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Flood Mitigation Approaches: Selected Cases Across Europe, Oceania and Asia

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Abstract: Flood is natural phenomenon that cannot be completely controlled by man. Flood is a global problem. Even urban areas which have good development planning and drainage systems are susceptible to floods. Flooding in urban area is usually associated with poor drainage system maintenance, failure to plan drainage system, area development is not planned properly, and climate change factors. Typically, engineering measures are meant to reduce severity of flood problems and they are quite costly. Goal of this paper is to assess the various mitigation approaches that have been used to mitigate floods across Europe, Oceania and Asia continents. Selected case studies involving the North Sea flood, as well as floods in the Netherlands, Scotland, New Zealand, Australia, Hong Kong, Taiwan, Singapore and Malaysia were considered. Approaches that were highlighted include construction of dam, breakwater, canal, and pumping system. It has also been found that flood solution methods by way of source control is not so popular to be fully practiced. Hence, the sustainability of good development is actually a solution to problem of flooding, especially to mitigate flash floods that often occur in an urban areas.

Keywords: Asia, Europe, flood, mitigation, urbanization

1. Introduction

Flood is defined as overflow of water from banks of drainage system that can cause destruction of property and loss of life. It affects psychological, financial and health (Raphael et al., 2000). Floodwaters that initially flow in subcritical state can overnight turn violent and cause great destruction. Scientists around the world have tried to find methods and solutions to overcome floodings. Urbanization process which has been continuing, unknowingly has changed natural nature of land and resulted in reduction in percentage of water infiltrating into soil. Planning, land reclamation control and more emphasis should be given to flood control at the source (Kundzewicz, 1999). It aims to ensure that all human activities will not burden the river's natural system.

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Floods can not only be overcome by implementing flood mitigation projects that require large amount of allocation. In fact, flooding can be reduced in its effects or overcome at an earlier stage, which is by implementing good natural resource management and planning development based on environmentally friendly concepts.

2. Flood Preventive Measures in Europe

Floodings also hit the European continent. In parts of Western Europe, floods occur in series. The Netherlands (Holland) is a country that will be severely affected if flooding occurs (Slager et al., 2021). Countries close to the Netherlands including Germany, Spain, Belgium and Portugal also face the same risks. Most of the floods that occur are in the form of "flash floods", occurring in a short time due to heavy rain and at the same time the sea water is full.

2.1 North Sea Flood of 1953

The flood occurred in early 1953 involving several countries, namely the Netherlands, the United Kingdom (England and Scotland), and Belgium. A total of 2,551 people have been killed and most devastated area is in the Netherlands followed by England, Belgium and Scotland. The flood also destroyed many properties including farms, buildings and livestock.

Aware that such catastrophes occur regularly and it causes devastating effects, countries in Europe especially the Netherlands and United Kingdom have carried out number of studies towards strengthening coastal defenses including against sea level rise attacks that can exacerbate floodings. In 1953, after the great flood of North Sea, the Netherlands has launched Delta Works (**Fig. 1**), a series of construction project to strengthen flood barrier banks in addition to building a system of dams and storm surge barriers, especially along the coast (d'Angremond, 2003). The United Kingdom also built overflow barriers along the Thames and Hull rivers. The Delta Works project aims to strengthen defence system against flood disasters which is also recognized by American Society of Civil Engineers as one of seven wonders of modern world. The project is expected to reduce risk of flooding in south Netherlands and Zeeland to once every 10,000 years (Kuster, 2008). As of today, these places have not been affected by the terrible floods such as in 1953. Success of the project has been proven. For example, at the end of 2015, floods have hit adjacent European countries with much property destruction, but the Netherlands has escaped it.

Fig. 1 - Delta Works consisted of storm surge barriers, dams, sluices and dykes close off streams of delta from the sea and keep the land safe from floods (Rietveld et al., 2017; Pilarczyk, 2006)

2.2 The Netherlands

The Netherlands is a country where almost a third of its area is located below sea level. Most of its residential areas are located in areas at risk of flooding. The country has introduced the polder system (**Fig. 2**, **Fig. 3** and **Fig. 4**) to prevent the threat of floods and high tides (de Jager, 2022; Rosenberg, 2020;). One of the earliest polders the Wieringermeer is created in 1927 (Waterman et al., 1998). Polders are land reclamations. Polders are tracts of land below sea level and are reclaimed from sea or wetlands through construction of dykes, drainage canals and pumping stations. Apart from flood mitigation measure, polders are also used for providing land for residential, commercial, industrial and military needs (Tang, 2019).

Fig. 2 shows the principle of polder systems. Hundreds of diesel-electric pumps (replacing 10,000 windmills used previously) are operating day and night keeping the country 'dry' (Waterman et al., 1998). Lowest level of the new land is 6.5 m below mean seal level. Besides pumping costs of more than 1.5 million USD annually, the Netherlands also managed to deal with land subsidence of reclaimed land due to compaction of layers of clay and peat.

