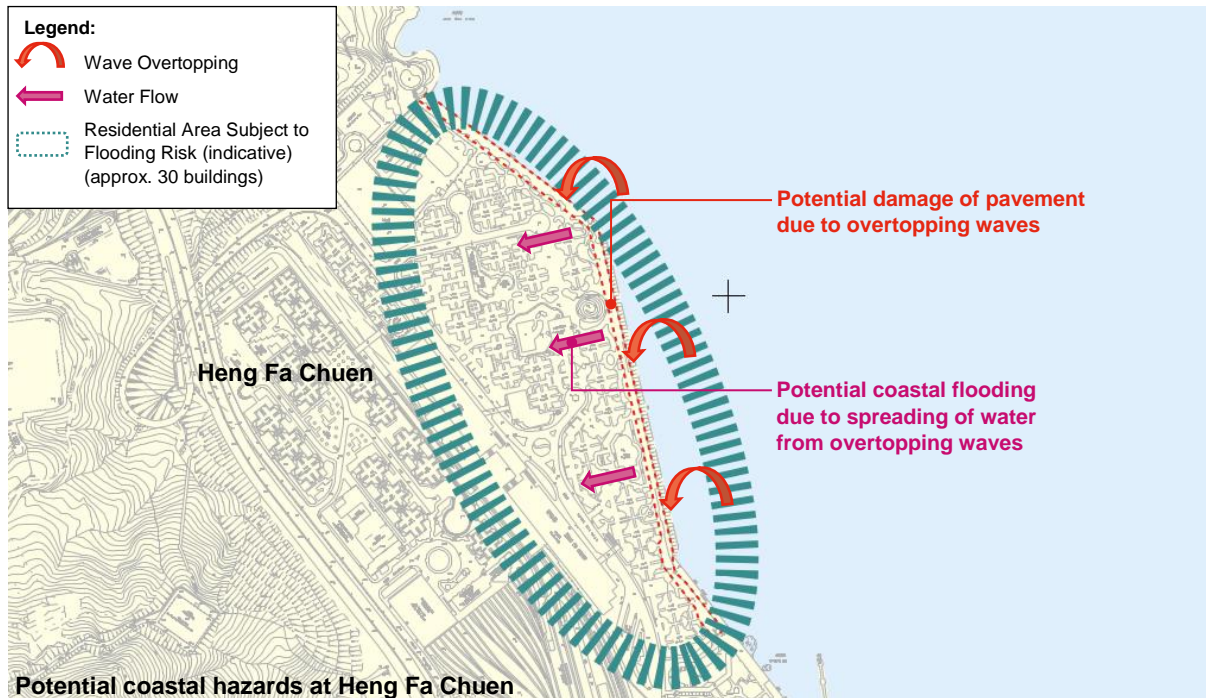


Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards.



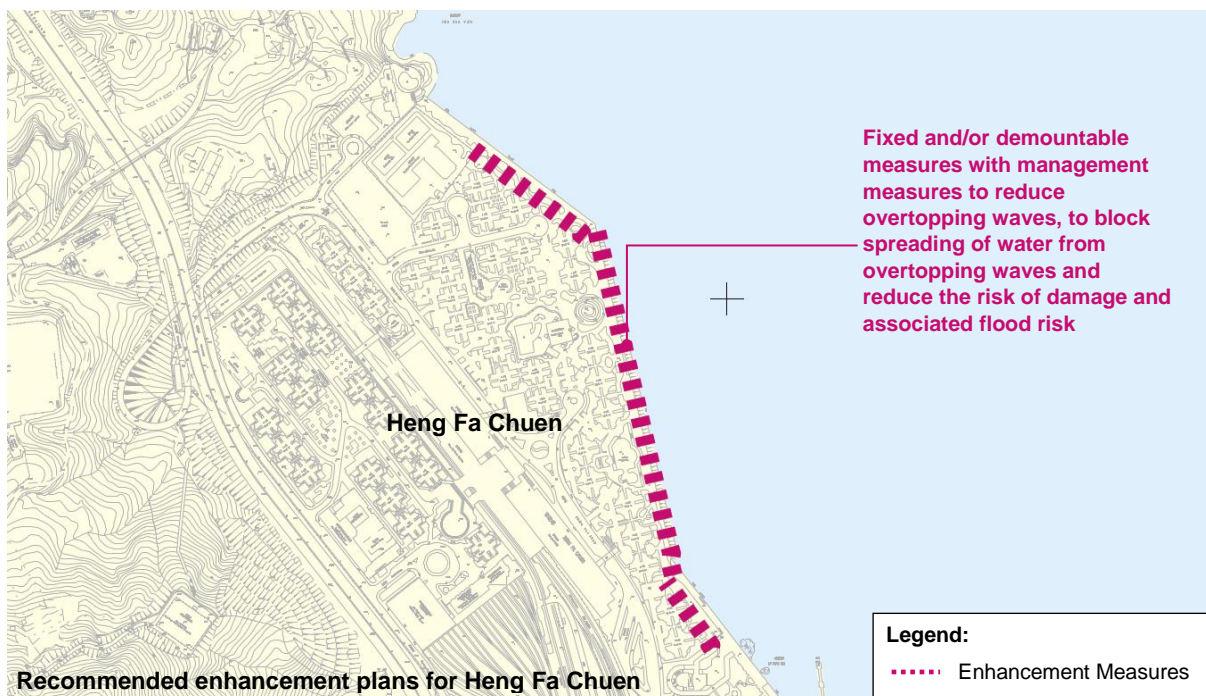
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Heng Fa Chuen with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: Heng Fa Chuen had provided deployable flood barriers to building blocks entrances along coastline and existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

- 1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
- 2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

3. SHEK O VILLAGE

SITE DESCRIPTION

Shek O Village is located at Southern Hong Kong Island and is adjoined by two shoreline – northern shoreline facing Shek O Wan and southern shoreline facing Island Bay. The site is exposed to offshore waves and swells approaching from the South China Sea and was subjected to overtopping waves and associated flooding / damages during past typhoon events. Specific observation around the site includes:



Shek O Village – Coastal flooding due to spreading of water from overtopping waves



Shek O Beach – Damage of waterfront due to overtopping waves

Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



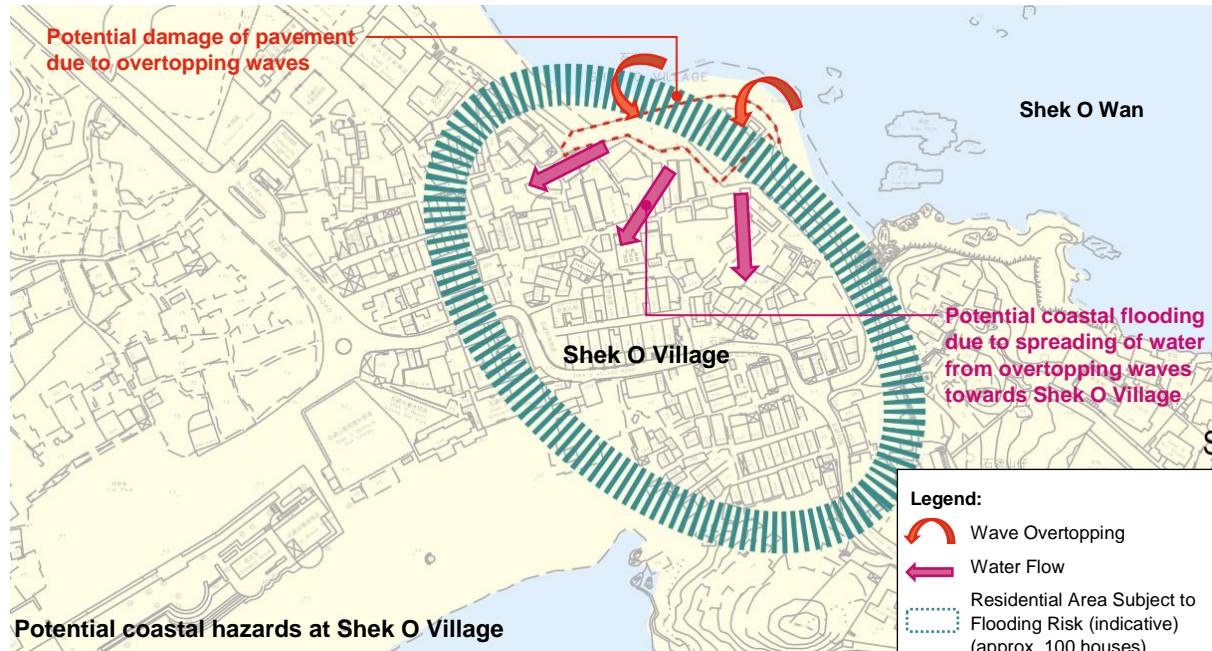
Shek O Village – Deployable flood barrier at entrance of houses



Shek O Beach – Concrete parapet wall along seafront walkway

POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Shek O Village with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

4. PAK KAN, STANLEY

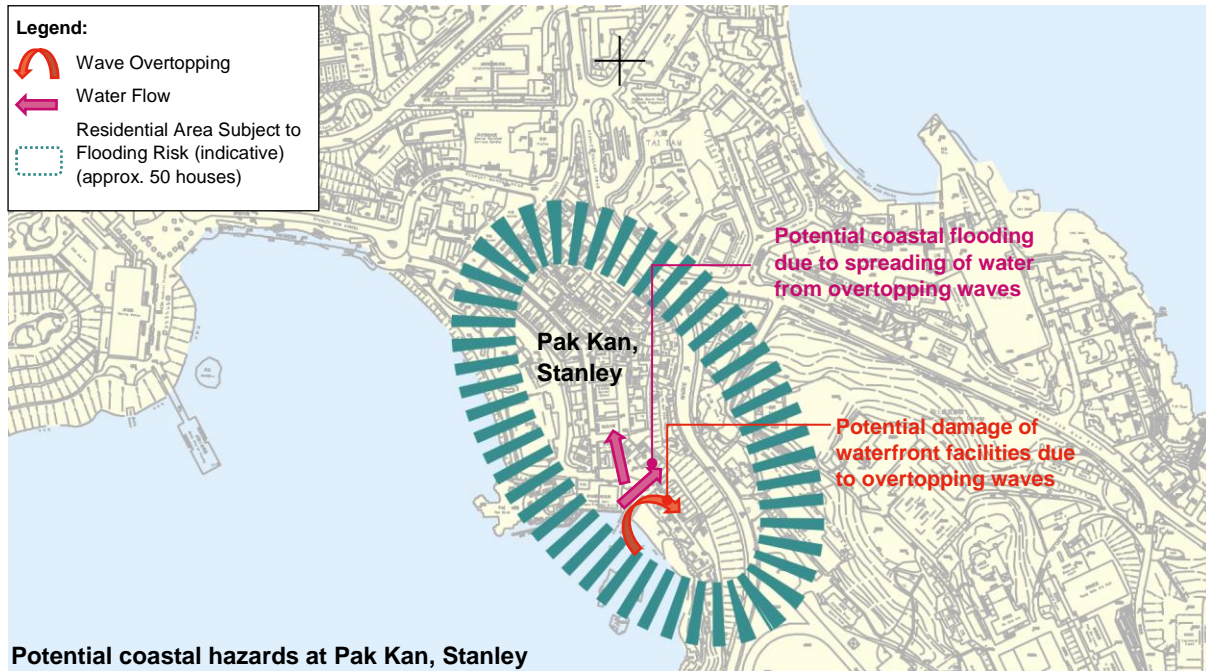
SITE DESCRIPTION

Pak Kan, Stanley is located at Southern Hong Kong Island with a shoreline facing to Stanley Bay. The site is exposed to offshore waves and swells approaching from the South China Sea. Some local area of the site was subjected to overtopping waves and associated damages during past typhoon events. Specific observation around the site includes:



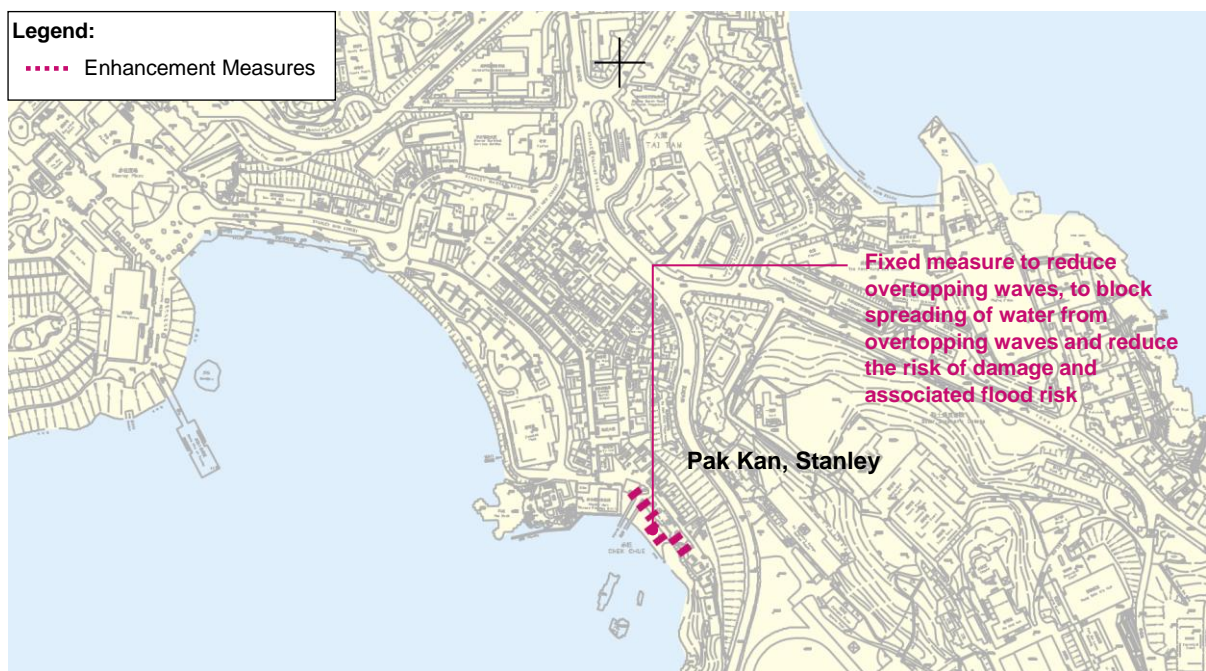
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Pak Kan, Stanley with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Fixed enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



- Note:**
- Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
 - Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

5. SOUTH HORIZONS

SITE DESCRIPTION

South Horizons is located at the south coast of Ap Lei Chau Island. The site is exposed to offshore waves and swells approaching from the South China Sea. Some local area of the site was subjected to overtopping waves and associated damages during past typhoon events. Specific observation around the site includes:



South Horizons – Flooding at Carpark
(situation during typhoon)

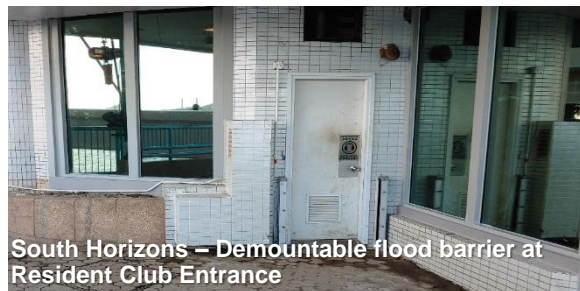


South Horizons – Damage of promenade
(situation after typhoon)

Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



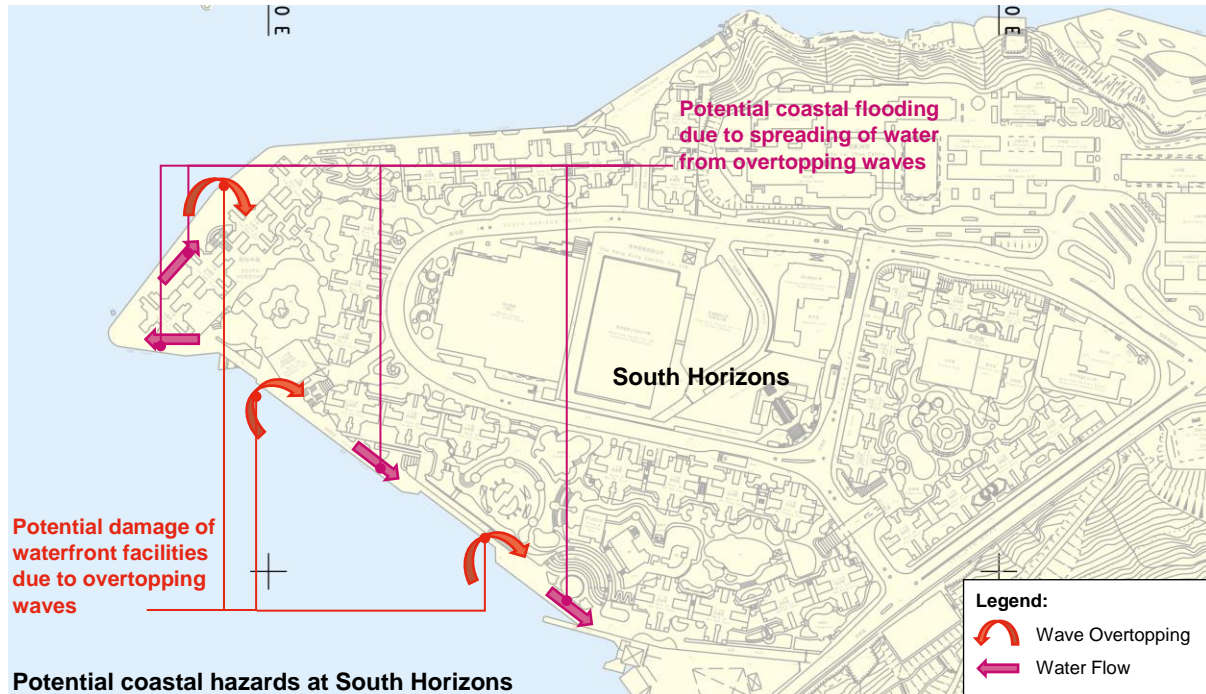
South Horizons – Demountable flood barrier at
Car Park Entrance



