Comparison of Sustainable Flood Risk Management by four countries: the United Kingdom, the Netherlands, the United States, & Japan, and the implications for Asian coastal megacities

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Abstract. Sustainable flood risk management (SFRM) has become popular since the 1980s. Many governmental and non-governmental organisations have been keen on implementing the SFRM strategies by integrating social, ecological, and economic themes into their flood risk management (FRM) practices. However, the justifications for SFRM are still somewhat embryonic and it is not yet clear whether this concept is influencing current policies in different countries. This paper reviews the past and current flood management experiences from flood defence to SFRM in four developed countries to highlight lessons for coastal megacities in development. The paper explored recent strategies such as "*Making Space for Water, PPS 25, and NPPF*" in the UK; and "*Room for the Rivers*" in the Netherlands which was implemented to mitigate flooding, integrate FRM with sustainability concepts, and deliver sound FRM practice for future generations. In this context, the United States has also established a National Flood Insurance Program (NFIP), and in a different approach, Japan has developed an advanced flood warning and evacuation contingency system to prepare for climatic extremes. These case studies give good lessons in achieving long term SFRM to deliver sound flood management practices considering social-economic and environmental concerns. Most developing coastal megacities especially in Asia are still heavily reliant on a traditional hard-engineering

approach, which may not be enough to mitigate substantial risks due to human factors (e.g. large population, rapid socio-economic growth, subsidence from excessive groundwater extraction, etc.) and natural factors (e.g. climate change including sea-level rise and land subsidence). It is clear that different countries and cities have their interpretation of SFRM but this paper explores policymakers how they can adopt "mixed options" towards long term thinking about sustainability with social, economic, and environmental considerations.

Keywords: Coastal megacities, Flood risk, flood management paradigms, Sustainable Development.

1 Introduction

Flooding is a natural phenomenon that has occurred over a long period of human history (Plate, 2002; Yang, et al., 2019). Different types of flood can be caused by: coastal flooding: storm, high tides, SLR and not sufficient protection; river/fluvial floods: snowmelt or high precipitation in catchment area leading to flash floods or riverine floods; pluvial floods: extreme rainfall and failing drainage systems or compound floods from cyclonic monsoon effects enhanced intensive rainstorms and surges together, or by rapid snowmelt (Kundzewicz, 1999). In Asian coastal megacities, flood risk, the frequency, or impact of floods is increasing (Hanson et al., 2011; Hallegatte et al., 2013; Yang, et al. 2015; Chan, et al., 2021), through two routes. First, flood hazard is increasing as climate change raises sea surface temperature, driving oceanic thermal expansion and increasing the intensity and frequency of precipitation events, and natural land subsidence (Meehl et al., 2007; Hulme et al., 2002). Second, the assets exposed to flood hazards, including people and property, are growing through rapid land-use change, urbanisation, and economic expansion (Yang, et al., 2010). Ways to mitigate flood risk in urban coastal areas are varied, and in principle could necessitate relocation of people and properties from high-risk areas i.e. the Indonesian Government is gradually moving the capital away from Jakarta. However, such measures are extreme and costly and are likely seen as impractical, with few people and firms willing to relocate, particularly from within dense economically vibrant cities such as Guangzhou, Shanghai, Jakarta, Ho Chi Minh City, Bangkok, and Singapore. A major challenge for such cities is therefore to manage flood risk, whilst addressing development needs.

Looking elsewhere in Asia, for example, cyclone Nargis flooded Yangon, Myanmar in 2008 and led to more than 140,000 casualties and US$17 billion in economic impact (Terry et al., 2012). In 2011, the Chao Phraya River catchment flood caused severe inundation in Bangkok, Thailand, flooded several districts of the city, and caused serious economic losses, exceeding US$4 billion (Chan et al., 2018). These examples demonstrate that Asian coastal cities are exposed to several types of floods often in combination (e.g. surface water/waterlogging, fluvial in urban catchments, and coastal, etc.), and the impacts and consequences are highly related to growing economies and population. In addition, these cities are also experiencing complex human-induced factors (e.g. reclamation of coastal areas without considering sea-level rise and surges, inadequate urban drainage system, and over-extraction of groundwater resources that enhances land subsidence, to name a few). Experience from other countries which have faced severe flooding suggests lessons for dealing with flood risk. Asian megacities tend to