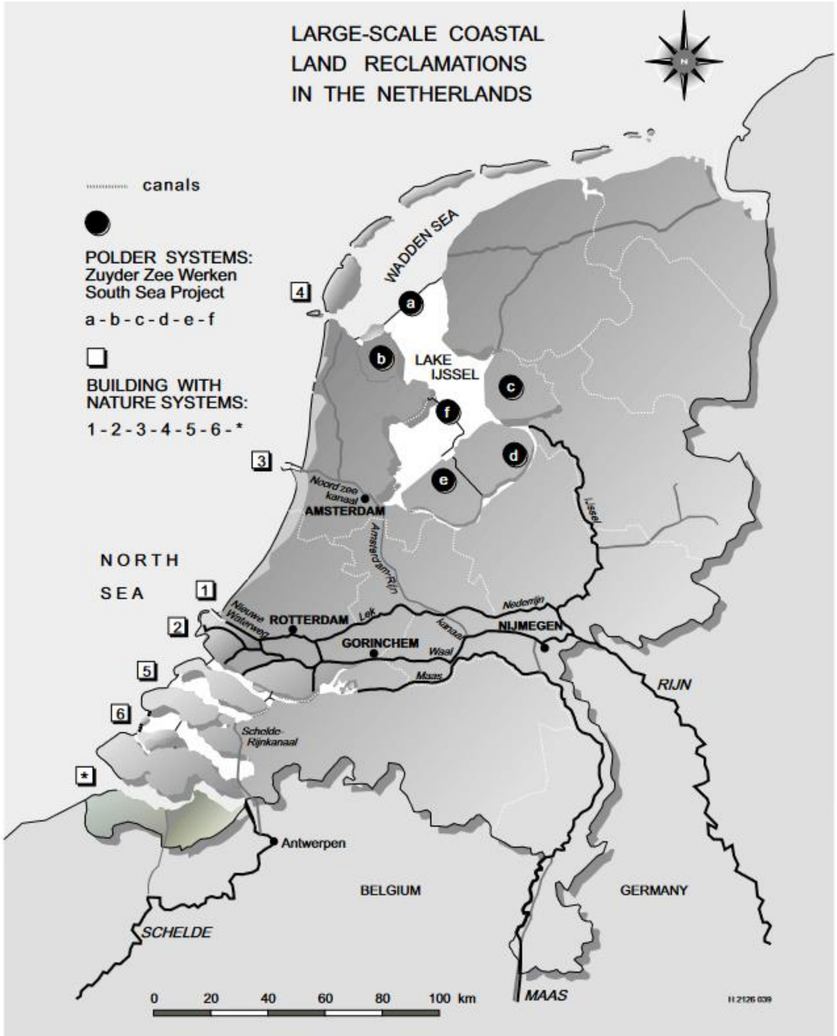

Fig. 2 - Map showing systems of The Netherlands floods protection. Polder systems are (a) Enclosure Dike; (b) Wieringmeer Polder; (c) North-East Polder; (d) East Flevoland Polder; (e) South Flevoland Polder; (f) Compartment Dike Lelystad-Enkhuizen. Building-with-nature systems (part of Delta Works) are (g) Plan 1. Scheveningen-Hoek van Holland; (h) Plan 2. Extension of Euro-Meuse Plain; (i) Plan 3. Seaport Marina Ijmuiden; (j) Shoal attachment to Texel; (k) Potential pumped storage basin; (l) Neeltje Jans Island; *-potential area for shoal development (Waterman, 1998)

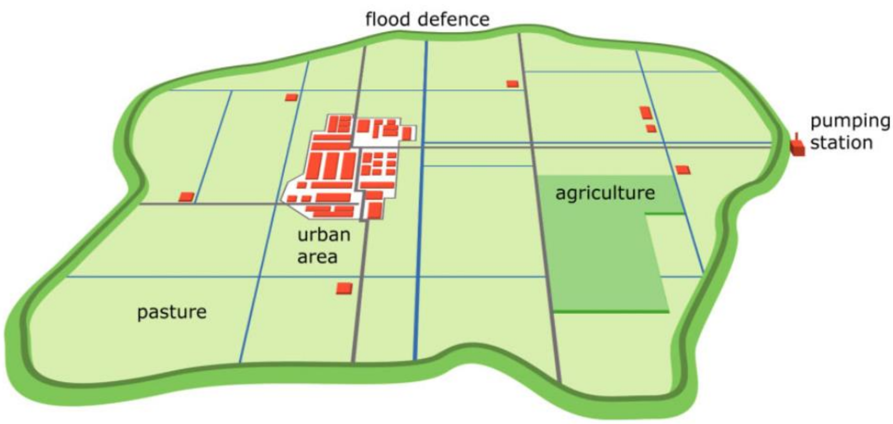

Fig. 3 - Schematic view of a polder system with pumping station that remove excess water and surrounding flood defence (Stijnen et al., 2014)

Fig. 4 - Polder landscape of Jisp village, north of the Netherlands (Steves, 2014)

There are three types of polders, i.e. land reclaimed from a body of water such as lake or seabed, flood plains separated from the sea or river by a dike, or marshes separated from surround water by a dike. Currently, about 50% of the overall land of the Netherlands is situated in polders, and always below mean sea level (de Jager, 2022).

2.3 Scotland

Scotland is a region in the union of Great Britain or the United Kingdom and its physical features consists of maritime. The region is also often the subject of news reports due to floods. Flooding in Scotland usually involves coastal areas and is caused by heavy rain, rising sea levels (tides) and strong winds. Major floods hit Scotland in late 2015 and lasted until early January 2016. It is said that its main river, Don river reached its highest level in 45 years (Philip et al., 2020). Scotland also faced devastating floods in 2009 (ICE Scotland, 2020). Although not as frequent as in Malaysia, Scotland has taken series of immediate preventive measures to avoid further flooding issues. In 2018, Scotland has carried out works on development of Glasglow's Smart Canal which has been completed in 2020.

Smart Canal uses advanced computer modelling to mitigate risk of flooding (**Fig. 5**) (Hardy, 2021). The model forecast rainfall data received from meteorology office on a three hourly feed and it is connected to SCADA network data that provides information about status of the canal including canal levels and expected runoff into the canal. Based on rainfall forecast and canal status, decision will be made whether to activate sluice gates, and preemptively lowers the canal in anticipation of receiving surface water (**Fig. 6**). At the end of any rainfall event, the canal will return to its normal operating level.

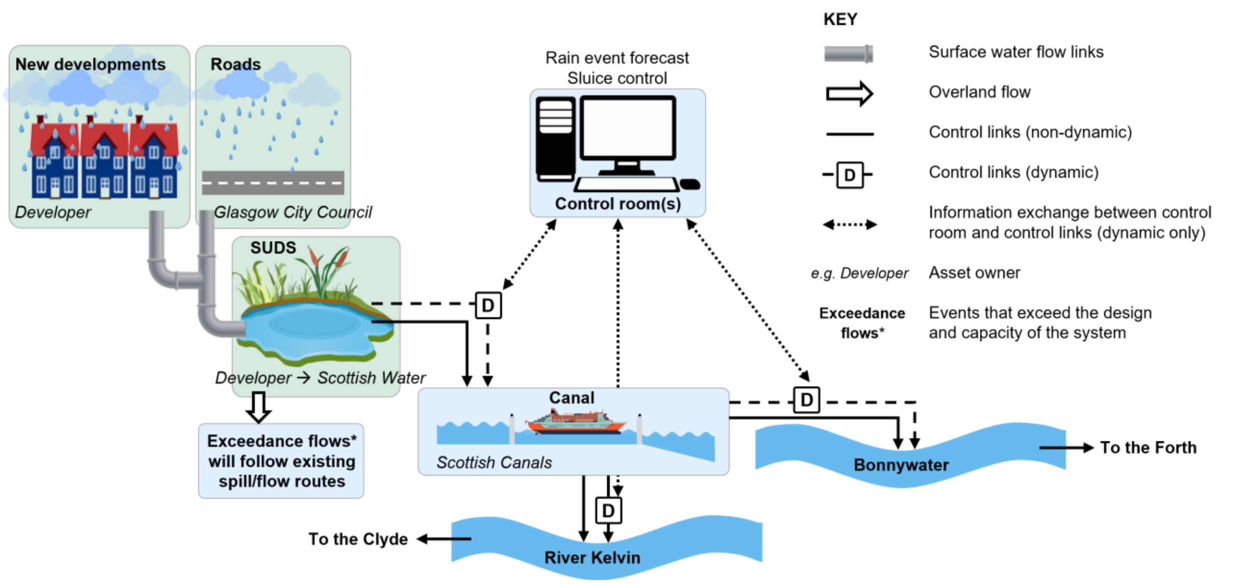

Fig. 5 - Glasgow's Smart Canal also dubbed as 'sponge city' has created 55,000 m^3 of storage for floodwater (Fairfield Control Systems Ltd, 2022)