South Horizons – Demountable flood barrier at
Resident Club Entrance

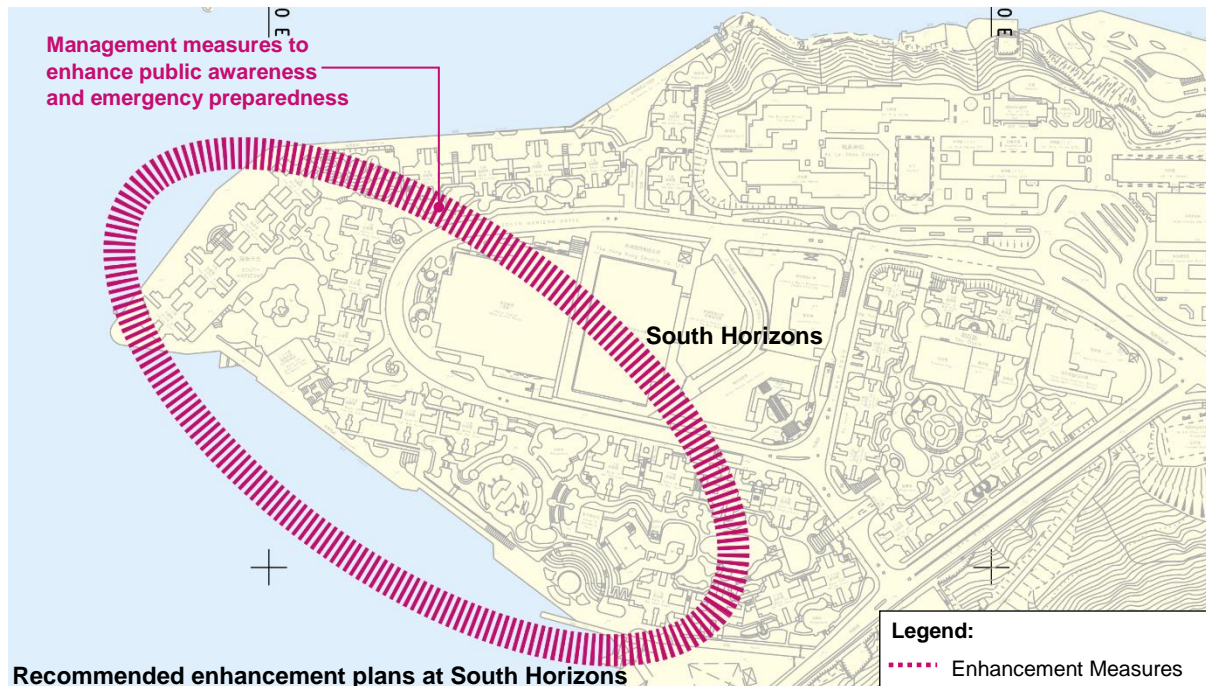
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at South Horizons promenade with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: South Horizons had provided demountable flood barriers to some facilities along promenade and existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

6. TUNG CHUNG BAY

SITE DESCRIPTION

Tung Chung Bay is located at Northern Lantau Island with a shoreline facing towards Chek Lap Kok Island. The site is a low-lying area and was subjected to flooding due to inundation of seawater during past typhoon events. Specific observation around the site includes:



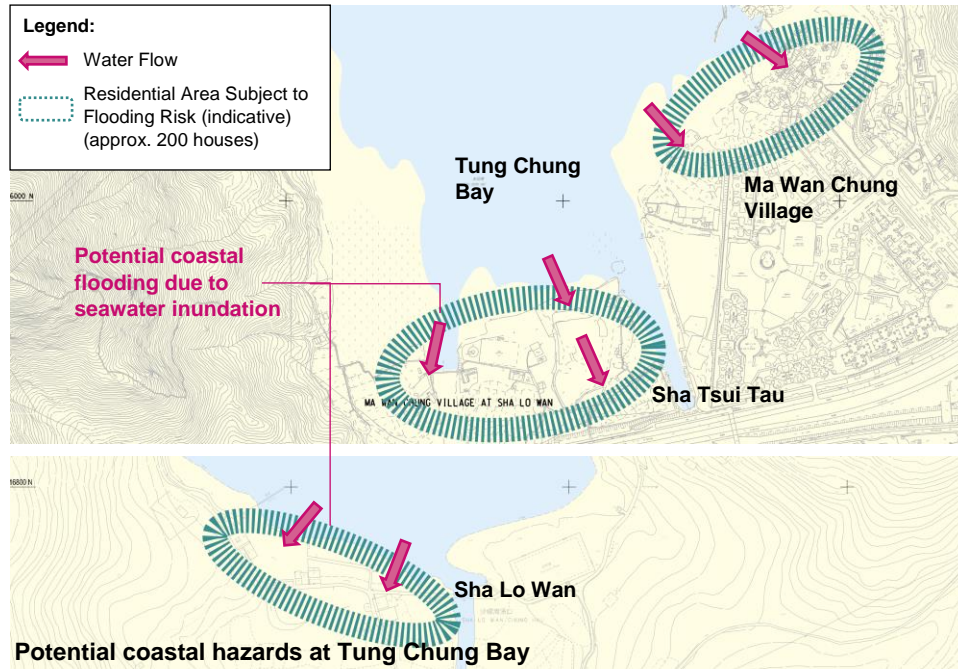
Tung Chung Bay – Flooding at low-lying villages
(photos taken after typhoon)



Tung Chung Bay – Flooding at low-lying villages
(photos taken after typhoon)

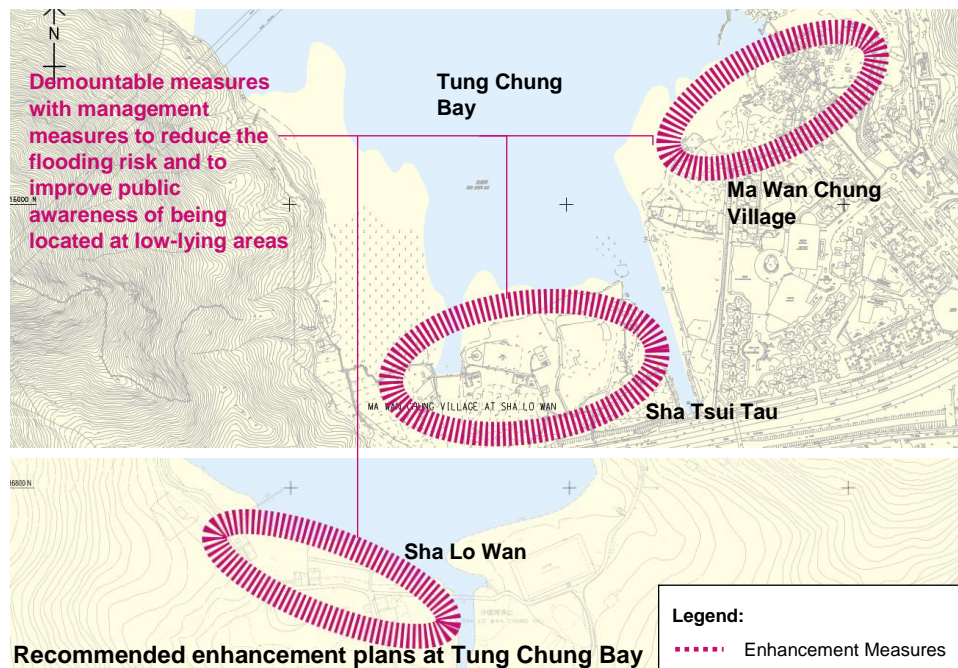
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Tung Chung Bay with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

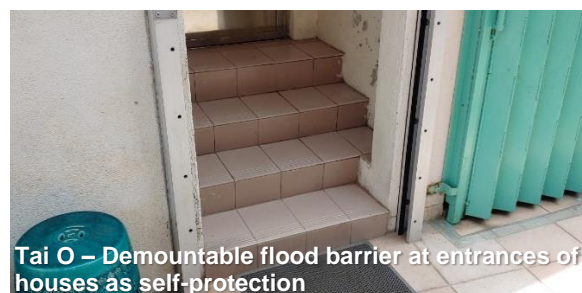
7. TAI O

SITE DESCRIPTION

Tai O is located at Western Lantau Island and lies on the estuary of the Ling Fung Stream. The site is mainly a low-lying area vulnerable to storm surges and extreme sea / river water level. It was subjected to coastal flooding due to overflow of seawater / Tai O river during past typhoon events. Specific observation around the site includes:



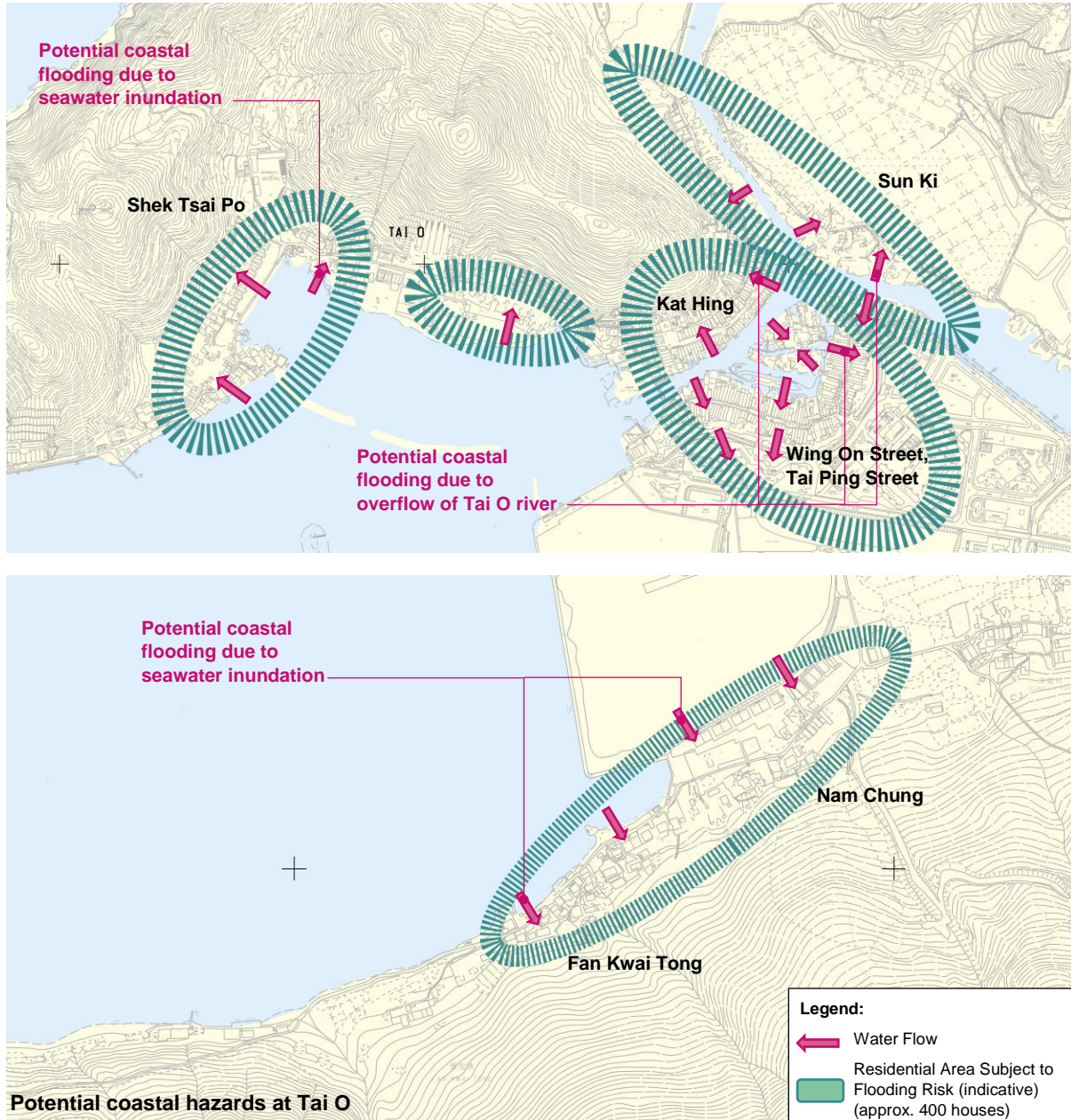
Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



Over the past years, different types of management measures have been implemented to alleviate the impact of coastal hazards. This include establishment of emergency response team, early alert system and temporary shelter at Tai O Rural Committee and YMCA Tai O Office.

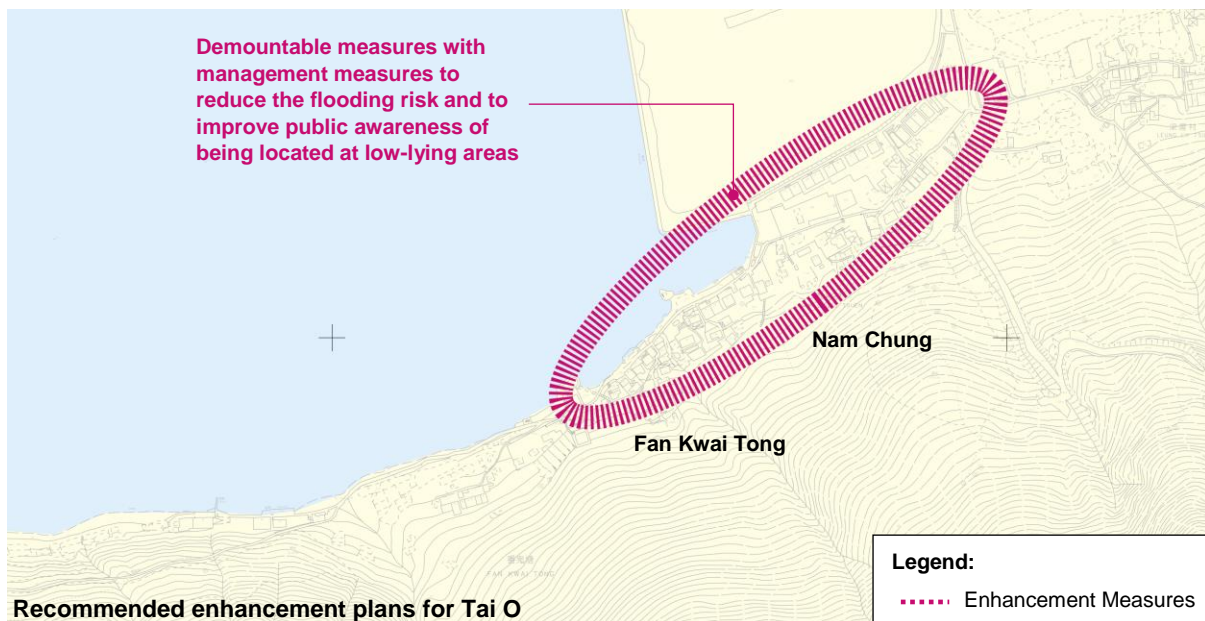
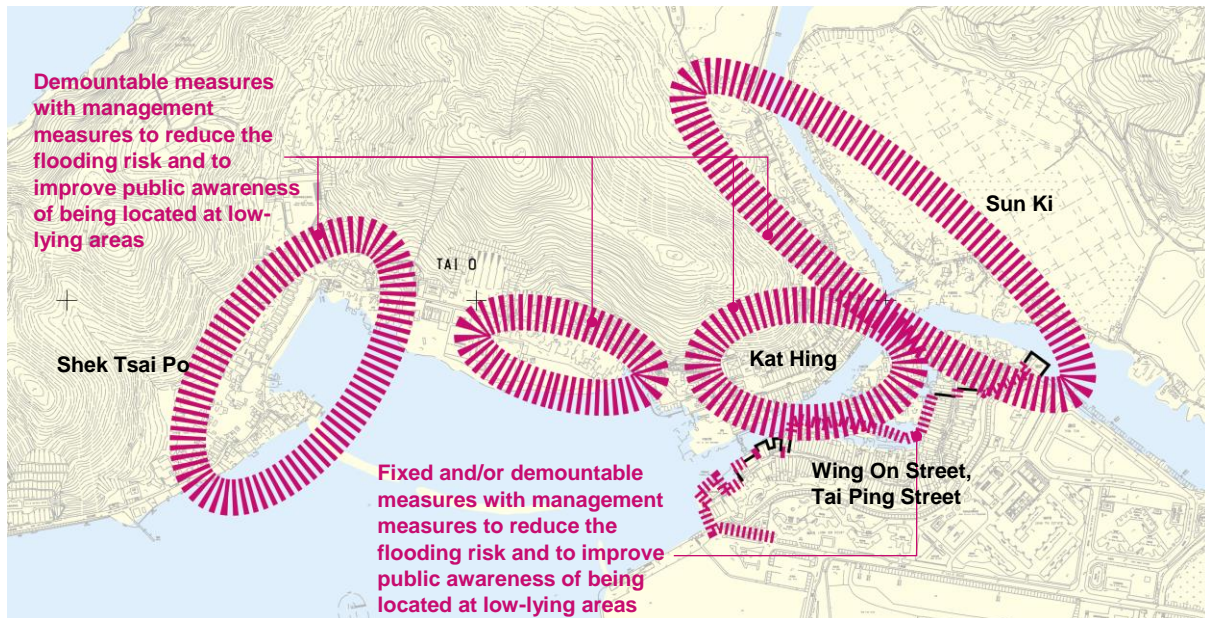
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Tai O with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Recommended enhancement plans for Tai O

Remark: Existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

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8. SHAP LONG AND CHEUNG SHA LOWER VILLAGE, LANTAU ISLAND

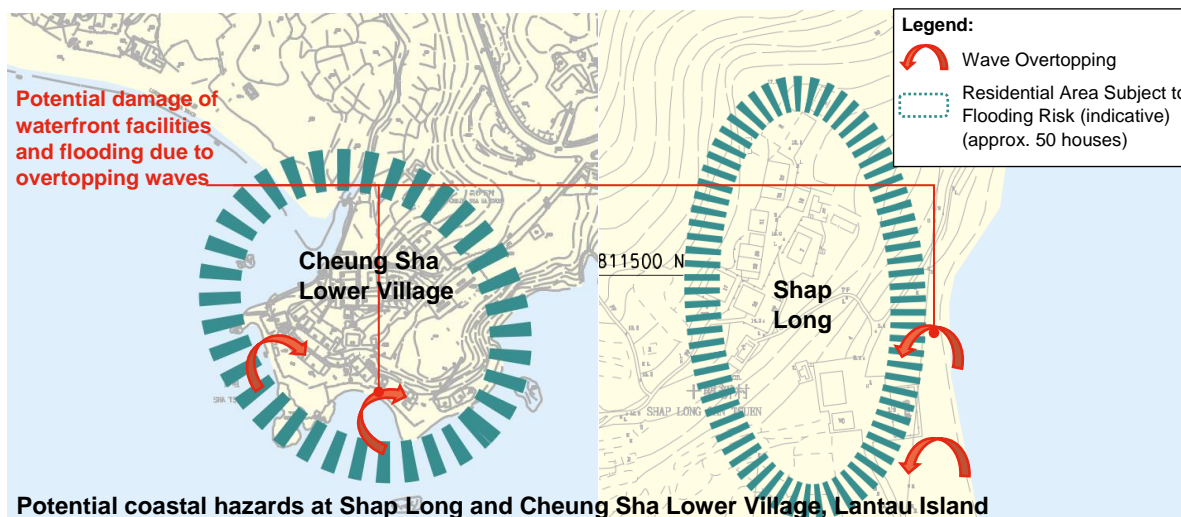
SITE DESCRIPTION

Shap Long and Cheung Sha Lower Village is located at Southern Lantau Island with shorelines facing Chi Ma Wan and Cha Kwo Chau. The site is exposed to waves and swells from the South China Sea and some local areas were subjected to overtopping waves and associated damages during past typhoon events. Specific observation around the site includes:



POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Shap Long and Cheung Sha Lower Village, Lantau Island with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Fixed enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