rely on a one-dimensional, hard engineering approach to protect against flooding (Chan et al., 2018; Yang et al., 2020), whereas in many other places, this approach is increasingly seen as untenable, as it is financially unrealistic to protect against all floods. Therefore, flood risk management (FRM) has developed, an approach that addresses not just structural defence, but preparation (e.g. land-use zoning, adaptation), non-structural protective measures, population preparedness, and emergency response and recovery mechanisms to reduce flood risk (Samuels, 2006). FRM reflects a growing awareness of the uncertainties, vulnerabilities, and costs associated with flooding, and is the flooding paradigm widely accepted in Europe and some other advanced economies (Janssen, 2008), but to a much lesser extent in Asian cities. With the intention of drawing lessons for Asian coastal megacities, in this paper, we review FRM experience in four economies which are at the front end in applying the FRM approach (the UK, NL, United States, and Japan) (section 2). It additionally explores the wider concept of Sustainable FRM that extends the scope of FRM to consider wider social and environmental goals (Section 3). The paper also reviews the development of flood management practices in five selected Asian coastal cities (Jakarta, Indonesia; Bangkok, Thailand; Ho Chi Minh City, Vietnam; Guangzhou, China, and Shanghai, China) to demonstrate the latest progress of FRM in these cities that are exposed to flooding from various sources and to understand the implications of SFRM elsewhere for effectively influencing their flood management practices.

The overall aim of the paper is to contribute to the understanding of SFRM and practice and to argue for consideration of flood mitigation strategies for Asian coastal megacities developed through a consideration of sustainable development principles. Making such information available is of prime importance because Asian megacities already face massive flood management challenges, and flood damages – whether human or material – are growing rapidly.

2 Learning from the four countries

2.1 The road from traditional flood management to SFRM

Responses to flooding have historically developed through several distinct phases. Initially, (pre-1980's) responses were aimed at controlling and defending against floods by relying on "*hard engineering solutions*" (Penning-Rowsell et al., 2006), and there have been evidently countries (e.g. China, Netherlands, Germany, US) are using flood defences to protect villages and towns in low-lying deltaic areas for centuries (Wang et al., 2003; Van Stokkom et al., 2005; Parker and Fordham, 1996; Arnell, 1984). This paradigm of "*flood control*" (the 1950s to 1960s) sought to reduce flooding that might damage agricultural production and compromise food security and focused on the engineering approaches and materials used (e.g. concrete). Land drainage constructions and channelization were used to quickly drain floodwater away from agricultural lands by the driving principle of increasing in-channel conveyance. This aims to reduce flood impacts on agriculture. Later in the 1970s, the paradigm of "*flood defence*" was adopted, as the economic interest of flood control was widened to encompass manufacturing and tertiary industries. This "*flood defence*" phase sought to protect infrastructure, people, and property by using structural engineering measures such as seawalls, dykes, embankments, breakwaters, and levees.

Through the 1980s a "*flood management*" approach emerged, which emphasised coping with flooding rather than solely controlling floods. This occurred as policymakers realised it was increasingly difficult to defend against all flooding due to increasing climatic extremes (i.e. intensive precipitation), whilst social and environmental concerns were also recognised as important. This change in focus gave greater attention to flood preparedness and public awareness through, for example, the flood forecasting and warning systems that were developed across Europe. Such changes have been the basis of further development of the FRM paradigm (Lumbroso et al., 2011; Parker and Fordham, 1996). In the 2000s, the focus changed again to more explicitly consider flood risk (Plate, 2002), including the probability of a given flood hazard (e.g. precipitation, storm frequency, sea-level rise) (Kundzewicz et al., 2002; Schanze et al., 2005; Tol et al., 2003) and the vulnerability of, and consequences for populations and economic assets exposed to that flood hazard (Brown and Damery, 2002; Schanze, 2006). Thus, FRM now seeks to prevent damage by reducing the exposure and vulnerability of people and properties prone to flooding. It is not possible to eliminate flood risk, hence FRM considers the costs and benefits of flood risk mitigation for society at large (Butler and Pidgeon, 2011). The objective of FRM is thus to reduce the harmful consequences of flooding and to balance risk reduction alongside other political considerations and priorities. An important aspect of FRM is to manage flood risk through engagement with wider stakeholders (e.g. households, practitioners, politicians, flood engineers, planners, and communities), to identify multi-disciplinary perspectives and solutions (Pitt, 2008, Yang, 2020).