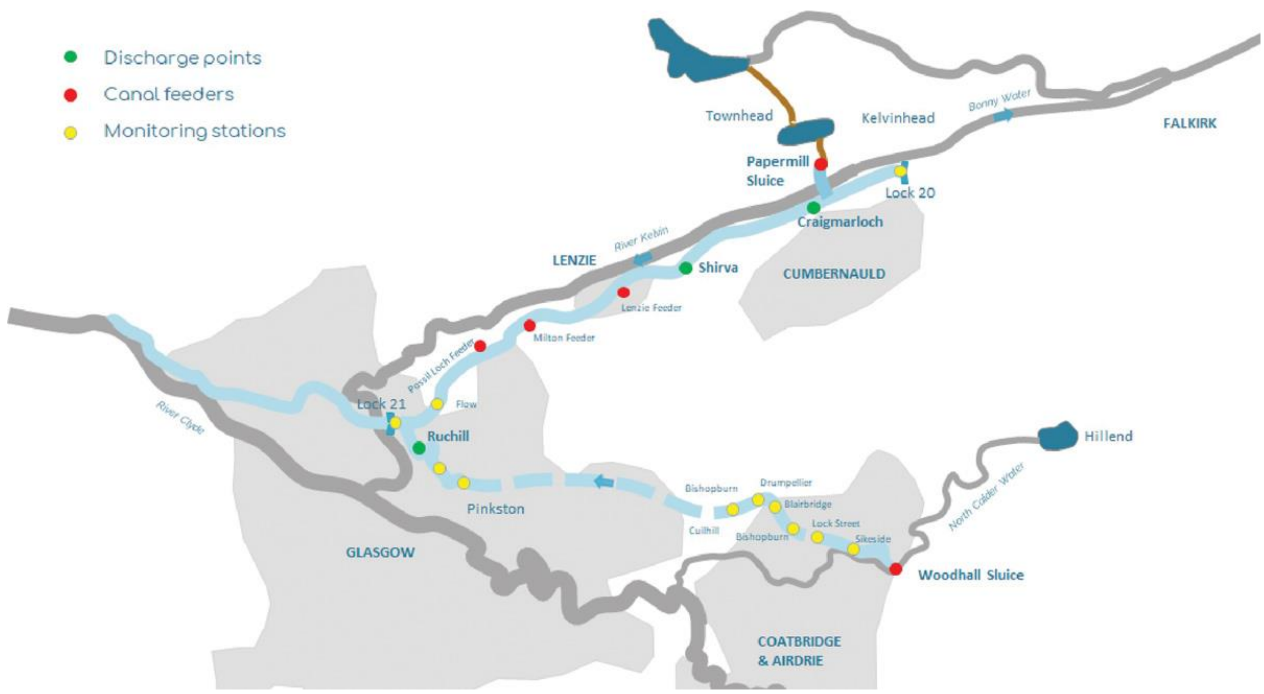

Fig. 6 - Schematic of Glasgow's Smart Canal infrastructure. During normal operation, default positions of discharge sluices are closed and feeder sluices are open (Hay-Smith, 2022)

Smart Canal has created 55,000 m^3 (equivalent of 22 Olympic-sized swimming pools) of extra capacity for floodwater (Hardy, 2021). In 2021, this system has been awarded as the "Greatest Contribution to Scotland" by Institution of Civil Engineers (ICE) Scotland and Civil Engineering Contractors Association (CECA) Scotland.

Understanding the needs to address this disaster, Scotland has also created several bodies of thought and implementation in managing this problem. Among them is periodic assessment for flood risk i.e. the National Flood Risk Assessment (SEPA, 2022). Flood management in Scotland leads to the establishment of institutions related to water management such as the Center of Expertise of Waters (CREW) (Ferrier et al., 2021). Such bodies will continue to carry out studies and the findings will be recommended to authorities for action. Following the actions and measures being taken, Scotland is expected to be able to survive risk of devastating floods that often hit coastal areas in future.

3. Flood Preventive Measures in Oceania

Oceania countries located between Eastern and Western hemispheres are island countries, which include Australia, New Zealand and Pacific Islands. Like other countries in the world, these countries are not immune to the threat of floods.

3.1 New Zealand

New Zealand recognizes that floods are the biggest disaster that has to be faced both in terms of frequency, ongoing losses and also National Emergency Management Agency. New Zealand not only suffers from floods, but the country also faces the problem of earthquake disasters. Two-thirds of New Zealand's population lives in flood-prone areas (Mason et al., 2019). New Zealand has been hit by series of floods almost annually (Reid et al., 2021). These floods have caused release of the statement that "New Zealand can be exposed to a flood disaster at any time". Between 1968 and 2017, New Zealand experienced over 80 damaging floods. From 1976 to 2004, the Insurance Council estimated that the payment of claims for losses due to floods was as much as NZ$17 million per year (McSaveney, 2017).

In 2016 alone, series of floods have hit New Zealand in various districts. According to news reports, in January, Northland, Auckland and Coromandel are flooded (Otago Daily Times, 2016), in mid-February, Nelson city and the Tasman district received floods (Davies, 2016a), at the end of March 2016, west coast of South Island has been hit by flood disaster (Davies, 2016b), and in mid-April 2016, floods hit Coromandel Peninsula (NZ Herald, 2016). Otago Times Daily (2016) has reported different parts of New Zealand being flooded throughout January-December 2016. This means that almost every month in 2016 alone, New Zealand is subjected to risk of floods. Projected future extreme weather have further made New Zealand as one of the countries that need to develop their own methods and strategies to deal with floods. In order to find a solution, New Zealand authorities have conducted various studies related to floods including causes and reasons for occurrence of floods. Most floods occur due to prolonged heavy rains that hit particular areas. In addition to that, human activities also further worsen floods impact. Deforestation leads to rapid runoff and increased groundwater levels.

According to Tonkin & Taylor Ltd (2018), New Zealand flood protection and land drainage schemes which deal with management of rainfall runoff within catchment can be broadly classified into four scheme types based on nature of benefit, which are:

a. Land drainage - getting water off the land into a stream or river
b. Flood protection - keeping water in the river and off land
c. River management - keeping the river where it is
d. Tidal inundation - keeping sea water off land.