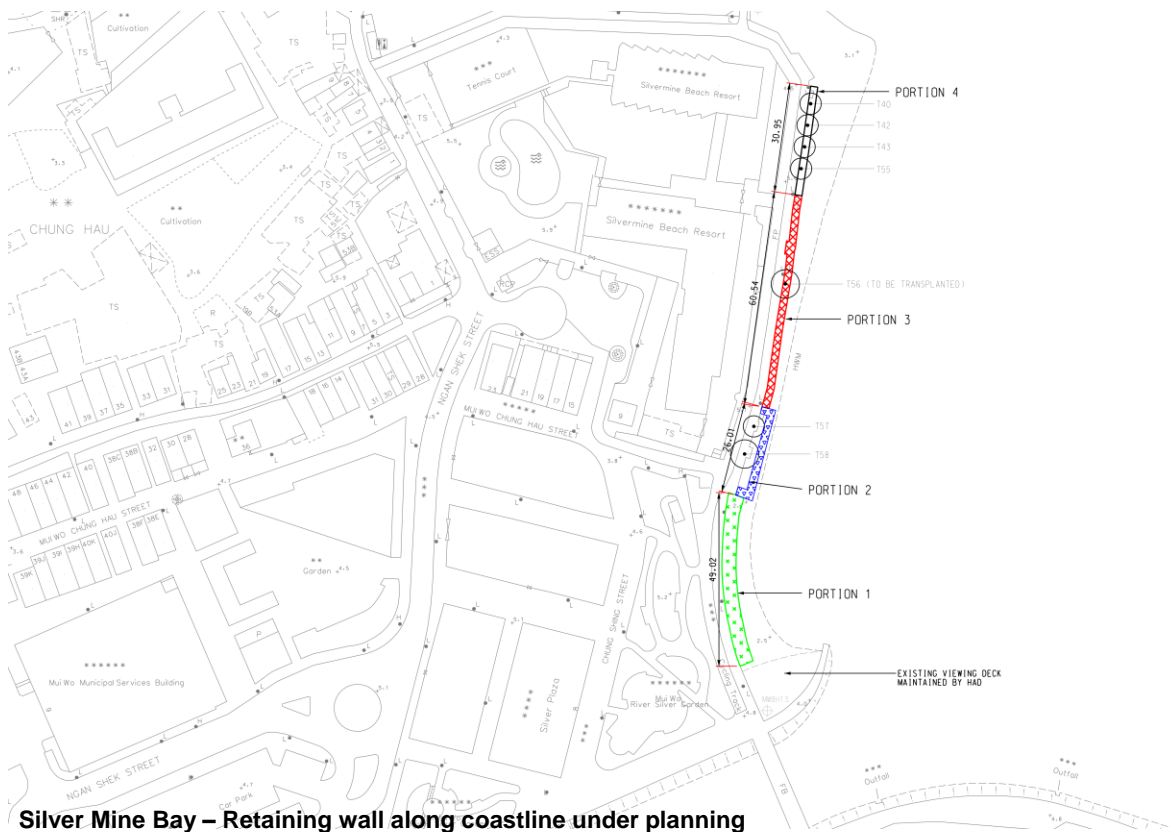
9. MA PO TSUEN AND CHUNG HAU, MUI WO

SITE DESCRIPTION

Ma Po Tsuen and Chung Hau, Mui Wo is located along Wang Tong River and Mui Wo River respectively. The site is a low-lying area potentially exposed to flooding due to overflow of river water. Specific observation during past typhoon events near the site includes:



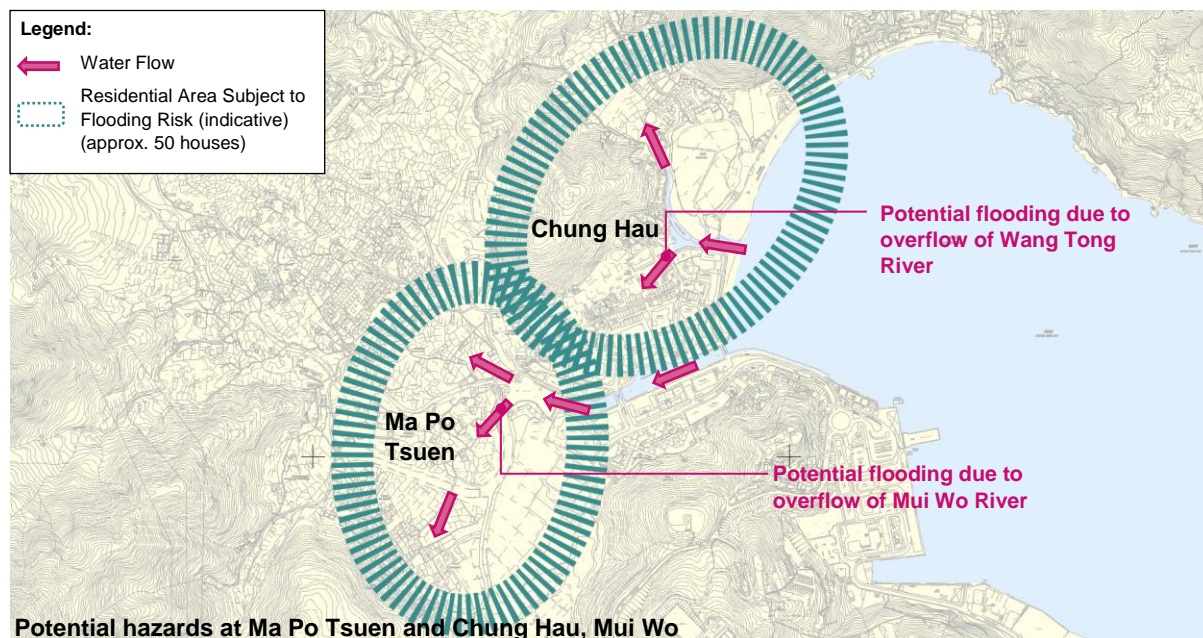
A1-1.1.1 Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



Silver Mine Bay – Retaining wall along coastline under planning

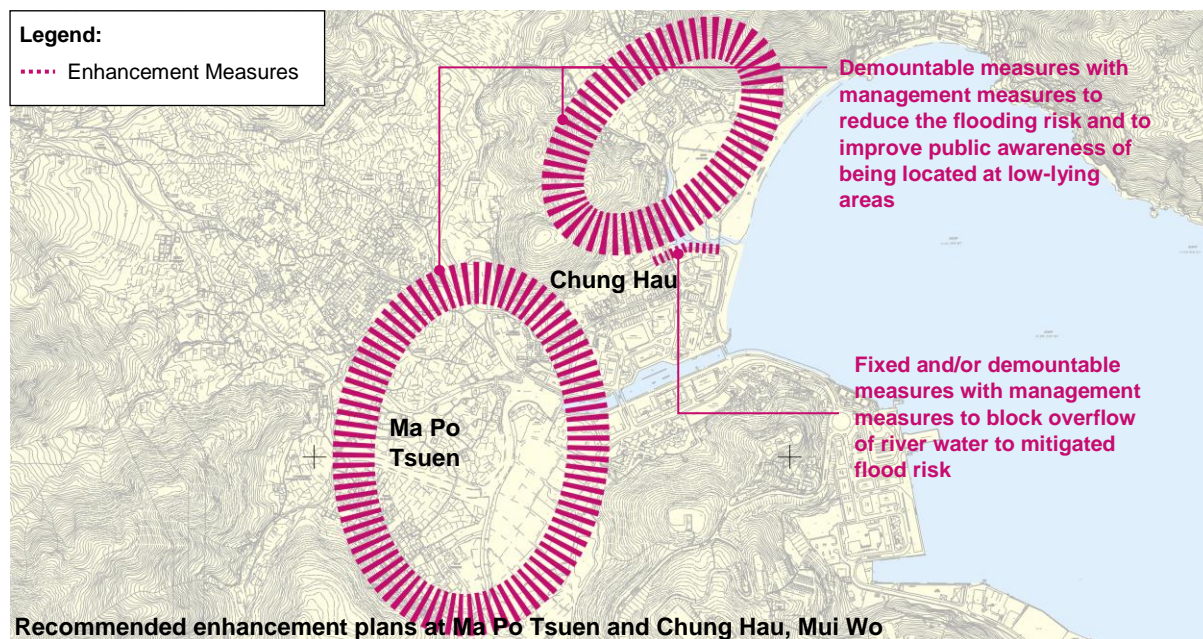
POTENTIAL COASTAL HAZARDS

Potential hazards at Ma Po Tsuen and Chung Hau, Mui Wo with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

10. PENG CHAU WEST AREAS

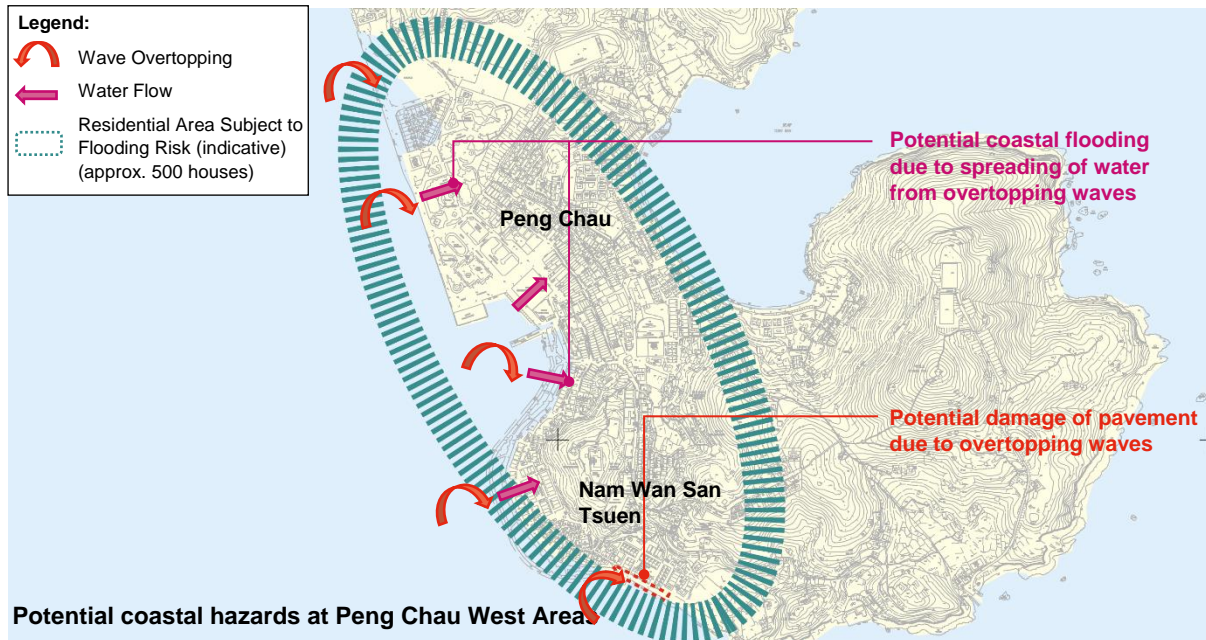
SITE DESCRIPTION

Peng Chau West Areas is located at along the south and west coast of Peng Chau Island. The site is exposed to waves and swells from South China Sea and some local areas were subjected to overtopping waves and associated damages during past typhoon events. Specific observation around the site includes:



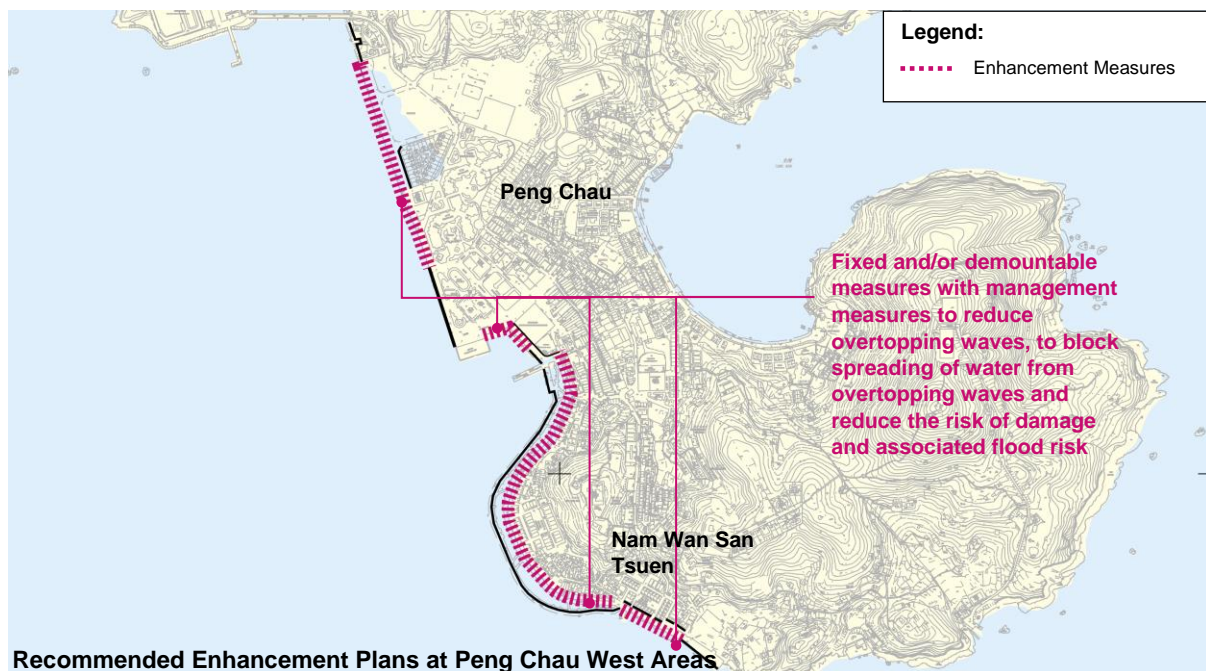
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Peng Chau west areas with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

- Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
- Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

11. CHEUNG CHAU WEST AREAS

SITE DESCRIPTION

Cheung Chau West Areas is located at along the west coast of Cheung Chau Island. The site is exposed to waves and swells from South China Sea and some local areas were subjected to overtopping waves and associated damages and floods during past typhoon events. Specific observation around / near the site includes:

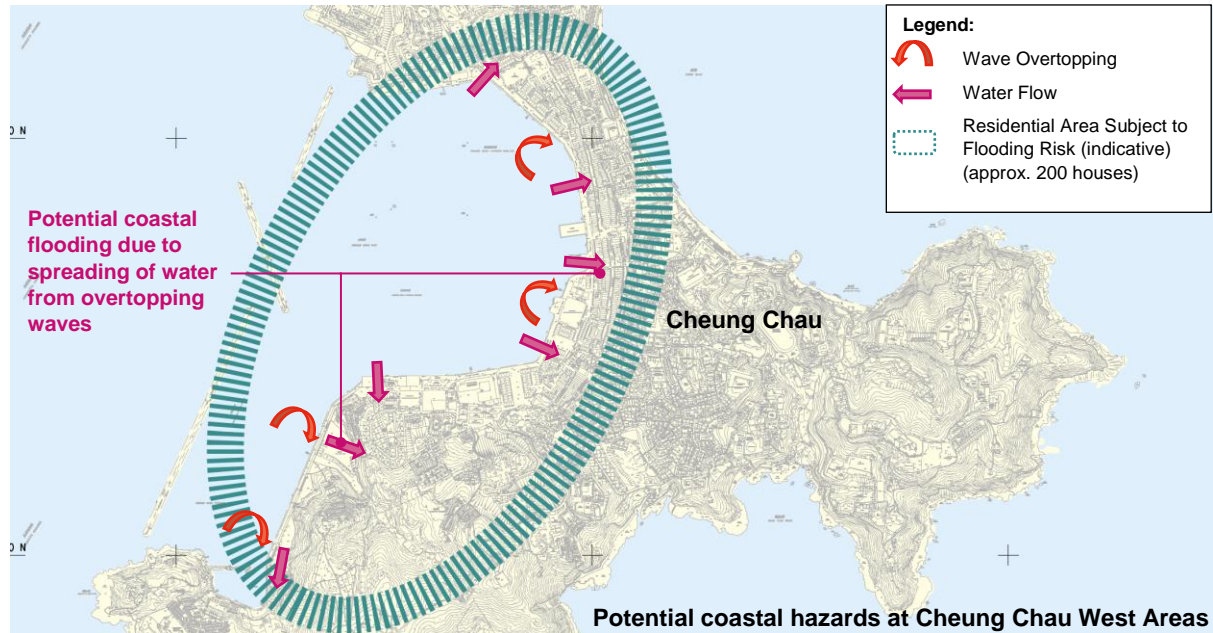


Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards.



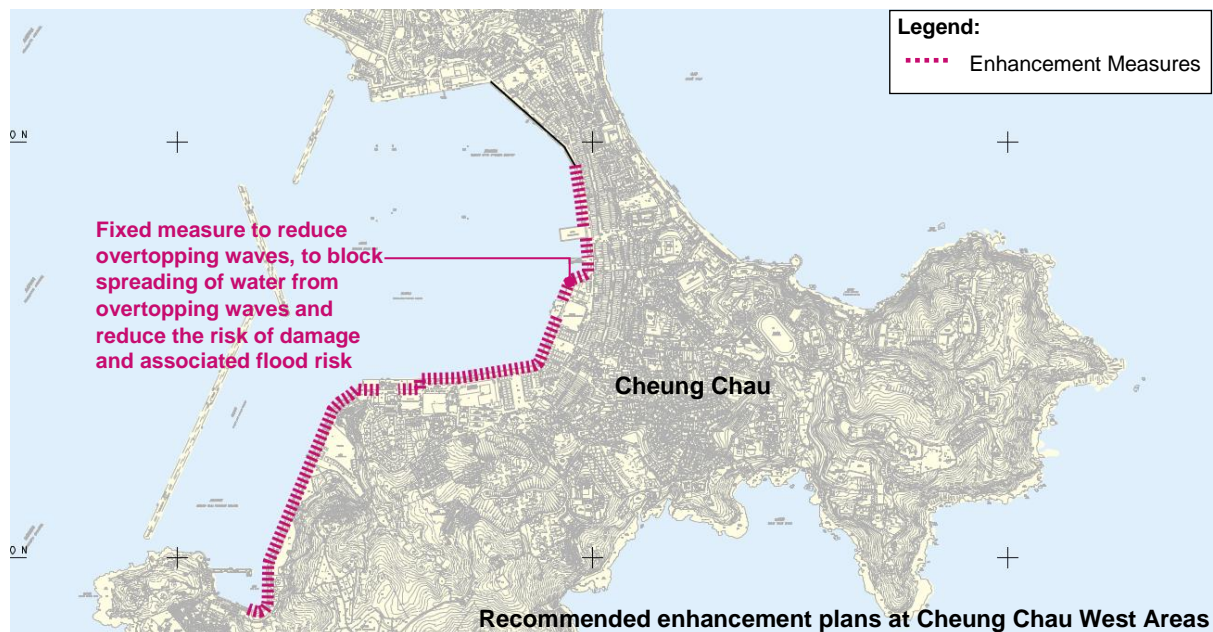
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Cheung Chau West Areas with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Fixed enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

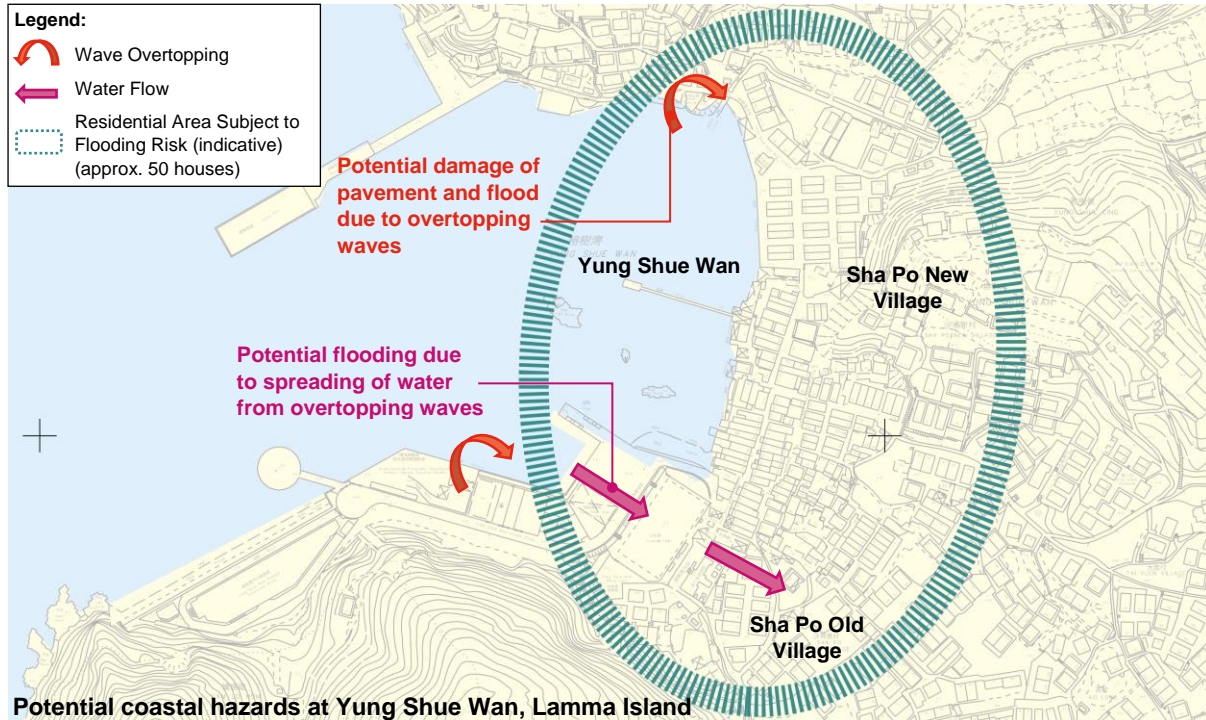
12. YUNG SHUE WAN, LAMMA ISLAND

SITE DESCRIPTION

Yung Shue Wan, Lamma Island is located along the north-east coast of Lamma Island with a shoreline facing West Lamma Channel. The site is exposed to offshore waves and swells approaching from the South China Sea and was subjected to overtopping waves and associated flooding / damages during past typhoon events.