In this context, it is important to reflect on the national experiences of FRM to identify lessons for countries where flood defence and control continue to be the dominant response to flooding. Therefore, we are suggested to consider the experience of flood management in the UK, the Netherlands, the US, and Japan, where flood management practice has evolved significantly in recent decades, and we show how the practice has evolved from defending against floods to living with floods. Whilst acknowledging dissimilarities of human-induced factors (e.g. urbanisation, population, etc.) and physical factors (e.g. meteorological, hydrological, topography, etc.). Afterwards, these valuable experiences offer lessons for FRM in Asian coastal megacities such as managing urban flooding through the integration of urban planning practices, addressing climate change and promoting sustainability.

2.2 The United Kingdom

From the early part of the twentieth century, clear phases of flood management history can be identified in the UK, with the first phase pre-1970s. During this period, flood policy was governed and implemented by the Ministry of Agriculture, Fisheries, and Food (MAFF), whilst the internal drainage boards (IDBs) were responsible for carrying out flood alleviation by engineering practices (drainage, etc.) in the UK. In general, the UK Government adopted land drainage and hard-engineered defences such as river straightening, and embankment construction in rural and urban flood policy responses during this era, this approach has prevented many minor floods and protected the agricultural infrastructure (e.g. farmlands, crops, etc.) in adverse weather. However, the major floods in 1947 and 1953 which inundated 65,000 ha and 280,000 ha of farmland respectively, and escalated the changes and further swifts of flood management strategies as these floods have damaged

agricultural output during the post-war period when many foodstuffs were in short supply and food production was challenging (Penning-Rowsell and Chatterton, 1977).

During the 1970s, the UK Government adopted cost-benefit appraisal (CBA) to evaluate drainage projects. Where MAFF found high-yielding crops (particularly sugar beets, cereal, sugar, and potatoes) to be threatened, the IDB and local authorities would help farmers to develop measures to control flooding, usually through the construction of embankments and drainage channels (Penning-Rowsell and Green, 2000). Johnson et al. (2007) argued that despite the application of CBA by the government, flood policy was biased in favour of farmers and landowners, as they were the major (private) beneficiaries of public expenditure. However, the UK remained unusual in that it was one of few countries at the time to apply CBA to flood control measures.

During the 1980s, the priority of the UK flood policy was to "*keep the water out*" (Johnson et al., 2007). The emphasis had moved from protecting farmland to protecting a broader asset base that underpinned economic growth. Thus, policymakers were keen on implementing flood alleviation schemes and projects that defended people and property (homes and businesses) (Johnson and Priest, 2008). Criticism was however now directed at the use of CBA, for being overly focused on economic aspects. For example, flood measures/schemes tended to be approved if they protected high-value properties in a floodplain (e.g. riverside houses) but ignored adverse ecological factors (e.g. fish and invertebrates affected by channelisation) and other environmental impacts caused by the flood defence projects themselves (Green et al., 1991; Hey et al., 1994; Penning-Rowsell et al. 2006). Thus, through the 1980s and 1990s, flood defence was largely driven by CBA that considered net benefits (but not their distribution) and neglected external factors (e.g. inflations and market prices of the construction and labour cost, etc.). In England and Wales, more than 4 million people, and property valued at more than £200 billion are currently located in areas at risk of a 1-in-100-year flood (Lo and Chan, 2017). Forecast flood damages are currently £1.4 billion annually but are expected to rise to as much as £27 billion by 2100 (Evans et al., 2006). In 2002, the Institute of Civil Engineers emphasised that flood engineering measures remain important, but will no longer be enough, and advocated the approach of "*living with floods*" (Fleming, 2002). This gave impetus to a further paradigm shift in flood management policy, with concern for wider aspects, recognising socio-economic and environmental values, and impacts of climate change (Hall et al., 2003). Innovations in flood and coastal erosion risk management included the "*Making Space for Water*" (MSW) strategy (Defra, 2007) and "*Planning Policy Statement 25*" (PPS25) (DCLG, 2007) which sought to implement elements of that strategy via the land use planning system in different types of floods.