Fig. 7 shows a representation of New Zealand flood protection and land drainage schemes.

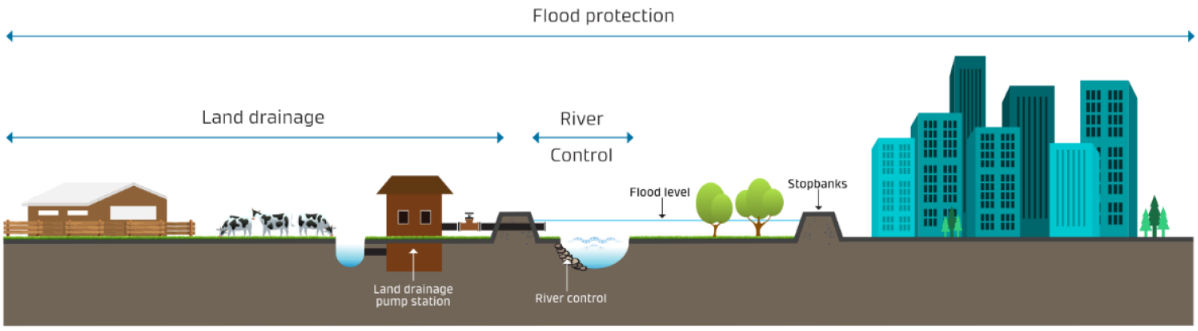

Fig. 7 - Schematic representation of flood protection, river control and land drainage services in New Zealand (Tonkin & Taylor Ltd, 2018)

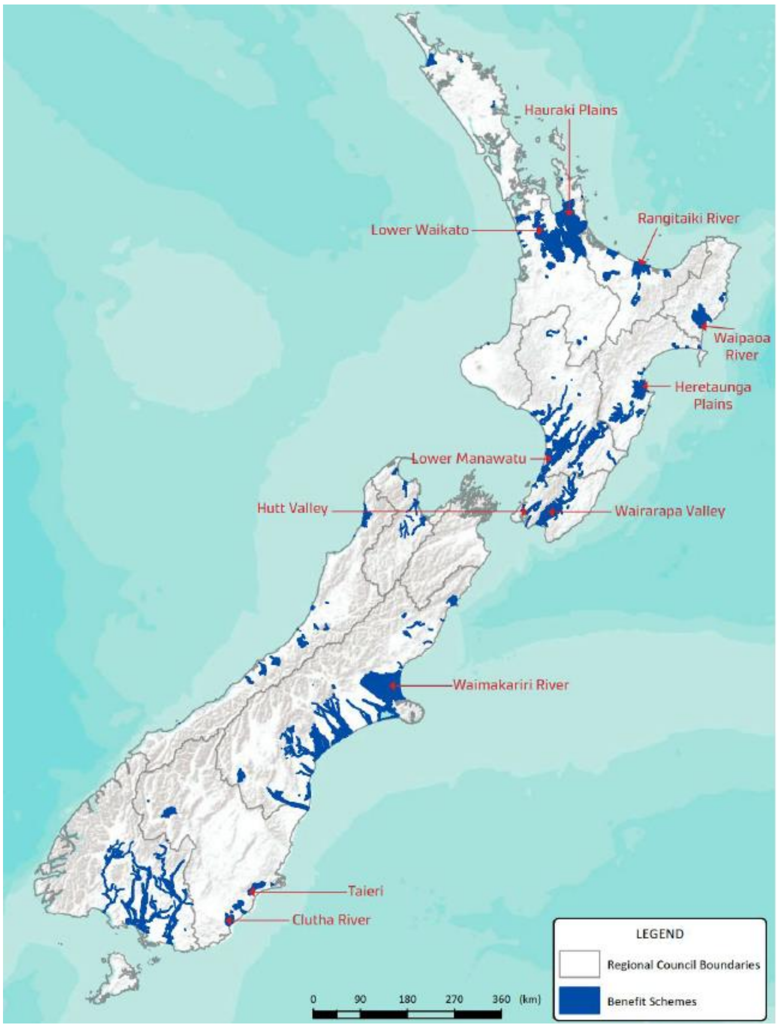

Fig. 8 - Areas shaded in blue are areas benefited from river control, flood protection and land drainage schemes (Tonkin & Taylor Ltd, 2018)

There are more than 364 river control, flood protection and land drainage schemes across New Zealand (Tonkin & Taylor Ltd, 2018). These schemes have provided direct benefit to more than 1.5 million hectares of land (approximately 5.6% of New Zealand land area) (**Fig. 8**). Nevertheless, some schemes may need to be maintained, upgraded or may even need to be downgraded throughout time in order to achieve desired level of service.

New Zealand authorities have introduced flood control laws and controlled condition of all rivers, especially large rivers that cause flooding problems. Among the river control methods made are lowering the river bed by removing rocks; straighten the drainage; removing obstructions to water flow; changing the direction of water flow; building sluice; and building dam.

3.2 Australia

Australia is an island country in Oceania that is often exposed to coastal, fluvial and pluvial flooding, particularly in urban areas (The Geneva Association, 2020). Coastal areas, especially the eastern and southern parts, are exposed to floods at any time, especially during heavy rainfall (Queensland Government, 2011). Floods could also be caused by water management operations such as dam releases.

For example, on 13 January 2011, major flooding occurred in most of Brisbane river catchment area (van den Honert & McAneney, 2011). Toowoomba and Lockyer creek, Bremer river, and Brisbane are the worst affected areas. Insurance claims have been made by 56,200 people with a total payment of A$ 2.55 billion. Wivenhoe dam said to be the cause of destruction downstream was actually built in response to the worst flood problem in 1974 and it is now the main source of water supply in Brisbane (van den Honert & McAneney, 2011). The event has led to establishment of a board of inquiry. In report issued by investigating board, it was found that the incident was not caused by dam workers' mistakes nor was it caused by design error. Excess water released by engineer on duty was in accordance with standard of procedure, because water had exceeded the permissible level. It was the excess water released that caused the major flood along Brisbane river that year (van den Honert & McAneney, 2011).