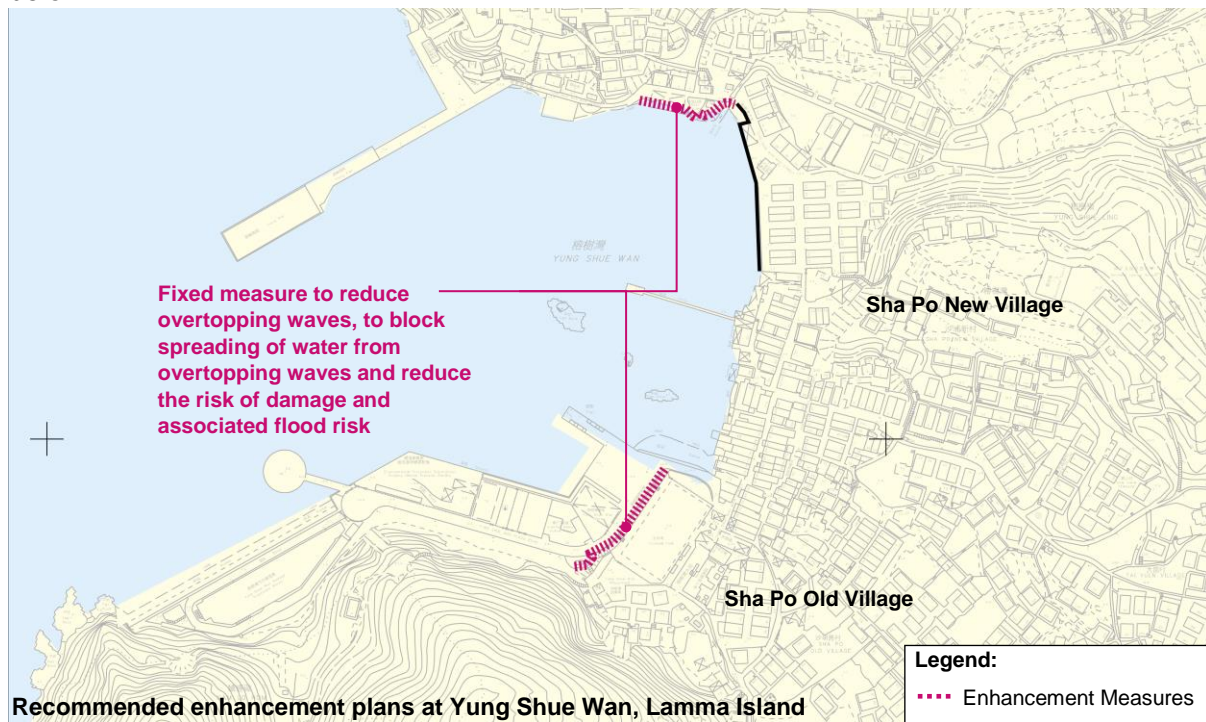
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Yung Shue Wan, Lamma Island with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Fixed enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

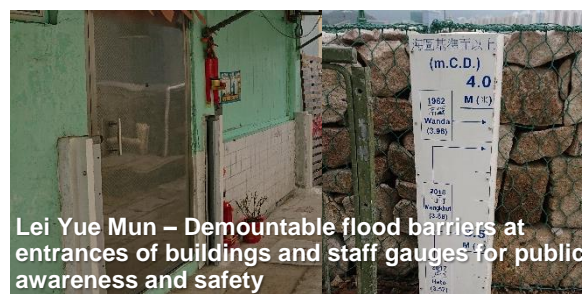
13. LEI YUE MUN

SITE DESCRIPTION

Lei Yue Mun is located at Eastern Kowloon with shoreline facing Eastern Victoria Harbour. The site is exposed to offshore waves and swells approaching from the South China Sea and was subjected to overtopping waves and associated flooding / damages during past typhoon events. In addition, it is also a coastal low-lying area subjected to inundation of seawater. Specific observation around the site includes:



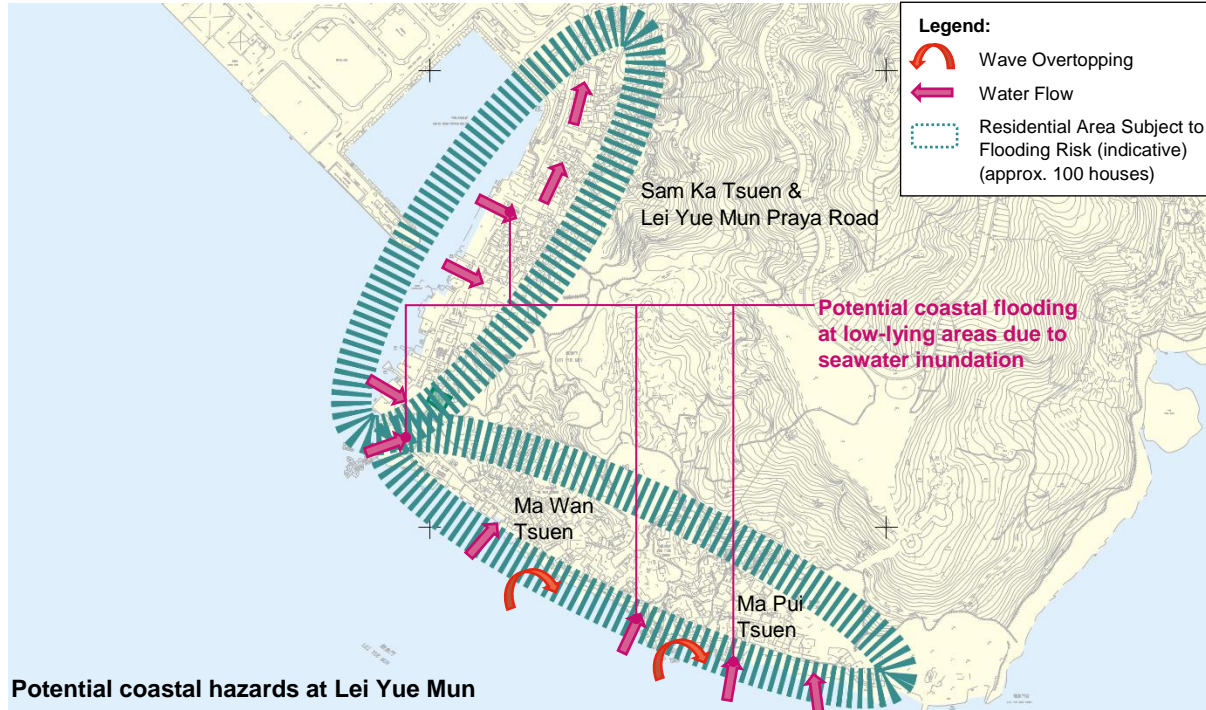
Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



Over the past years, different types of management measures have been implemented to alleviate the impact of coastal hazards. This include establishment of emergency response team and early alert system.

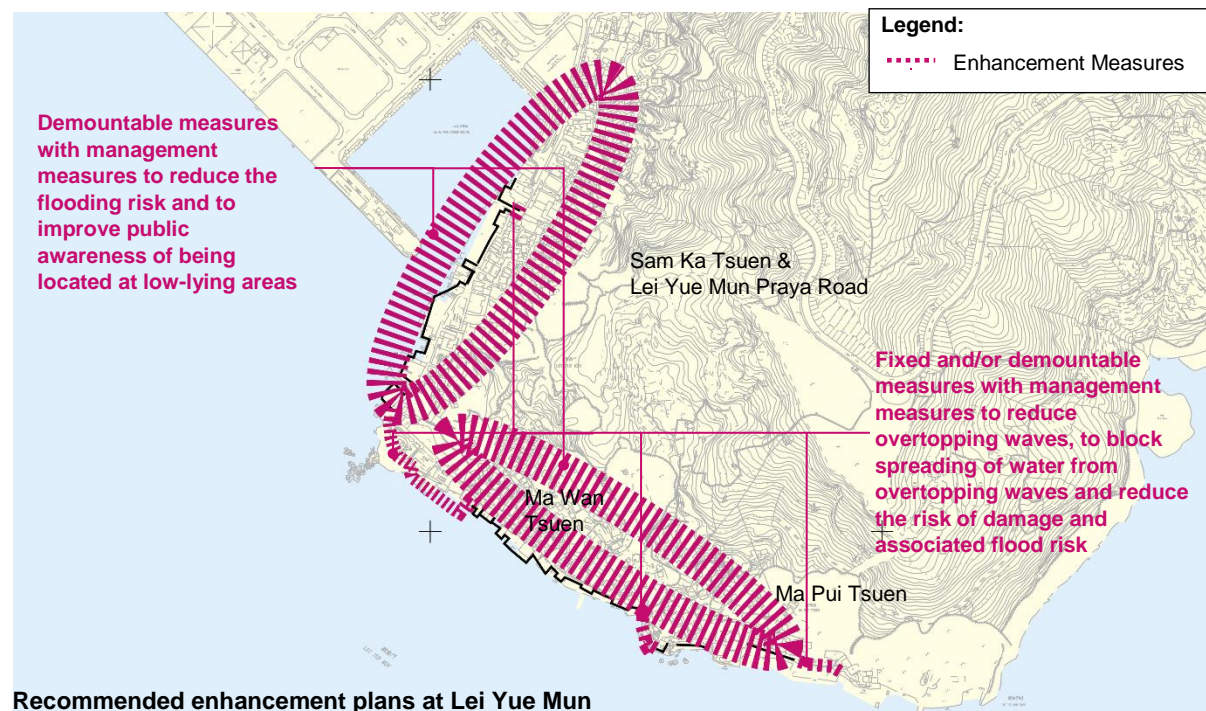
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Lei Yue Mun with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: Existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

14. SHA TAU KOK TOWN

SITE DESCRIPTION

Sha Tau Kok Town is located at north east New Territories with shoreline facing Starling Inlet. The site is a low-lying area and some local areas were subjected to inundation of seawater during past typhoon events. Specific observation around the site includes:



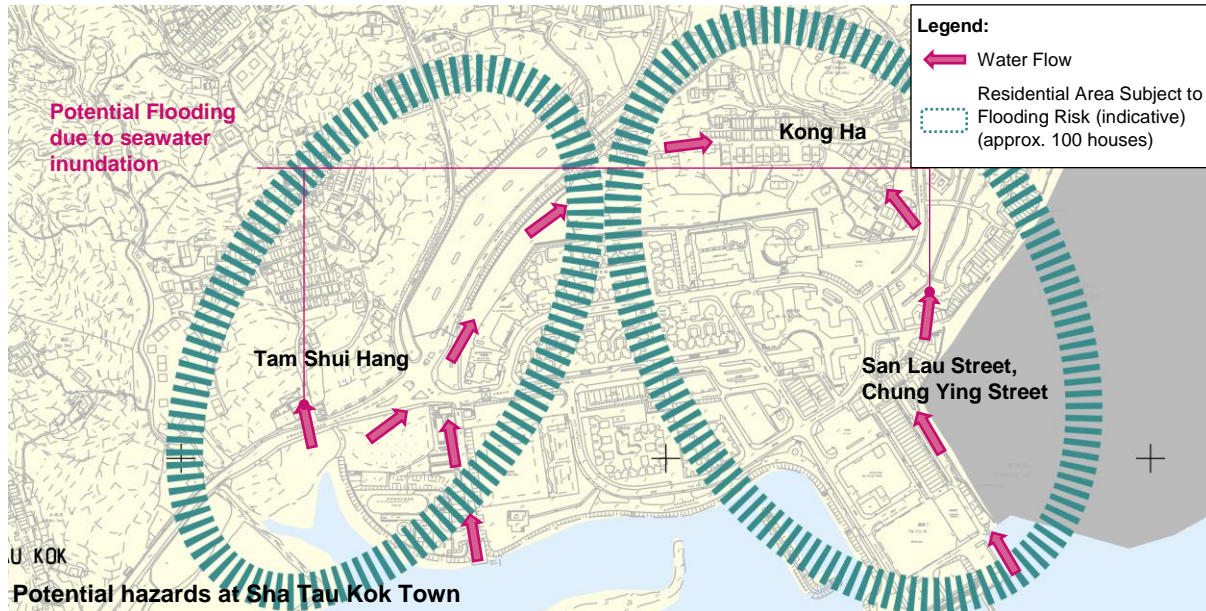
Sha Tau Kok – Flooding near Sha Tau Kok Pier



Sha Tau Kok – Flooding at San Lau Street

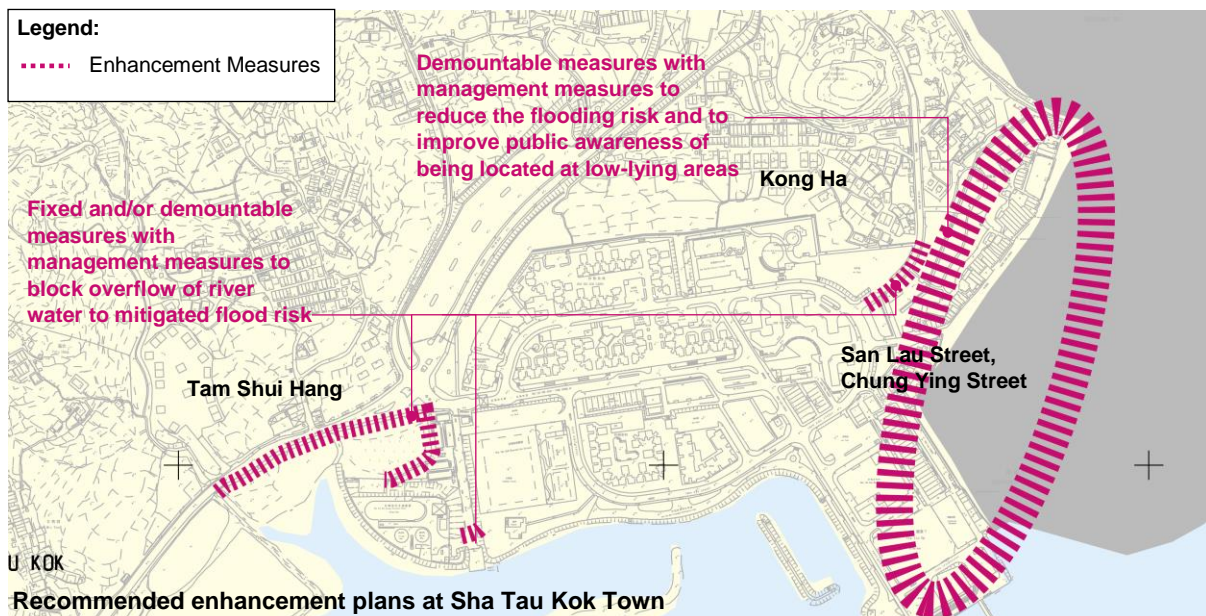
POTENTIAL COASTAL HAZARDS

Potential hazards at Sha Tau Kok Town with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

15. KAT O WEST LOW-LYING AREAS

SITE DESCRIPTION

Kat O West Low-lying Area is located at North-east New Territories and with a shoreline facing Crooked Harbour. The site is low-lying area and some local areas were subjected to flooding due to seawater inundation during past typhoon events. Specific observation around the site includes:



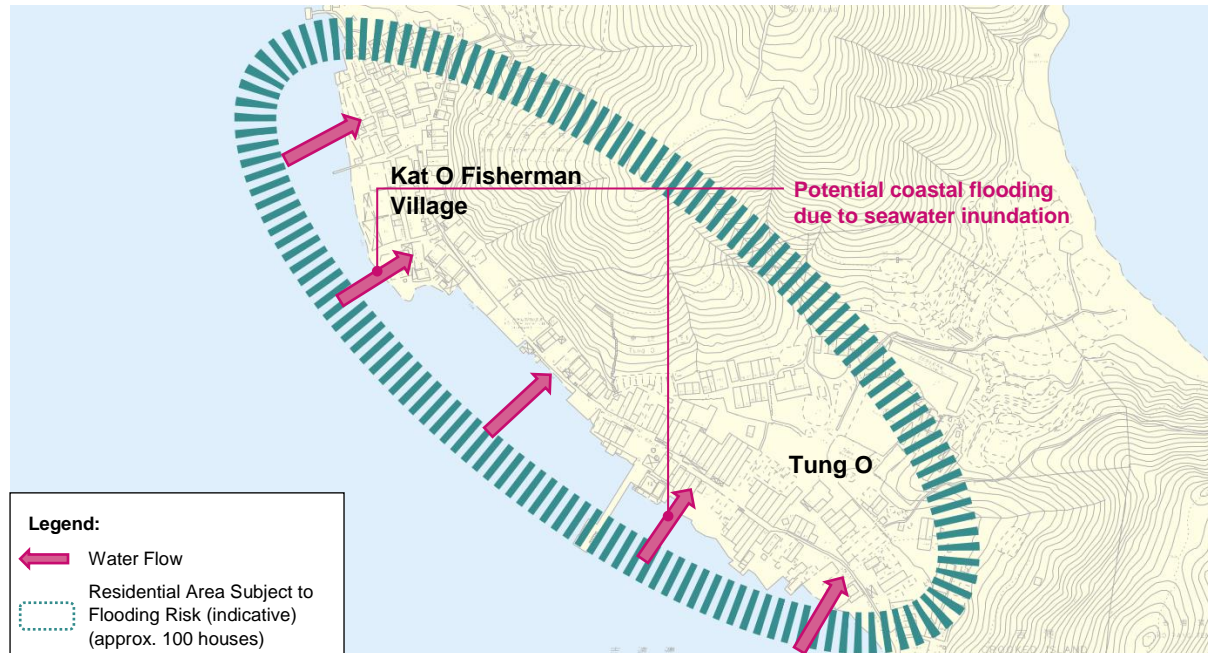
Kat O West – Coastal flooding due to seawater inundation



Kat O West – Damages of waterfront facilities due to seawater inundation

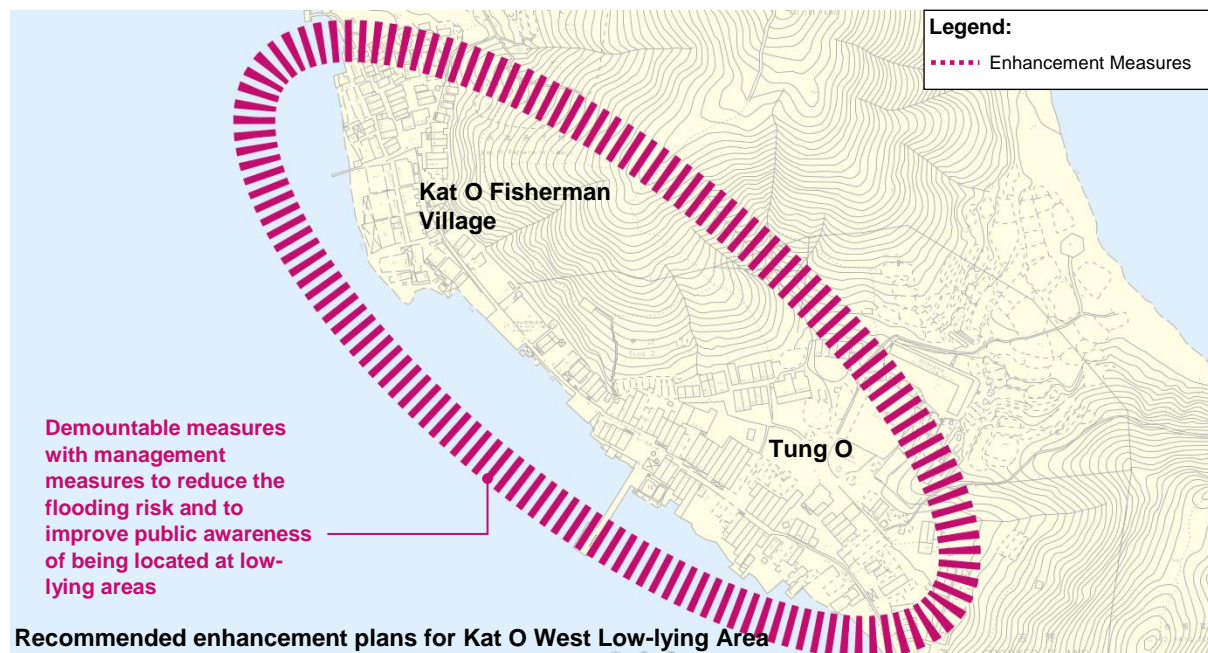
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Kat O West Low-lying Area with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Recommended enhancement plans for Kat O West Low-lying Area

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

16. SAM MUN TSAI NEW VILLAGE, TAI PO

SITE DESCRIPTION

Sam Mun Tsai New Village is located at east to Tai Po and with a shoreline facing Tolo Harbour. The site is a low-lying area and was subject to flooding due to seawater inundation during past typhoon events. Specific observations around / near the site includes:



Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



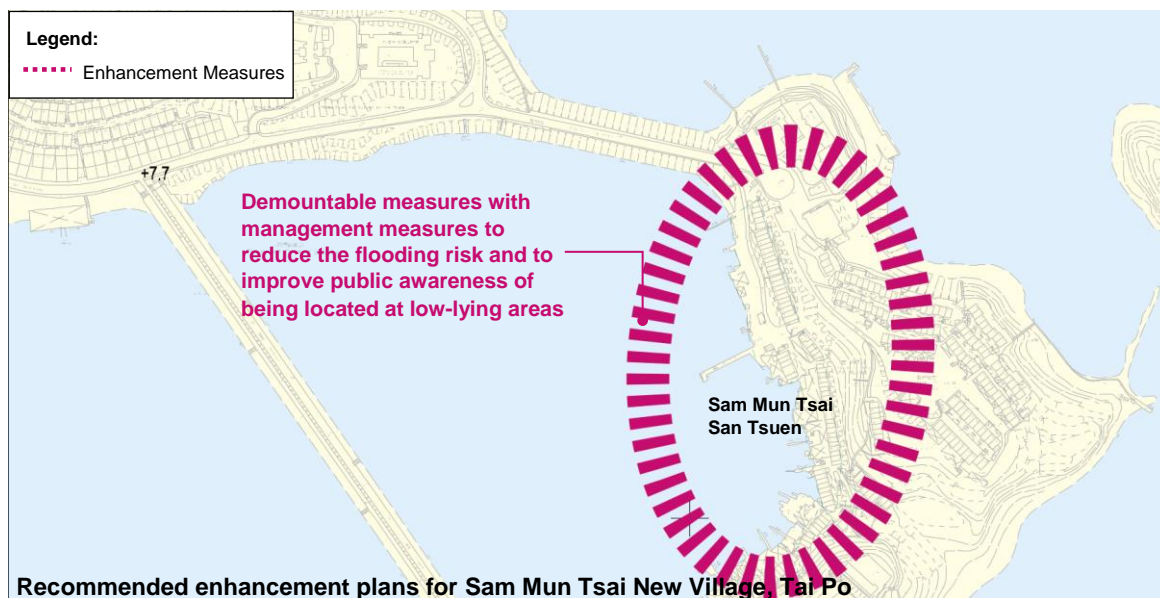
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Sam Mun Tsai New Village, Tai Po with climate change projections up to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

17. TAI PO MARKET (NEAR LAM TSUEN RIVER)

SITE DESCRIPTION

Tai Po Market is located near Lam Tsuen River of Tolo Harbour. The site is a low-lying area and was subjected to flooding due to overflow of Lam Tsuen River during past typhoon events. Specific observation around / near the site includes:



Tai Po Market (Plover Cove Road) – Flooding due to overflow of river water



Subway near Nam Wan Road – Flooding due to overflow of river water

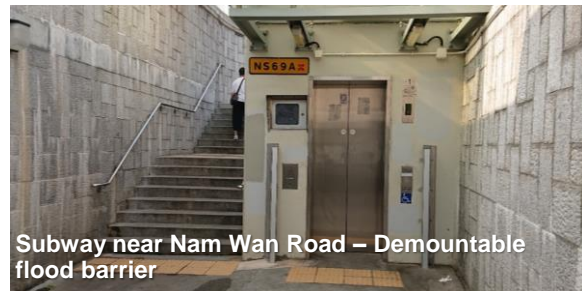


Lam Tsuen River – Local damage of river wall

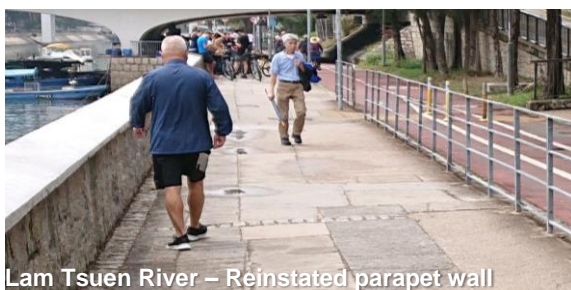
Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



Tai Po Market (Plover Cove Road) – Flood panel at drainage outfall



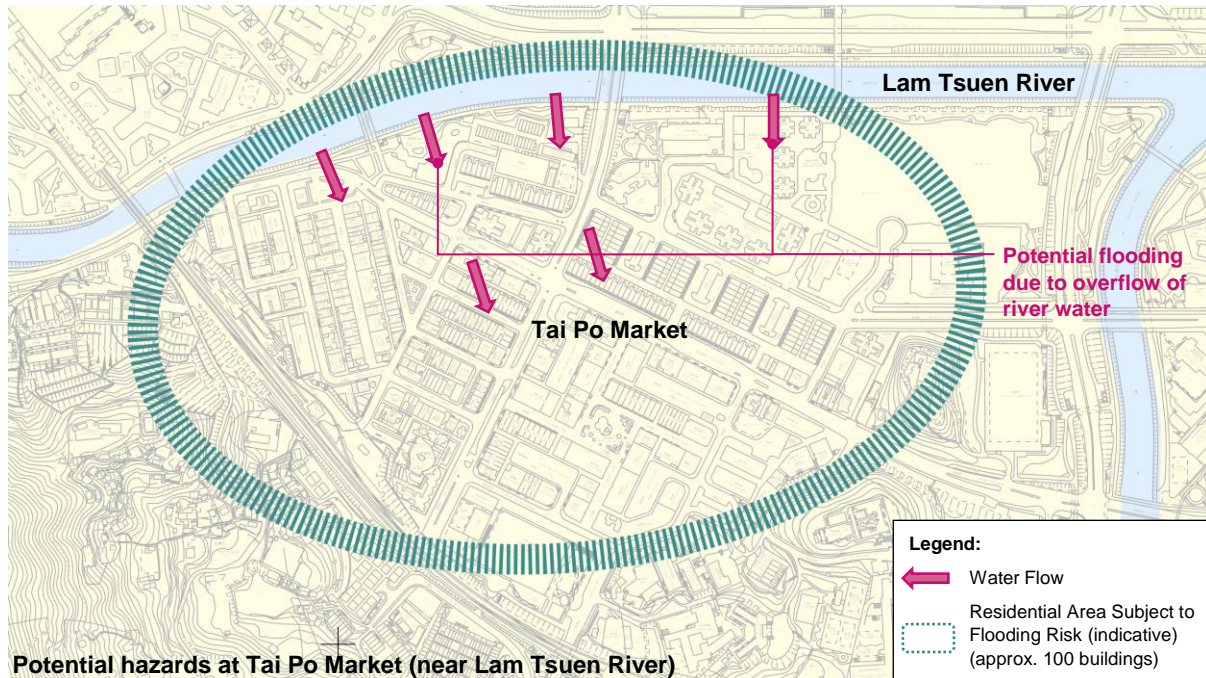
Subway near Nam Wan Road – Demountable flood barrier



Lam Tsuen River – Reinstated parapet wall

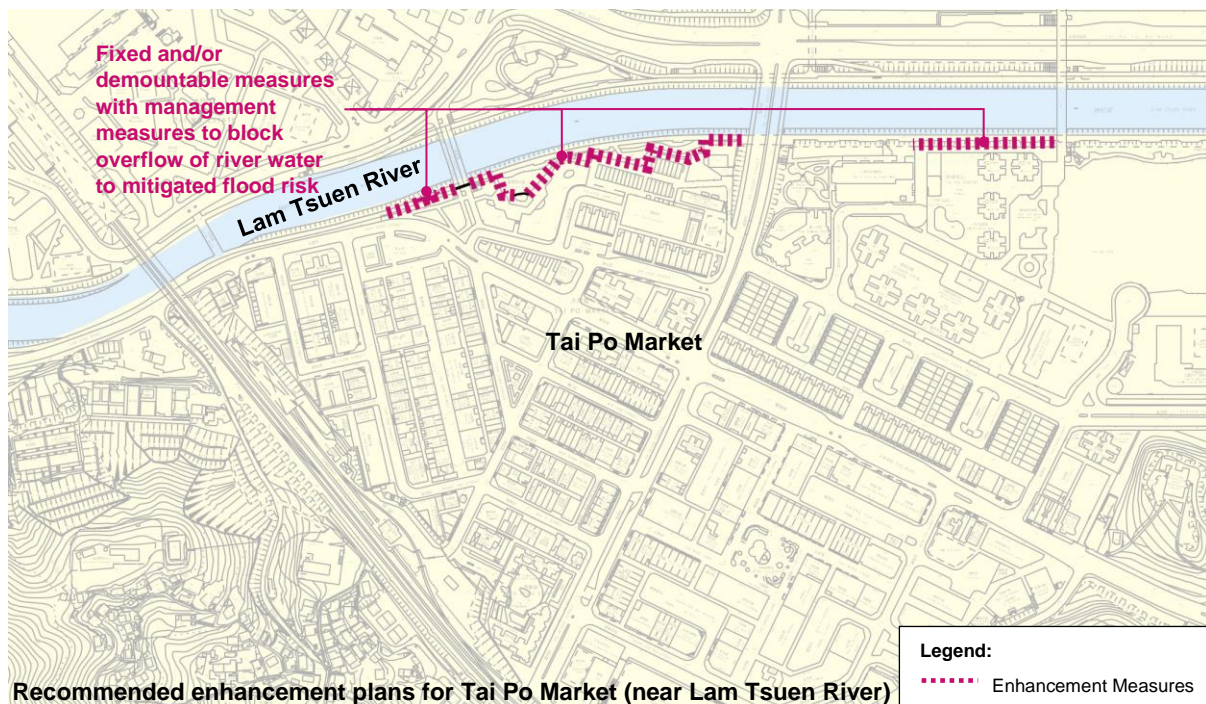
POTENTIAL COASTAL HAZARDS

Potential hazards at Tai Po Market (near Lam Tsuen River) with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

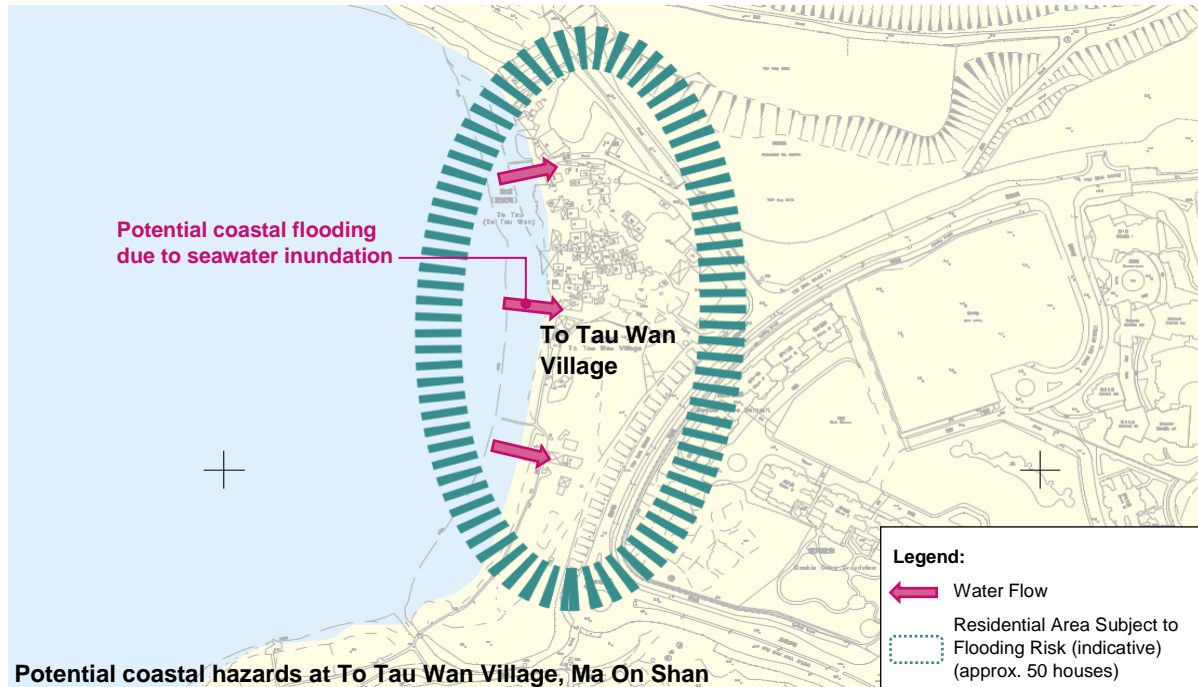
18. TO TAU WAN VILLAGE, MA ON SHAN

SITE DESCRIPTION

To Tau Wan Village, Ma On Shan is located at the north of Ma On Shan with a shoreline facing Tolo Harbour. The site is a low-lying area and is potentially subjected to coastal flooding due to seawater inundation during typhoon events.

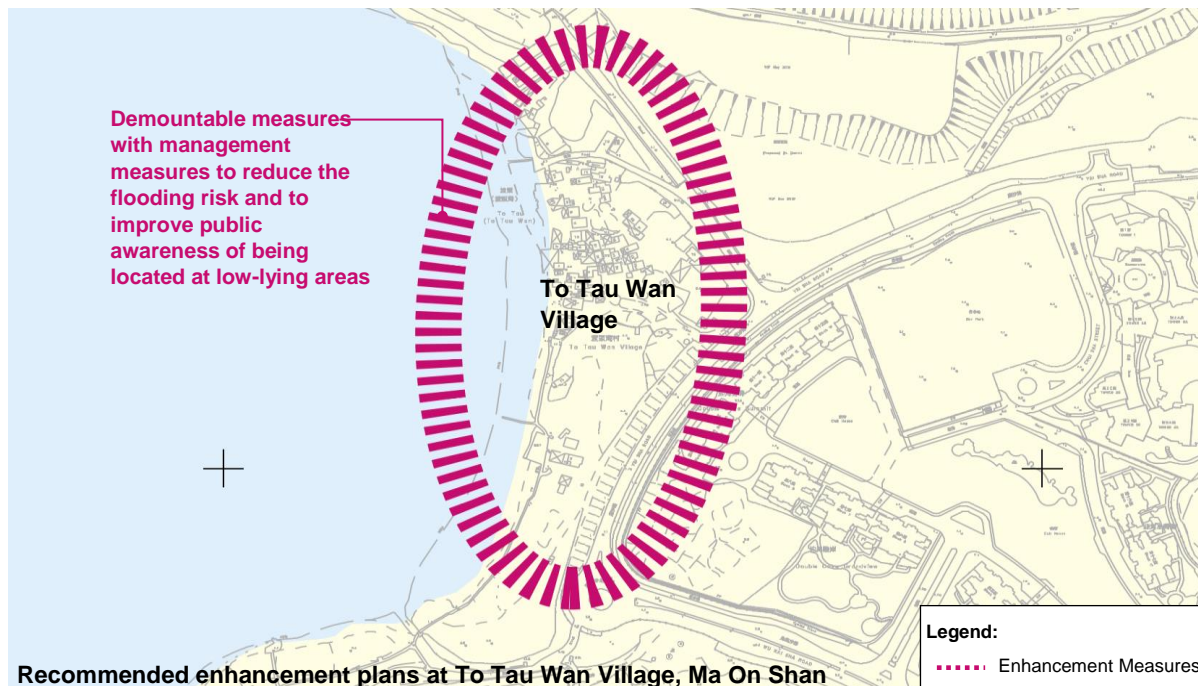
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at To Tau Wan Village, Ma On Shan with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

19. SAI KUNG TOWN CENTRE AND TUI MIN HOI

SITE DESCRIPTION

Sai Kung Town Centre and Tui Min Hoi is located at south-east side of New Territories with shoreline facing Inner Port Shelter. The site is exposed to offshore waves and swells approaching from the South China Sea and was subjected to overtopping waves and associated flooding / damages during past typhoon events. Specific observation around the site includes:

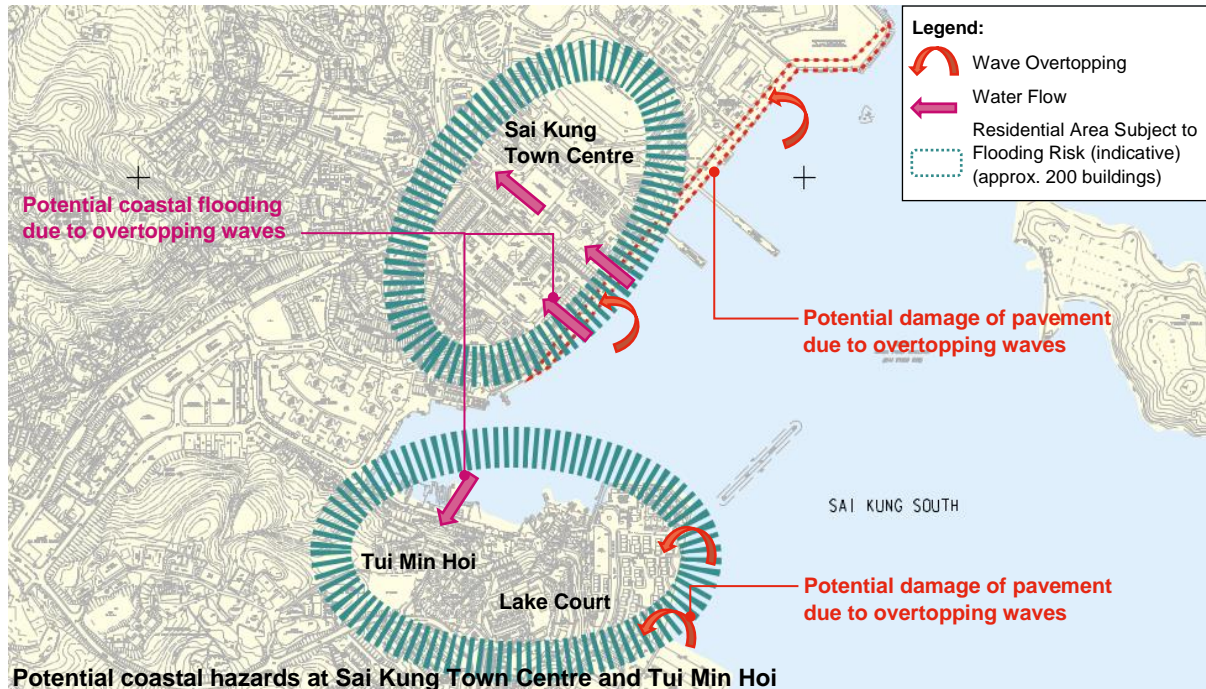


Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



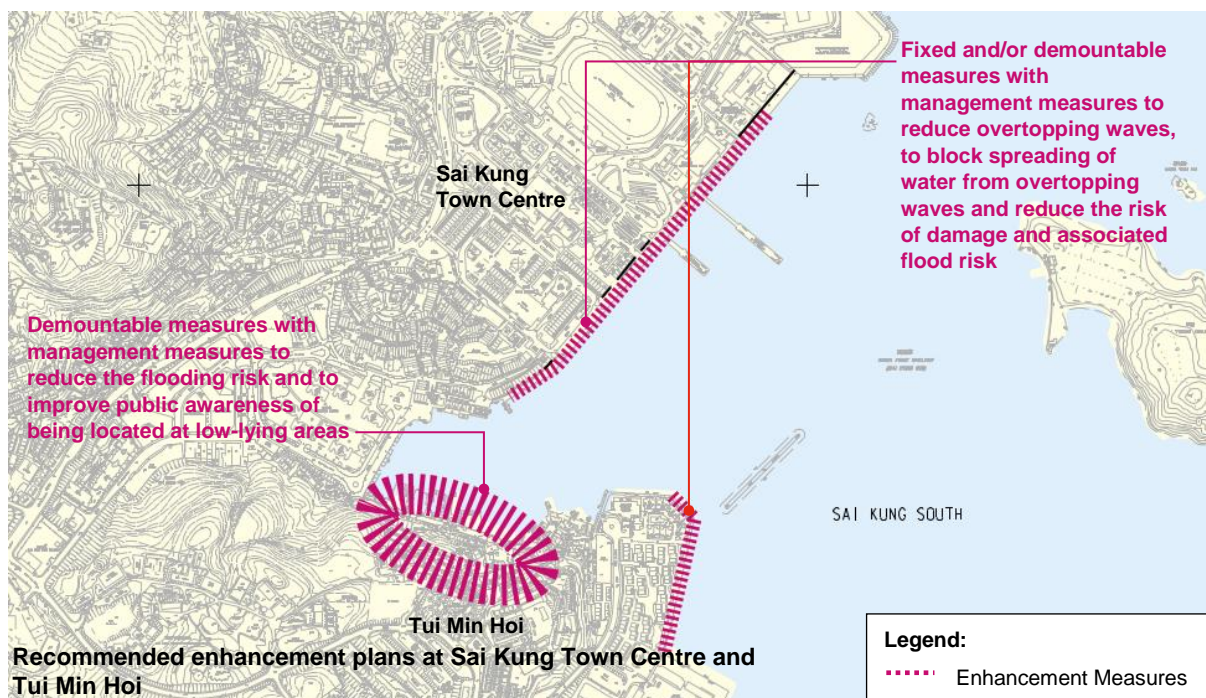
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Sai Kung Town Centre and Tui Min Hoi with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

20. NAM WAI / HEUNG CHUNG, SAI KUNG

SITE DESCRIPTION

Nam Wai / Heung Chung is located at south side of Sai Kung with a shoreline facing to Hebe Haven. The site is a low-lying area and was subjected to flooding due to seawater inundation during past typhoon events. Specific observation around the site includes:



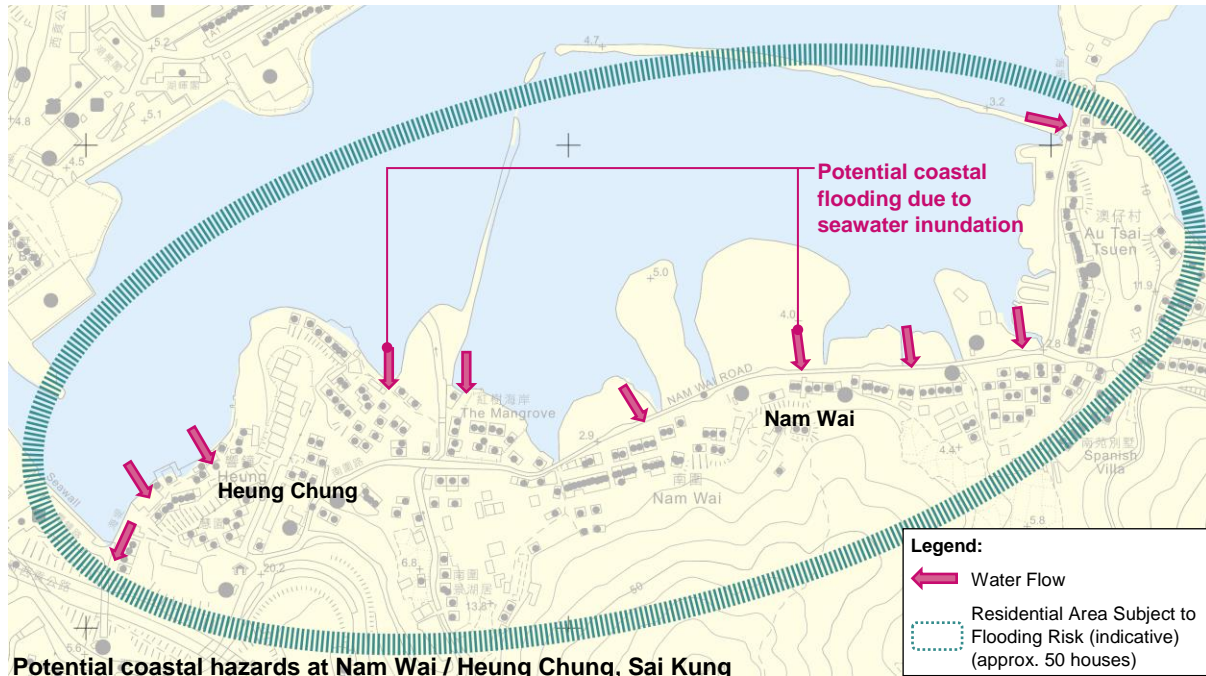
Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



Over the past years, different types of management measures have been implemented to alleviate the impact of coastal hazards. This include establishment of emergency response team and early alert system.

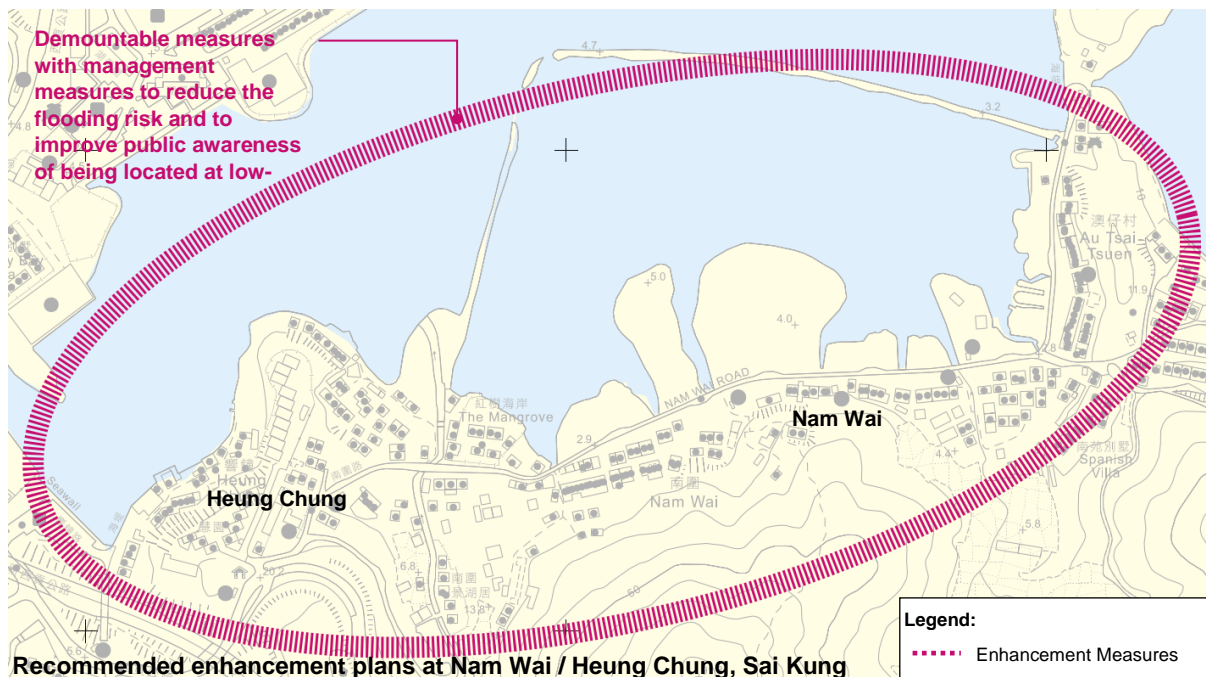
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Nam Wai / Heung Chung, Sai Kung with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: Existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

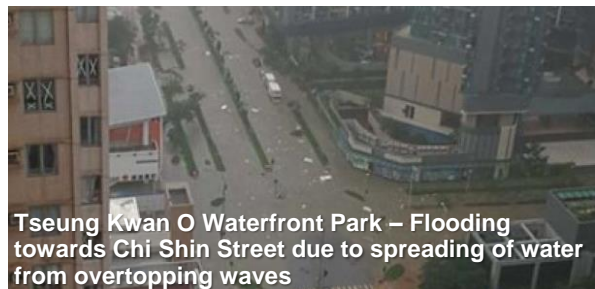
21. TSEUNG KWAN O SOUTH (TSEUNG KWAN O WATERFRONT PARK)

SITE DESCRIPTION

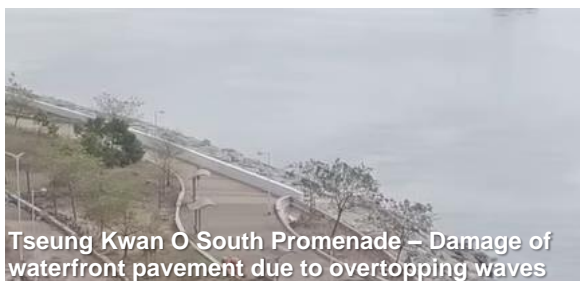
Tseung Kwan O South (Tseung Kwan O Waterfront Park) is located at north of Tseung Kwan O Junk Bay. Most of its shoreline facing south towards Tseung Kwan O Junk Bay. The site is subject to overtopping waves and associated flooding / damages during past typhoon events. Specific observations around / near the site includes:



Tseung Kwan O Waterfront Park – Damage of waterfront pavement due to overtopping waves

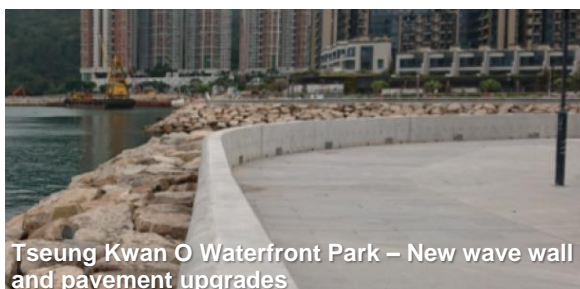


Tseung Kwan O Waterfront Park – Flooding towards Chi Shin Street due to spreading of water from overtopping waves

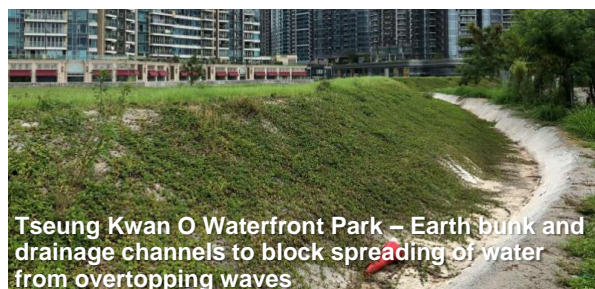


Tseung Kwan O South Promenade – Damage of waterfront pavement due to overtopping waves

Following the strike of Super Typhoon Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



Tseung Kwan O Waterfront Park – New wave wall and pavement upgrades



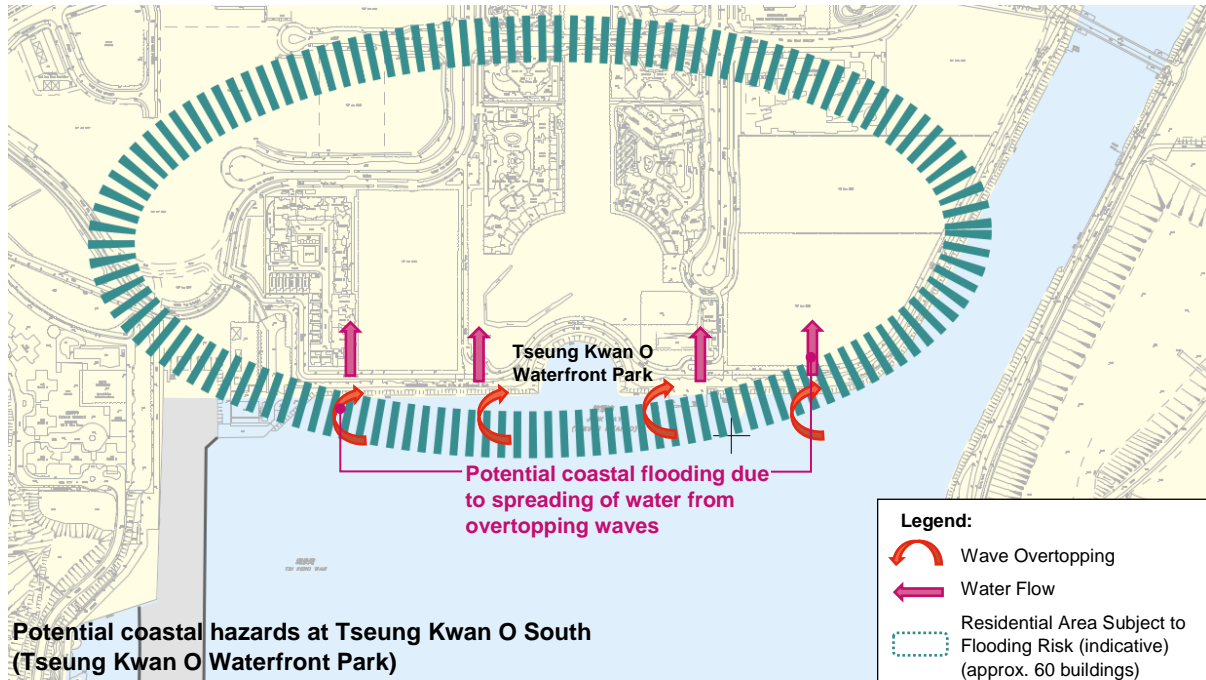
Tseung Kwan O Waterfront Park – Earth bank and drainage channels to block spreading of water from overtopping waves



Tseung Kwan O South Promenade – New wave wall to reduce overtopping waves

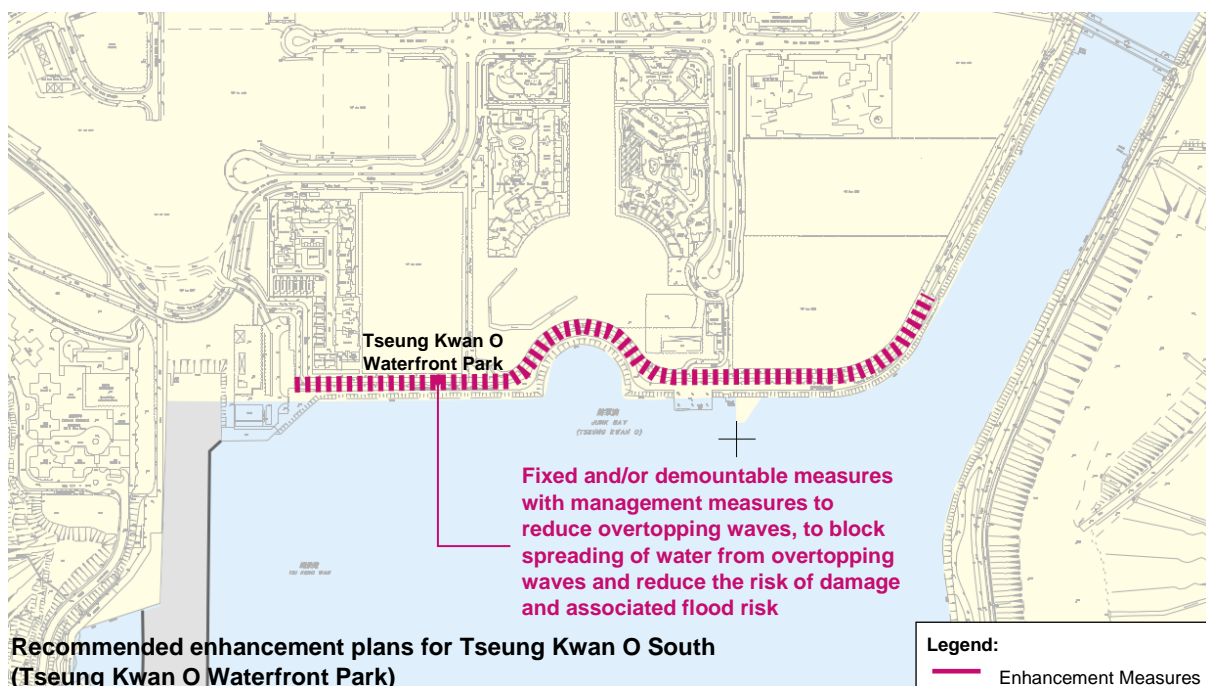
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Tseung Kwan O South (Tseung Kwan O Waterfront Park) with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: Tseung Kwan O Waterfront Park had constructed wave walls along coastline and existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