Relevant authorities and agencies have prepared various protocols as an effort to prevent and prepare for floods. What is interesting about the efforts made is that it includes the preparation of various reference documents, legislation and the implementation of structural efforts that are made diligently and comply with standard operating procedures. One of the documents that serves as a guideline for preparing for floods is the Floodplain Management In Australia: Best Practice Principles and Guidelines (ARMCANZ, 2000). Floodplain management measures highlighted in the guidelines are:

a. Structural flood mitigation works such as levees or channel improvements, which are aimed at modifying flood behaviour (i.e. keeping water away from people)
b. Land use planning controls such as zoning (**Fig. 9**), which are aimed at ensuring that land use is compatible with flood risk (i.e. keeping people away from the water)
c. Development and building controls such as minimum flood levels and floodproofing, are aimed at reducing the risk of inundation and amount of damage that occurs when such a flood eventuates (i.e. the water will get to people at some time)
d. Flood emergency measures such as flood warning, evacuation and recovery plans, are aimed at reducing flood hazard by modifying the response of the population at risk so that they will be able to better handle actual flood events (i.e. teaching people what to do).

These management measures can be integrated or mixed based on the needs of flood problem area.

Fig. 9 - Critical public infrastructure such as hospitals and emergency management centres are ideally located outside the influence of Probable Maximum Flood (PMF). Note that a 10% flood is 1 in 10-year flood and 1% flood is a 1in 100-year flood (Queensland Government, 2011)

As well as structural measures, authorities have invested high cost to build dams and to straighten and deepen main rivers that are prone to flooding. For instance, after the 1974 Queensland flood, the state government has built the Wivenhoe dam (Cook, 2017). Brisbane has not been flooded since then. However, after more than 30 years later, Queensland was once again hit by a large and severe flood. Similar to other parts of the world, floods that occur in Australia are also caused by continuous heavy rains that generate runoff which exceeded capacity of existing rivers and drainage system. It needs to be highlighted that flood mitigation method applied at one site may not be effective at another location eventhough they have same similar climatic and geographical characteristics.

4. Flood Mitigation Measures in Asia

4.1 Hong Kong

Hong Kong is located in the Pacific tropical cyclones region which experiences heavy rainfall with an annual depth of 2,399 mm (Chen et al., 2021; Ho, 2018; DSD, 2019). Its low-lying areas act as natural floodwater reservoir and some of old townships often encounter flash flood problems when heavy rain hit (DSD, 2019). Flooding problems encountered by Hong Kong today is due to rapid development of the city since 1980s. Proactive management in terms of technical requirements for short- and long-term mitigation has successfully minimize severity of floods impact over the last few years.

DSD (2019) reported measures taken by Hong Kong government in dealing with problems of flooding in the country. Main features of the measures are:

a. Develop Flood Protection Standards by adopting standards of other major cities in the world and adapting them with Hong Kong conditions in construction of new drainage system and maintaining exisiting drainage system;
b. Carry out comprehensive studies to identify the need for new drainage system works and to improve existing drainage system;
c. Implement identified new works and improvement works in increasing drainage capacity in accordance with the requirements of Flood Protection Standards;

d. Set-up of Drainage Authority under Land Drainage Ordinance which has legal authority to protect waterways especially in private areas;
e. Addressing drainage impacts brought by new developments; and
f. Carry out comprehensive drainage system maintenance works to ensure their proper functioning.

Flood control and protection strategies implemented in Hong Kong has been effective and successful with the use of Flood Protection Standards. The established standards has provided guidelines for effective flood mitigation management by inclusion of prevention strategies that helps in planning and design of drainage system that caters for heavy rainfall. The Hong Kong Government has adopted the following long-term improvement strategies that involve major capital works (DSD, 2019):

a. Expansion and improvement on existing drainage system to facilitate collection of higher surface runoff – successfully implemented for north New Territories, low-lying village;
b. River training works including straightening, widening (**Fig. 10**), deepening and provision of linings, for effective discharge of storm flow especially under extreme events – have significantly reduced flood risk at Shenzen river, Ng Tung river, Sheung Yue river, Shan Pui river, Kam Tin river and Pang Yuen river;

Fig. 10 - Widened Shenzen river at Liu Pok (Shenzen Govt., 2022)

c. Tunneling works (**Fig. 11**) for interception and diversion of storm flow from upland catchment to be discharged into sea, as to reduce loading into downstream drainage system. Currently, there are 4 drainage tunnels operating i.e. Kai Tak transfer scheme, Hong Kong west drainage tunnel, Lai Chi Kok drainage tunnel and Tsuen Wan drainage tunnel;

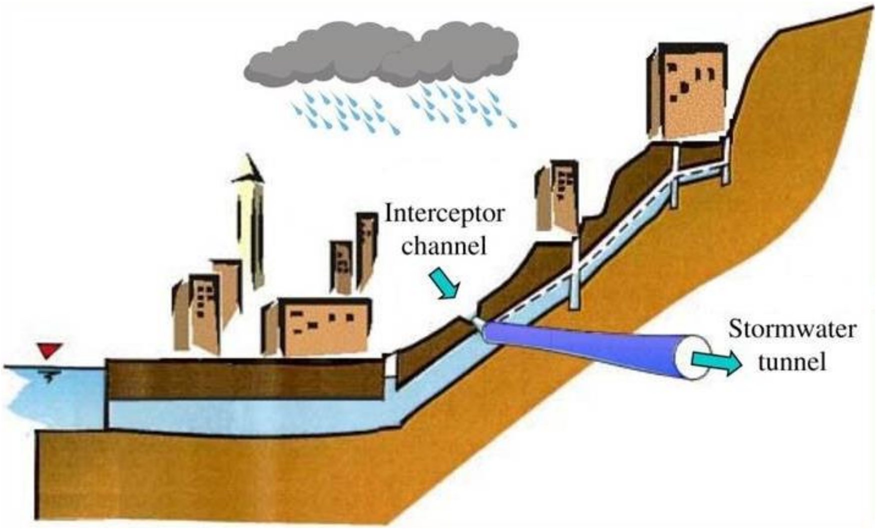

Fig. 11 - Conceptual diagram of stormwater diversion by drainage tunnel (DSD, 2019)

d. Stormwater storage facilities to temporarily retain storm flow from upland catchment in order to attenuate peak runoff loading on downstream drainage system. The Tai Hang Tung stormwater storage scheme (**Fig. 12**) and Happy Valley underground stormwater storage scheme were constructed to adress flood threats in Mong Kok and low-lying area of Happy Valley and Wan Chai. Meanwhile, a tide gate were constructed to prevent tidal back flow, and underground stormwater storage tank and pumping station at Chung Kong road, Sheung Wan; were constructed to provide new drainage path for stormwater from Wing Lok street.

(i) (ii)

Fig. 12 - (a) Layout of Tai Hang Tung stormwater storage tank and; (b) inside view of Tai Hang Tung stormwater storage tank (DSD, 2019)

e. Stormwater pumping scheme to pump and discharge storm flow at flood prone areas directly to sea;
f. Village flood protection scheme consisting of protective bund to stop storm flow from entering into low-lying village and a stormwater pumping station to pump away storm flow collected within the village (**Fig. 13**).