22. YUEN LONG CENTRAL LOW-LYING AREAS

SITE DESCRIPTION

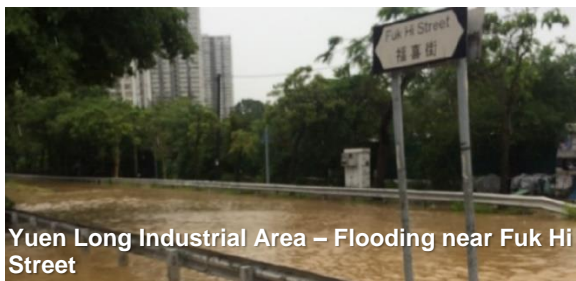
Yuen Long Central Low-lying Areas is located along Shan Pui River and Yuen Long Nullah. The site is a low-lying area and some local areas were subject to flooding due to overflow of Shan Pui River and Yuen Long Nullah during past typhoon events. Specific observations around the site includes:



Yuen Long Town Centre – Flooding near Tung Tai Street



Yuen Long Town Centre – Flooding near Castle Peak Road

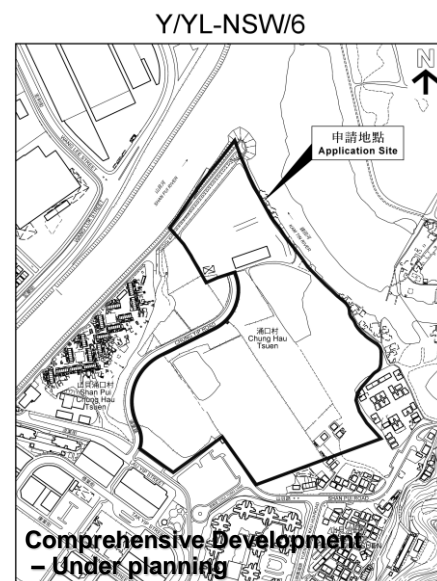
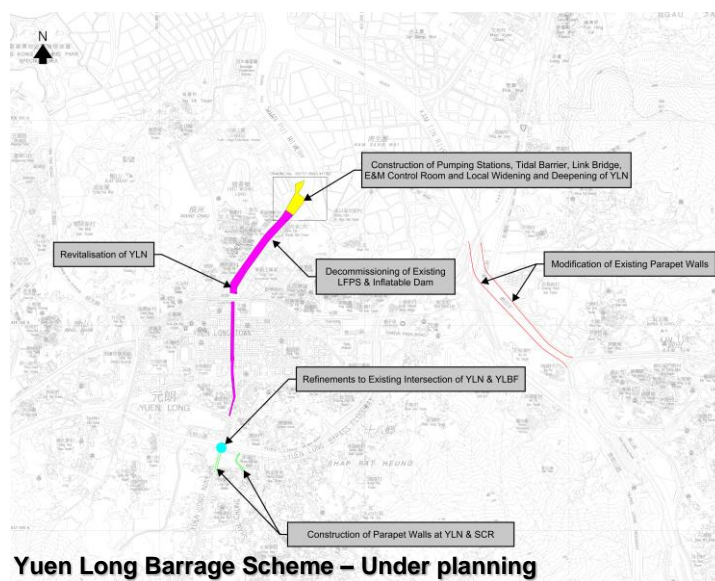


Yuen Long Industrial Area – Flooding near Fuk Hi Street



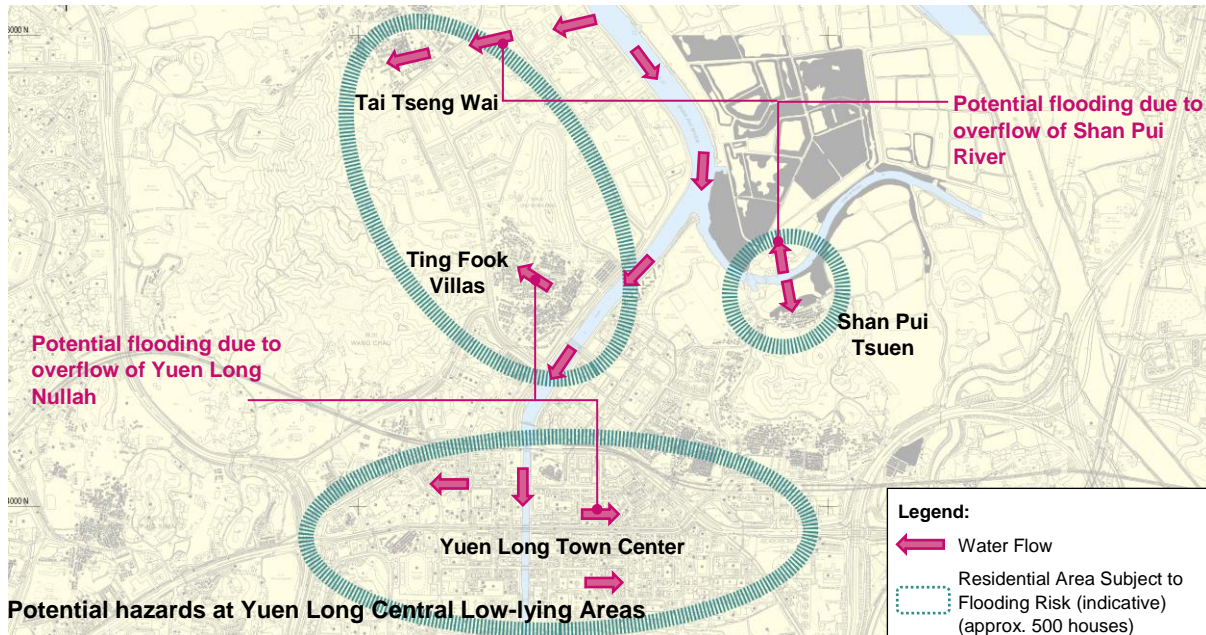
Tai Tseng Wai – Flooding at low-lying area

Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of remedial and improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



POTENTIAL COASTAL HAZARDS

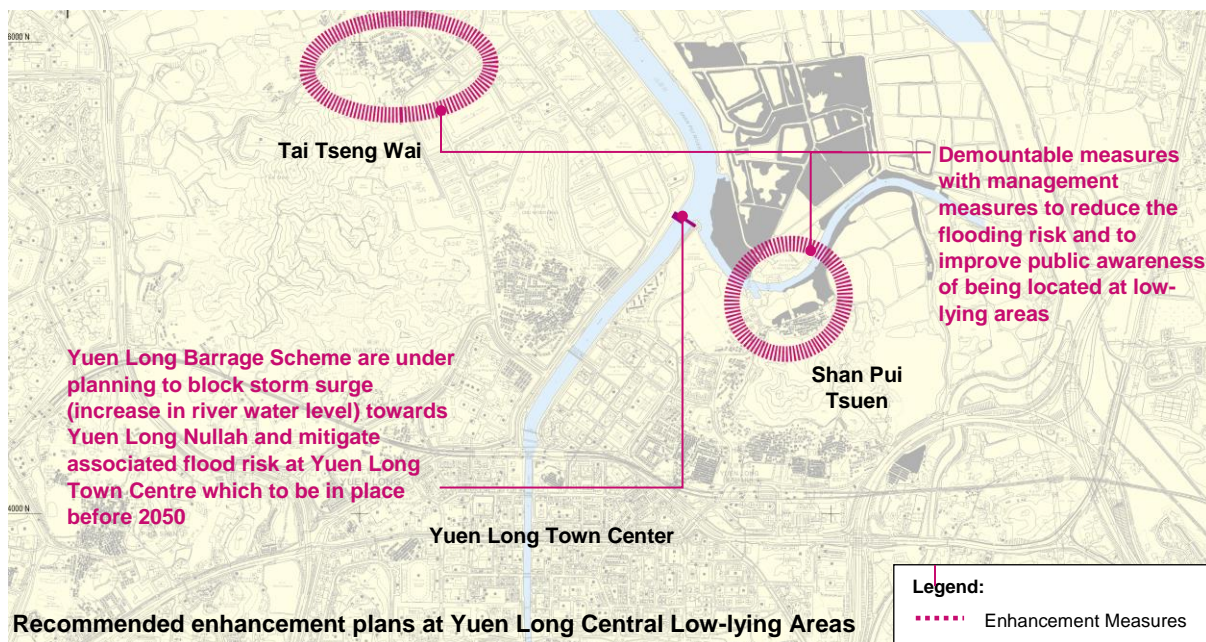
Potential hazards at Yuen Long Central Low-lying Areas with climate change projections to 2050 are identified as below:



Remark: Buildings/houses to be protected within Yuen Long Barrage Scheme is not counted in this Study

RECOMMENDED ENHANCEMENT PLANS

A combination of multi-layers of enhancement works is recommended to mitigate the impacts of potential hazards and enhance resilience and preparedness of the coastal communities as shown below:



Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

23. YUEN LONG NORTH WEST LOW-LYING COASTAL AREAS

SITE DESCRIPTION

Yuen Long North West Low-lying Coastal Areas is located west of Tin Shui Wai with a shoreline facing towards Deep Bay. The site is a low-lying area and was subject to flooding due to inundation of seawater during past typhoon events. Specific observations around / near the site includes:



Deep Bay Road at Lau Fau Shan – About 400mm of flood depth

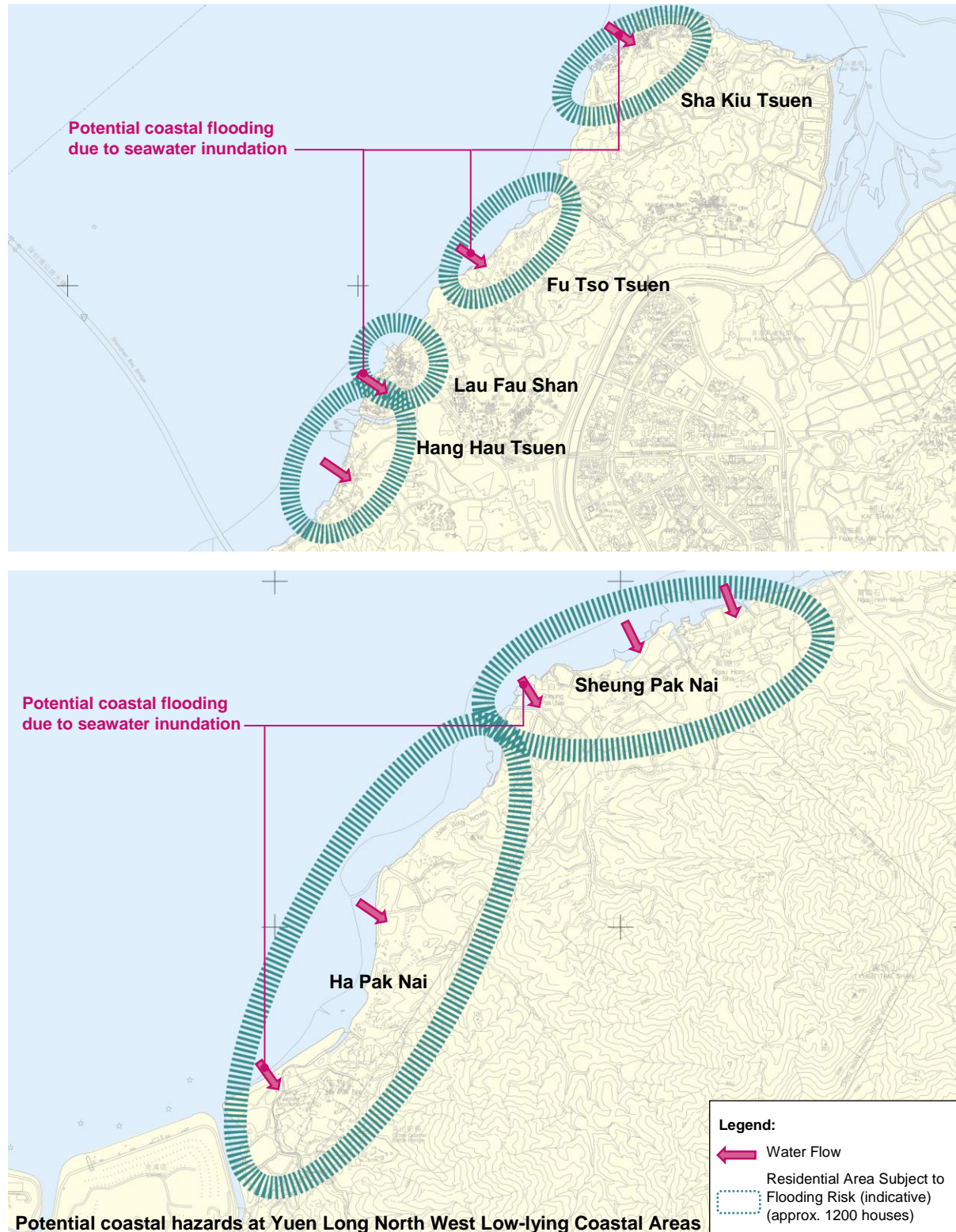


Shan Tung Street in Lau Fau Shan – Flooded village houses with about 300-400mm flood depth

Over the past years, different types of management measures have been implemented to alleviate the impact of coastal hazards. This include establishment of emergency response team, early alert system and temporary shelter at Tin Fai Road Community Centre.

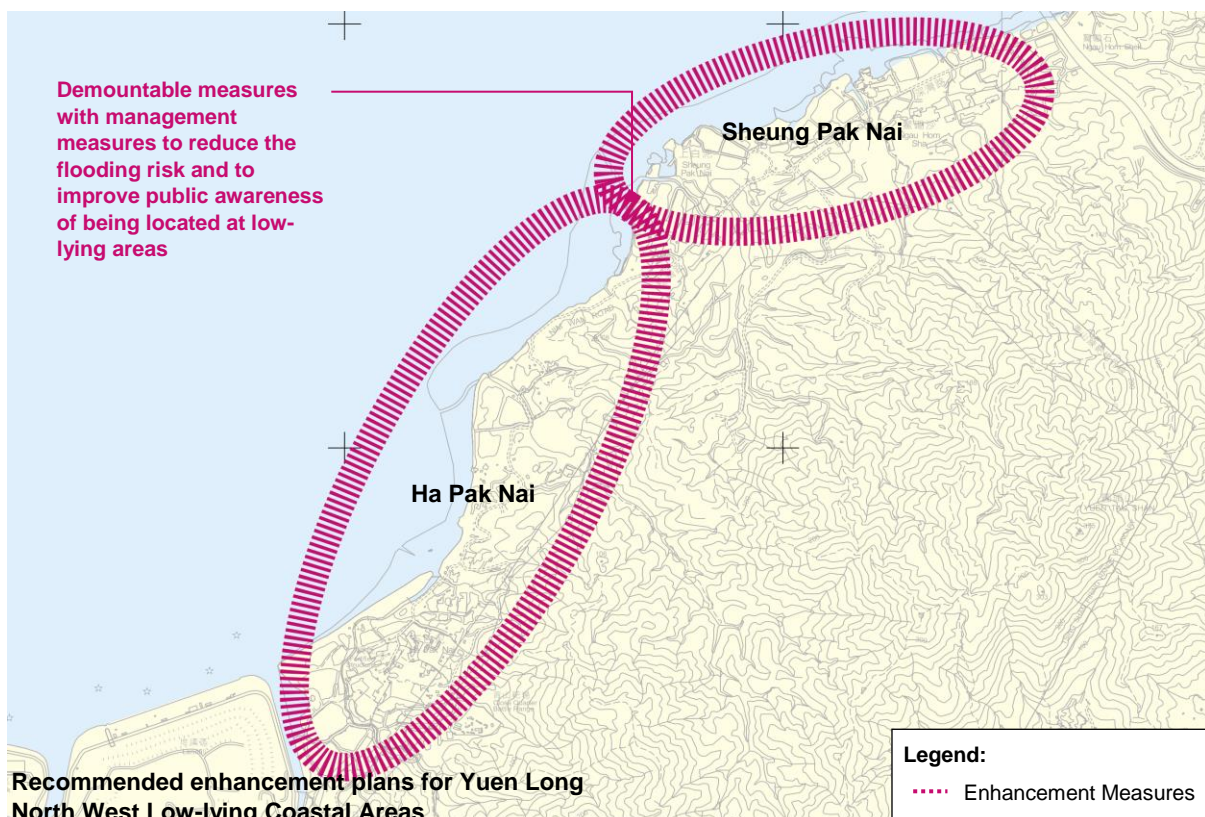
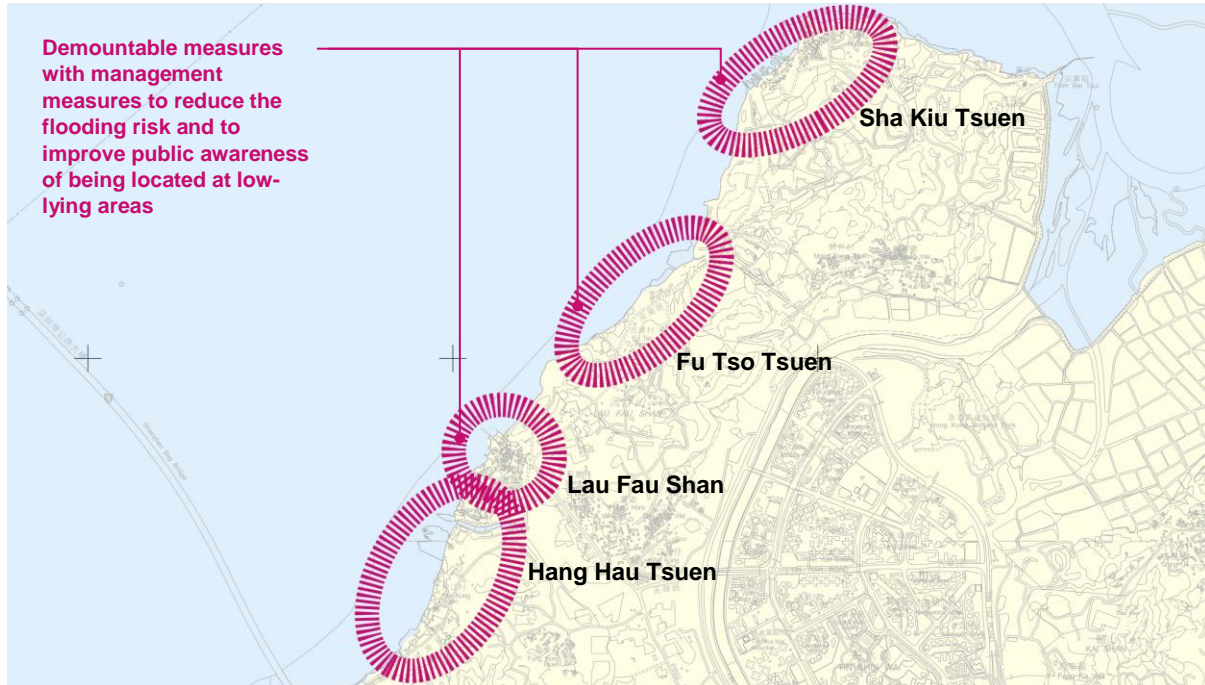
POTENTIAL COASTAL HAZARDS

Potential coastal hazards at Yuen Long North West Low-lying Coastal Areas with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential coastal hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: Existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

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24. LUEN ON SAN TSUEN, TAI LAM

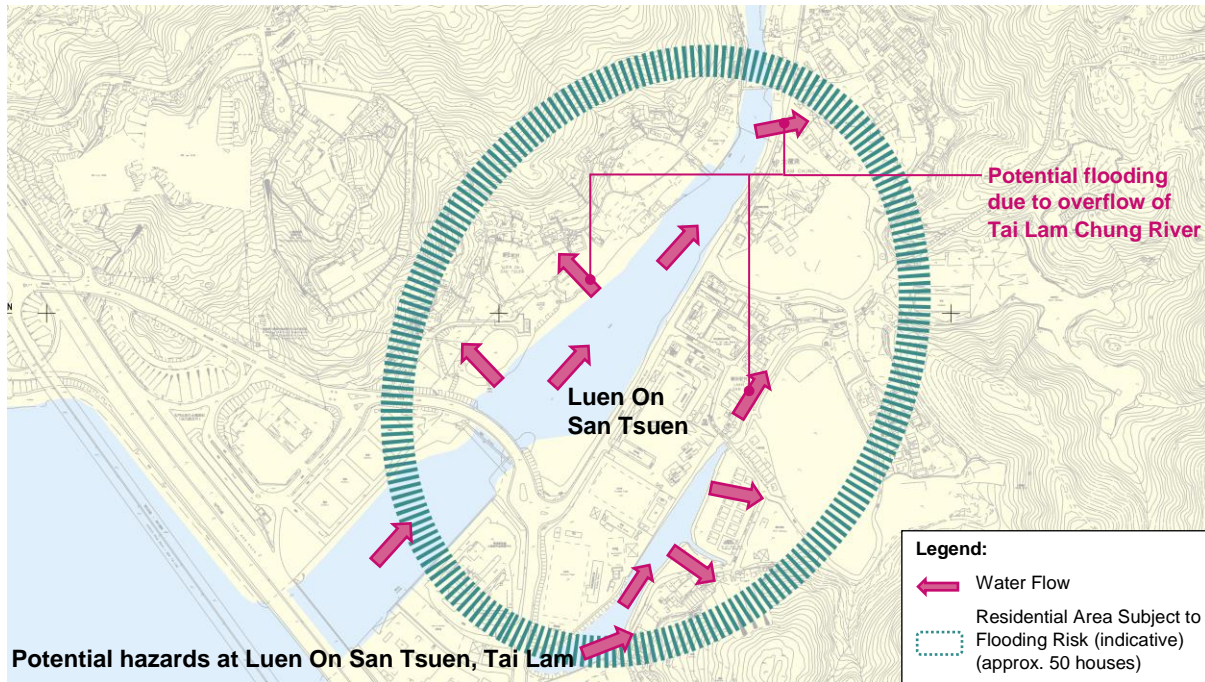
SITE DESCRIPTION

Luen On San Tsuen is located along Tai Lam Chung River. The site is a low-lying area and is potentially subjected to flooding caused by overflow of Tai Lam Chung River during typhoon events.