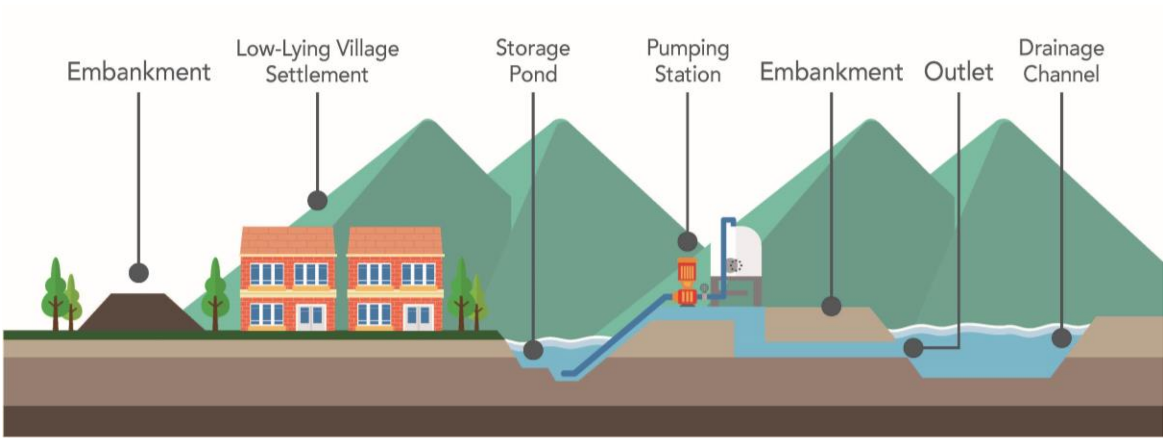

Fig. 13 - Illustration of village flood protection scheme (DSD, 2019)

4.2 Taiwan

Taiwan is a country located in the sub-tropical zone with high temperatures and frequent rainfall. Taiwan experiences torrential rains up to 2,500 mm per year and in inland areas up to 3,000 - 5,000 mm (Teng et al., 2006). Typhoon winds often bring heavy rains that hit the country between June and August every year. Heavy rain can reach up to 214.8 mm in one hour (recorded in Penghu, Taiwan) (Mack, 2021).

Apart from being caused by heavy rains brought by typhoons, floods that occur in Taiwan are also caused by steep and uncontrollable conditions of river and instability of land that can collapse and other surface structures.

To overcome this gproblem, Taiwanese Government has implemented several measures including structural and non-structural methods. The structural measures approaches of long-term flood mitigation measures are (Hsieh et al., 2006):

a. High-level protection levees and pumping stations - effective in protecting urban areas against river flooding. Construction of levees along Keelung river has the capability to contain 200-year rainfall. Meanwhile, pumping stations are designed to account for 70% of peak discharges under 5-year rainfalls.

b. Diversion channel – flood discharge of main stream is reduced through a diversion channel. Yuan-Shan-Zih next to Jui-Fang town is the starting point of diversion channel to the East Sea (**Fig. 14**). Inlet weir will divert flood water into diversion channel when mainstream discharge exceed 90 m^3/s. Maximum capacity of diversion channel is 1000 m^3/s.

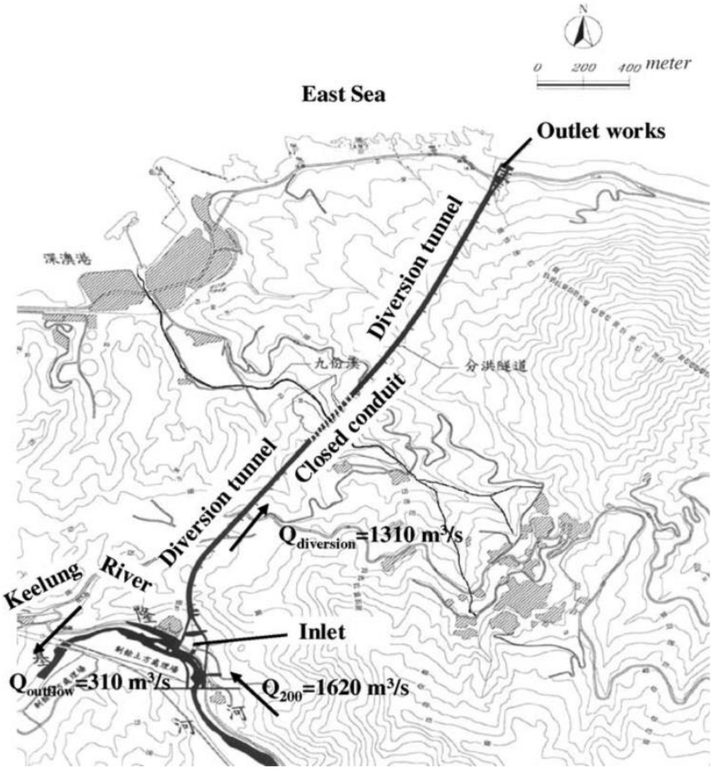

Fig. 14 - Yuan-Shan-Zih diversion into East Sea (Hsieh et al., 2006)

c. Detention reservoir – construction of a detention reservoir upstream can help solve flooding and water resources problems. In Taiwan, a reservoir with catchment area of 76 km^2 has been built in San-Diao-Ling. Its effective storage capacity is 19.05 million m^3 with dam height of 55 m. Maximum outflow is 100 m^3/s.

Hsieh et al. (2006) have also conducted priority evaluation against the structural measures. Non-structural flood mitigation measures implemented in Taiwan (Hsu & Gourbesville, 2022) are:

a. Risk maps and flooding maps – generated to be use for crisis management, which are published online for public access.
b. Warning and alert systems – official typhoon warnings were issued just 18 hours before typhoon radii were expected to hit on land.
c. Suspension and evaluation – before typhoon was to hit, city government will appeal to people to stay home and called off schools and works.
d. Traffic and deployment – portable pumps and rescue equipment were deployed at high-risk areas, and sandbangs and water gates were prepared before heavy rain at high flood potential areas and at every entrance of metro stations, according to risk maps and flood maps. Vehicles in high-risk areas will be moved, and public transport will either be cancelled or make a detour.
e. Telecommunication – in order to maintain communication, 5 network hosts were designed for administration. Other than radio, television and press media, government also utilised social messaging application and short message service cell broadcast to people within high-risk areas.
f. Power and water supply – Residents were asked to store water for possible water cut-off due to turbidity. Residents were also warned about power supply cut-off and they can use generators before restoration.
g. Volunteers, education and awareness – Volunteer and soldiers will be helping out in clearing, cleaning, providing and distributing materials, restoring and bringing relief to victims. In Taipei, before typhoons, people will be taught to clean trenches and inlets of sewer systems, deploy floodgates and sandbags against flood, and prepare food and water in case of cut-off.