Over the past years, different types of management measures have been implemented to alleviate the impact of coastal hazards. This include establishment of emergency response team, early alert system and temporary shelter at Butterfly Bay Community Centre.

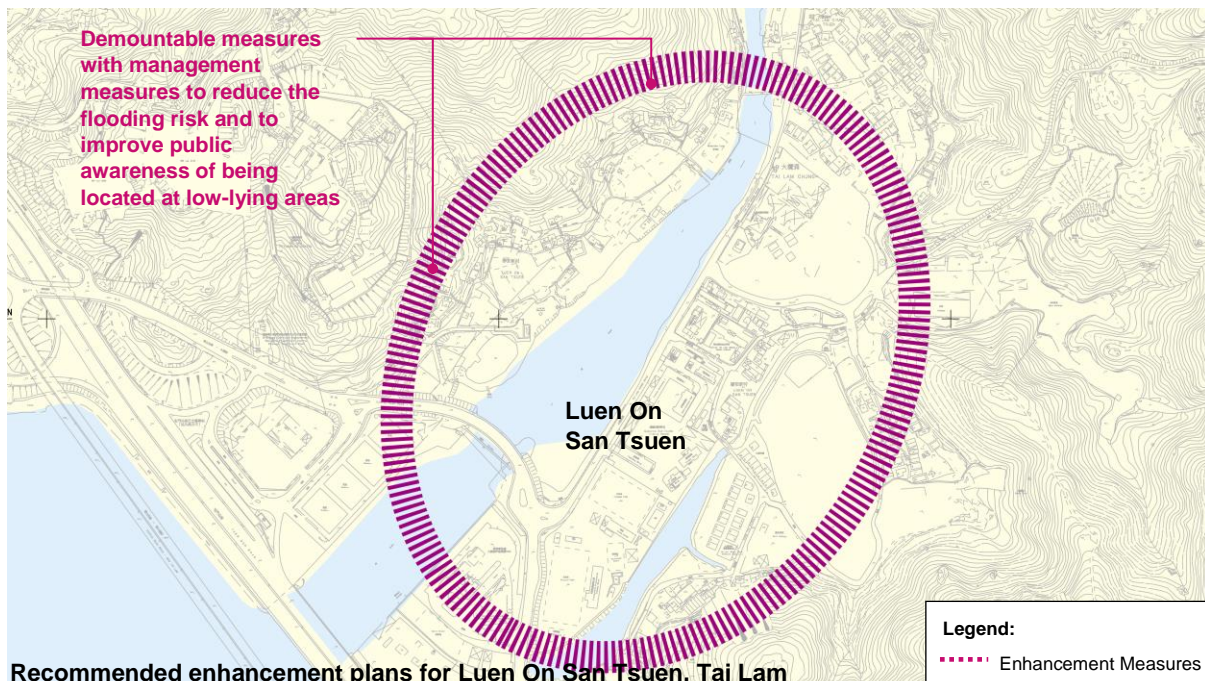
POTENTIAL COASTAL HAZARDS

Potential hazards at Luen On San Tsuen, Tai Lam with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: Existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

25. KAR WO LEI, TUEN MUN

SITE DESCRIPTION

Kar Wo Lei is located along So Kwun Wat River, Tuen Mun. The site is a low-lying area and was subject to flooding caused by overflow of So Kwun Wat River during past typhoon events. Specific observation around the site includes:

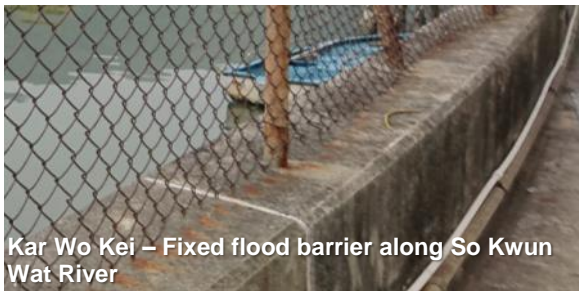


Kar Wo Kei – Flooding due to overflow of So Kwun Wat River

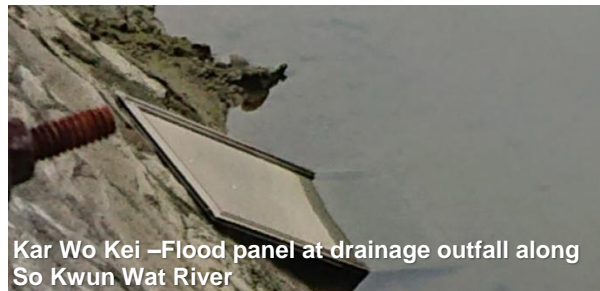


Kar Wo Kei – Flooding due to backflow of So Kwun Wat River through drainage outfall

Following the strike of Super Typhoons Hato (2017) and Mangkhut (2018), different types of improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



Kar Wo Kei – Fixed flood barrier along So Kwun Wat River

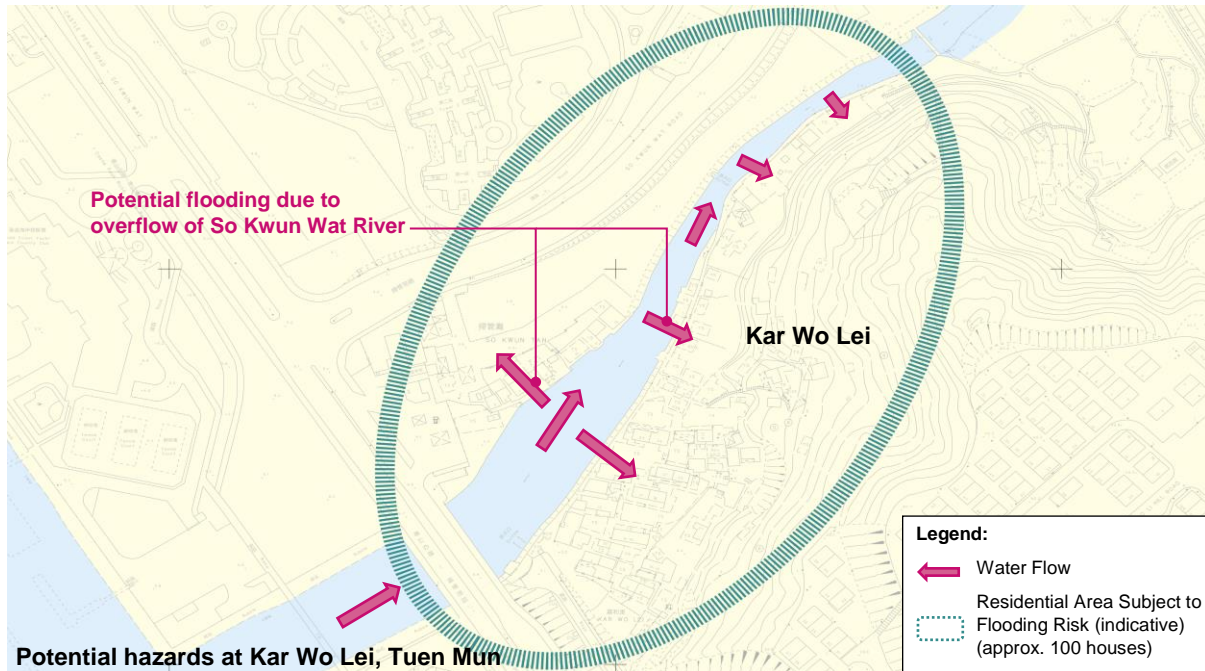


Kar Wo Kei – Flood panel at drainage outfall along So Kwun Wat River

Over the past years, different types of management measures have been implemented to alleviate the impact of coastal hazards. This include establishment of emergency response team and early alert system.

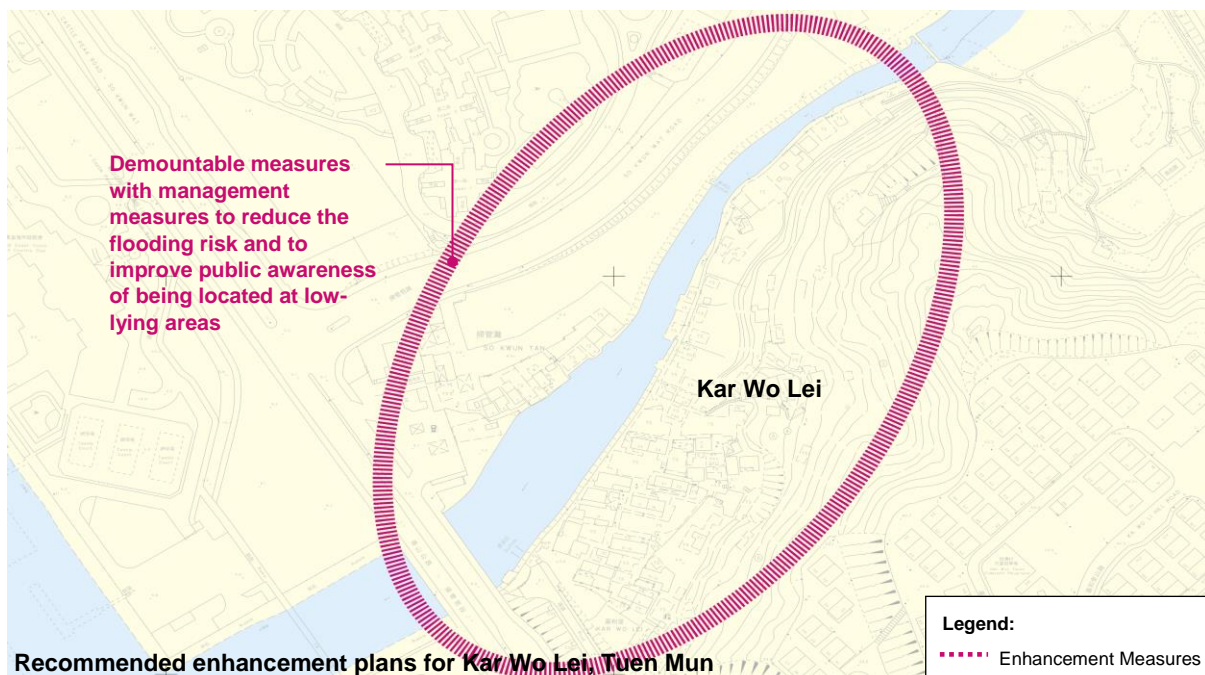
POTENTIAL COASTAL HAZARDS

Potential hazards at Kar Wo Lei, Tuen Mun with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: Existing action plan is implemented. It is recommended to maintain and keep in view regularly.
 Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.

26. SHAM TSENG SAN TSUEN

SITE DESCRIPTION

Sham Tseng San Tsuen is located along Sham Tseng River Channel. The site is a low-lying area and is potentially subject to flooding caused by overflow of Sham Tseng River Channel during typhoon events. Specific observations around / near the site includes:



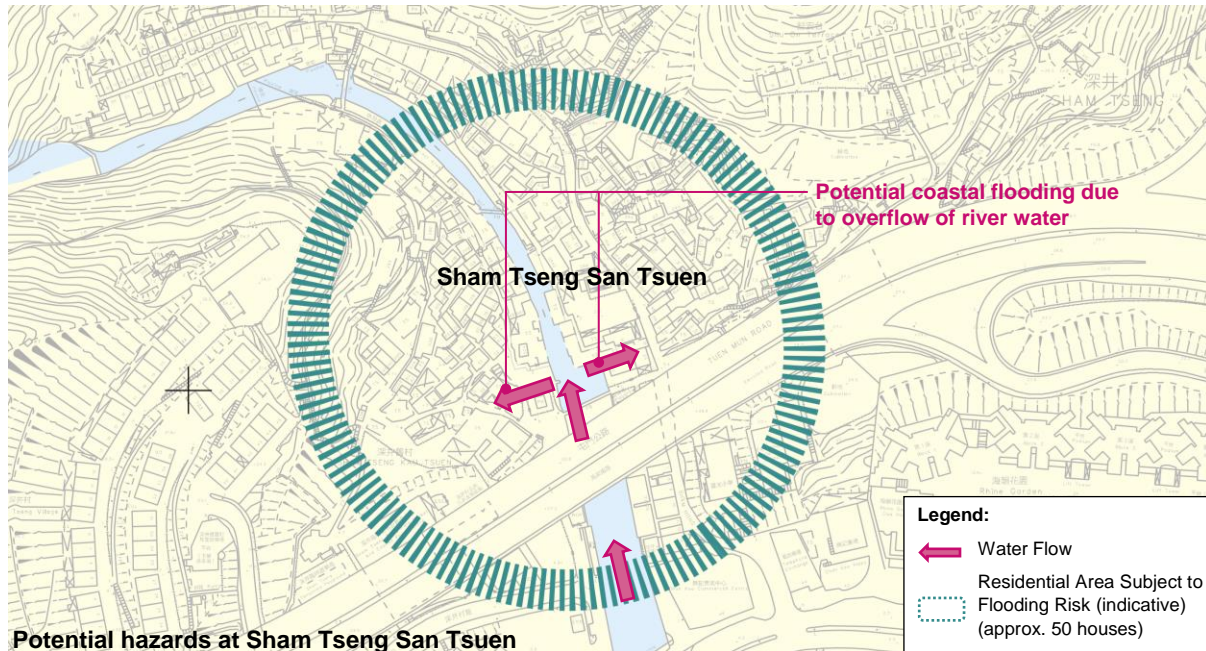
Over the past years, different types of improvement measures have been planned / implemented to alleviate the impact of coastal hazards. These measures include:



Over the past years, different types of management measures have been implemented to alleviate the impact of coastal hazards. This include establishment of emergency response team and early alert system.

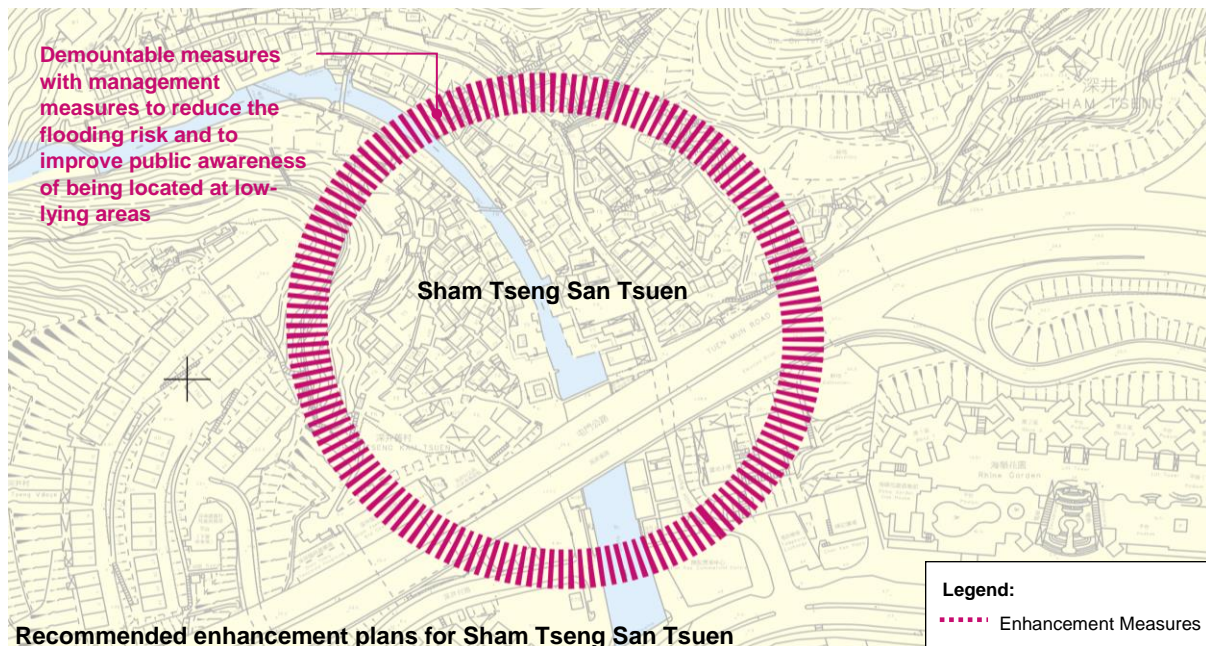
POTENTIAL COASTAL HAZARDS

Potential hazards at Sham Tseng San Tsuen with climate change projections to 2050 are identified as below:



RECOMMENDED ENHANCEMENT PLANS

Enhancement measure is recommended to mitigate the impacts of potential hazards and enhance resilience and preparedness of the coastal communities as shown below:



Remark: Existing action plan is implemented. It is recommended to maintain and keep in view regularly.

Note:

1. Extent of recommended enhancement measures are indicative only and details are subjected to detailed design.
2. Improvement of drainage system is recommended to be considered, if necessary, and further investigated separately.