4.3 Singapore

Singapore is an island country located south of Peninsular Malaysia. Singapore experiences rainfalls throughout the year. Floods are also a constant problem for Singapore.

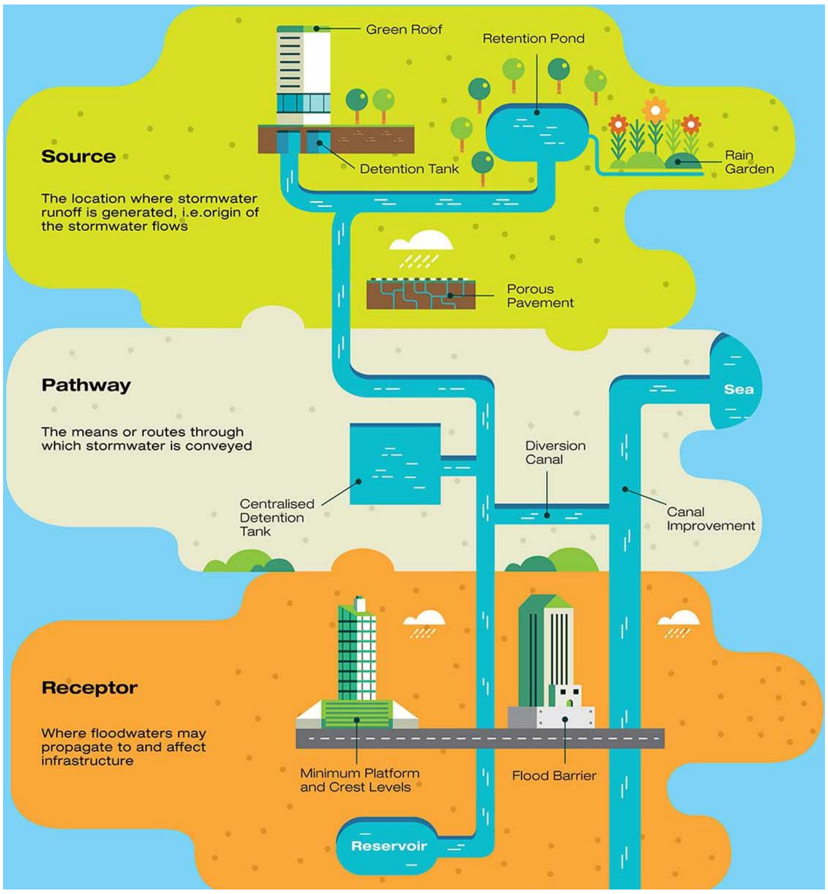

Fig. 15 - Source-pathway-receptor approach (NCCS, 2022)

In 2010, Singapore was hit by a series of flood disasters and the incident continued to haunt the country until 2016. Six flash floods have hit Singapore in 2010, nine times in 2011, eight times in 2012 and nine times in 2013. This has given the impression that Singapore is a flooded country. All the floods that occur have been caused by heavy rains. Flash flood occurrences in Singapore is still lingering to this day. In December 2015, heavy rains hit the island nation resulting in a series of flash floods (December 5 and 11, 2015). Likewise in February 2016, flash floods still haunt Singapore.

Among the big long-term steps taken by the authorities, the Public Utility Board, Singapore (PUB) is to build a tunnel that diverts water from the Orchard Road area to a water reservoir located underground. It is expected that this plan will reduce 30% of the water in the overflow, one of the big projects in addition to the current measures that have been implemented in Singapore (**Fig. 15**).

In a flood study report in Singapore, it was stated that PUB has managed the flood problem well for the past 40 years. However, the trend of increasing rainfall has caused a series of floods, for example the construction of the Stamford Canal has reduced many flooding problems for a long time, but the amount of rainfall lately (expected to continue to increase), this drainage is no longer able to cope with it. The report puts the problem of flooding on Singapore's rapid urbanization process at some point.

4.4 Malaysia

Malaysia is located on the Equator which is exposed to monsoon winds as well as hot and rainy conditions throughout the year making many locations in Malaysia vulnerable to flooding. The peninsula is exposed to monsoon winds from October to April, causing a lot of water content brought from South China Sea to be ready to become heavy rain in mountain ranges that are in upstream areas which then overflow the river and flow back to downstream areas towards South China sea.

In addition to that, coastal areas also receives rain as a result of the evaporation process of hot weather. Sabah and Sarawak are also affected by the same north-east monsoon winds, even added by south-west and north winds. Annual floods are common in Malaysia (D'iya et al., 2014). Therefore floods due to geographical position is a common flood that is experienced every year. Abundant presence of water in that season was adapted to the topography and corresponding drainage was available.

The pace of development and urbanization as well as rapid population growth has increased amount of impervious area which indirectly increases the amount of runoff that flows into drainage and drainage systems, making areas that has never flood prone to be flooding. In 2007, the Stormwater Management and Road Tunnel (SMART) started its operation in solving both traffic congestion and floods problem. The SMART tunnel has been recognised internationally, and has won the British Construction Industry Award (BCIA) for Best International Project and named one of the Most Innovative Projects in the world in a 2015 United Nations (UN) publication (MMC Gamuda, 2015).

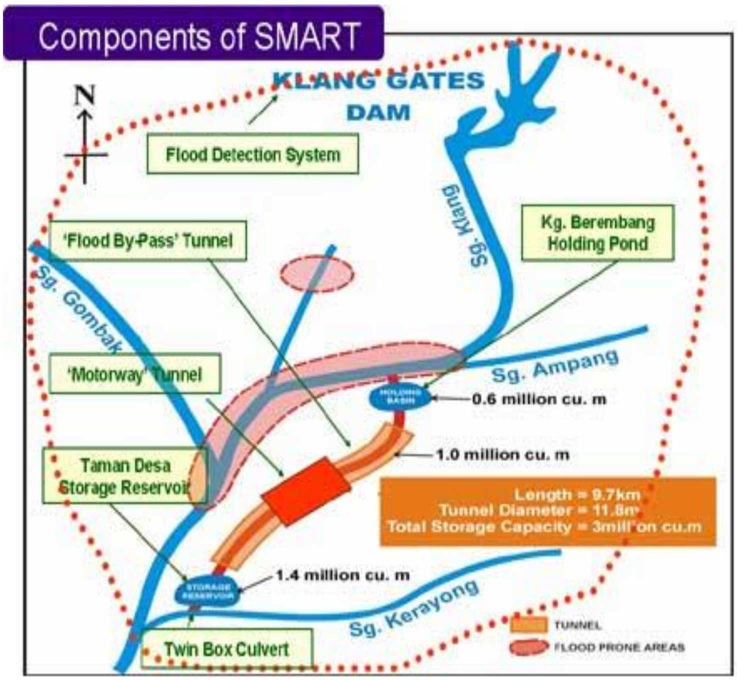

Fig. 16 - Stormwater Management and Road Tunnel (SMART) project to mitigate flood problem of Kuala Lumpur (DID, 2017)

4.4.1 Practicality of Urban Stormwater Management Manual for Malaysia (MSMA)

The environmentally-friendly Urban Stormwater Management Manual for Malaysia or simply known as MSMA has been introduced and practiced throughout the country beginning January 01, 2001 (DID, 2012).

This water management method is the latest one introduced by the government where it emphasizes surface runoff management, control at the source by means of storage (detention/ retention) using tanks or reservoirs, infiltration/absorption (infiltration) in the soil and cleaning (purification) using biotechnology. MSMA is a measure and method that has been implemented especially for new development as a control measure at the source to overcome the problem of flash floods in Malaysia.

5. Conclusions

Flood mitigation measures implemented in Europe, Oceania, and Asia countries can be summarized as in **Table 1**.

Table 1 - Structural and non-structural flood mitigation measures implemented in countries in Europe, Oceania and Asia

Continent	Country	Flood Mitigation Approach
Europe	Northern and Western European countries	**Delta Works** – construction begun in 1958 and completed in 1997. It consists of a system of 3,700 km primary and 14,000 km secondary flood defences (dams, dykes, levees, storm surge barriers, locks and sluices, **Fig. 1**) constructed along the coast, close off streams of delta from the sea. Protects 34,000 km^2 of the Netherlands' land surface against 250-year to 10,000-year floodings depending on coastal regions (Poelman, 2022; van Alphen, 2014).

	The Netherlands	**Polders** – large land-and-water areas completely surrounded by dikes (**Fig. 2**). Remarkable shift in landuse created by youngest polder started in 1930s. Ground elevation of the land is situated below mean sea level and water table within the polder is controlled. Protects about 17,000 km^2 (50%) of the Netherlands'. The system is expected to reduce risk of flooding in south Netherlands and Zeeland to once every 10,000 years (de Jager, 2022; Kuster, 2008).
	Scotland	**Glasgow's Smart Canal** - construction started in May 2018 and completed in 2020. Meteorological forecasting data and sensors give advanced warning of rainfall and controls water level in the Forth & Clyde canal (**Fig. 5**). The system is able to provide 55,000 m^3 of storage for runoff from residential and business areas. The canal system also unlocks 1.1 km^2 across north of Glasgow for investment, regeneration, and development (Greig & Rathjen, 2021). The system paves way for more than 3,000 new homes to be built, while avoiding over 30,000 tonnes of operational CO_2 (Hay-Smith, 2022).
Oceania	New Zealand	**River control, flood protection and land drainage schemes** - consisted of 364 infrastructure schemes that provide benefit to 15,000 km^2 of land. The schemes include flood detention/ storage dams, stopbanks, pump stations, floodgates, floodways, plantings, wetlands. Use of stopbanks has been reportedly unable to withstand extreme events and need upgrading over the time (Hutchings et al., 2019). These schemes provide flood protection against 5-year to 100-year event (Tonkin & Taylor Ltd, 2018) has been developed over the last 100 years (Hutchings et al., 2019) and is continually upgraded.
	Australia	**Structural flood mitigation works, land use planning controls, development and building controls, and flood emergency measures** - an integrated or appropriate mix of these flood management measures based on site specifics are recommended in Australia (ARMCANZ, 2000). Zonings (restricting location of development) can reduce risk of flooding for new development areas. For existing developed areas, structural (e.g. flood mitigation dam, levees, waterway or floodplain modifications) and property-modification (land filling, flood proofing, house raising, removal of development) measures are options to manage floods (Queensland Government, 2011).
Asia	Hong Kong	**Legislation of drainage system management, expansion of existing drainage system, river training works, tunneling works, stormwater storage facilities, stormwater pumping scheme, village protection schemes** implemented have been shown to be successfully reduce flood-risk in Hong Kong (DSD, 2019). Between 1994 and 2010, Hong Kong Drainage Services Department has completed Drainage Master Plan studies for 11 catchment areas and since 2008, Drainage Master Plan Review studies have been carried out for 12 catchment areas.
	Taiwan	Government of Taiwan has implemented structural and non-structural flood mitigation measures to reduce risk of flooding. Structural measures include **levees** (protection up to 200-year rainfall), **pumping stations** (up to 5-year rainfall), **diversion channel**, and **detention reservoir** (Hsieh et al., 2006). Non-structural flood mitigation measures are **risk- and flood-maps**, **warning and alert systems**, suspension and evacuation, traffic and deployment, power and water supply, volunteers, and education and awareness (Hsu & Gourbesville, 2022).
	Singapore	Singapore has implemented the **Source-Pathway-Receptor** approach to reduce flood risk (**Fig. 15**). Among the flood mitigation measures are **on-site detention** (at the source where stormwater runoff is generated), **widening and deepening of drains and canals** (carried out along the pathway), and through **platform levels, crest protection and flood barriers** (at the receptor where floods may occur) (NCCS, 2022). Besides that, since 2014, developers are required to implement on-site measures such as detention tanks, green roof, rain gardens or retention ponds.
	Malaysia	Structural and non-structural flood mitigation measures implemented in Malaysia are **flood control dams, canalization and related works (ring bund), flood diversion channel/ tunnel storage ponds** (**Fig. 16**), **Integrated River Basin Management (IRBM), guidelines and design standards, flood forecasting, warning system and evacuation plan** (Mohamad Yusoff et al., 2018).

Floods if evaluated from the perspective of damage, loss of property, destruction of agricultural products, loss of life, emotional disturbance and anything else from a negative perspective, it is a calamity and disaster that directly affects the well-being of the population and the economy of a country. Experts around the world specializing in this field are always looking for methods and carrying out studies to overcome flood problems, especially in relation to flash floods. Engineering solutions such as building pumps, dam structures, diversion drainage, reservoirs, etc. are commonly used methods. Although various prevention methods are practiced, the problem of flooding has not yet been completely overcome. Effectiveness of flood mitigation method is site specific. There is no one-size-fits-all method and detailed studies and variety of measures need to be considered to reduce flood risk.

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