The vision of MSW is that of making space for flood water rather than defending against it. Many coastal and inland areas have been regularly inundated, but defending against all flooding in these areas had become unaffordable. The MSW strategy is integrated with related regionally applicable policies including the "*Coastal Erosion Risk Management Evidence Plan*", "*Catchment Flood Management Plans*" and "*Directing the Flow: Priorities for Further Water Policy*" (Evans et al., 2004; Thorne, 2014) that encourage practitioners to deliver more sustainable flood management, which also considers water quality, biodiversity, and engagement with rural communities in addressing fluvial, pluvial and coastal floods. PPS25 is a land use planning policy, applicable at a site-specific level that guides how planners and developers should address flood risk. It includes

a risk-based sequential test intended to direct development to areas of lower flood risk. PPS25, and the 2014 "*National Planning Policy Framework*" that superseded it, adopt a broader Sustainability Appraisal (SA) of flood management, considering economic, social, and environmental impacts. They require consideration of the spatial distribution of flood risk and how that risk distribution changes in response to proposed mitigation measures, so as maximise the net benefit of flood management. This is co-produced by the Local Planning Authority (LPA), the Environment Agency (EA) and the relevant internal drainage board.

Since 2010, "*Surface Water Management Plans*" (SWMP) have been required by the government under the "*Flood and Water Act*". The SWMP outlines a preferred surface water management strategy indicating how flooding from sewers, groundwater, and non-main rivers will be managed. The adoption of sustainable urban drainage systems (SuDs) is encouraged to deal with runoff following intensive rainfall (Defra, 2010). The SWMP works alongside PPS25, assessing flood risk to inform local authority planning decisions, which are now required to ensure that new development does not increase flood risk. Flood risk modelling and mapping are generally conducted by the environmental regulator, the Environment Agency (Environment Agency, 2014c), on behalf of local authorities who have been made the Lead Local Flood Authority (following the Pitt (2008) review which identified institutional complexity as a major barrier to addressing flooding in the UK). The maps of flood probability are used in flood risk assessment and input to strategic planning. These policies and practices also encourage the participation of public and NGO stakeholders in the development of SWMPs.

The subsequently developed "*National Planning Policy Framework*" (NPPF) (DCLG, 2012) aims to restrict inappropriate development in areas at risk of flooding, directing development away from areas at highest risk, but where development is necessary, making it safe without increasing flood risk elsewhere. This requires a strategic flood risk assessment, an assessment by one or more local planning authorities to appraise the current and future flood risk from all sources (surface and ground waters, fluvial and coastal), and with consideration of possible impacts from climate change. The NPPF represents an extended version of PPS25 intended to more comprehensively assess the impact that land-use change and development will have on flood risk. For example, local planning authorities use flood risk information (i.e. Flood map for Planning – Rivers and Seas) provided by the EA (Environment Agency, 2014a), to consider opportunities for reducing flood risk to both existing communities and new developments. The NPPF also ensures that emergency planning capability is evaluated against the forecast flood risk (DCLG, 2012). The EA also provides a live flood warning map (indicating flood alert, warning, and severe warning) showing locations at risk (Environment Agency, 2014b). Through this public release of flood risk information, the intention is that public awareness, preparedness, and participation will be enhanced. Current UK flood policy thus seeks to integrate FRM with land-use planning, considering future development and flood risk, which addresses social, economic, and environmental criteria. Whilst this may be an example of good practice in strategic and sustainable FRM, the UK still has room to improve in aspects such as cost and time effectiveness, and in its complex governance structure such as the fragmented responsibilities across institutions and stakeholders in UK flood management (Ashley et al., 2020; Green, 2014).

2.3 The Netherlands

The total land area of the Netherlands is about 34,000 km^2 of which more than 67% is situated below mean sea level (Beck, 2012). The safety standard of dike-rings and other measures is legislated for and reviewed every five years. The population is about 16.8 million with over 8.9 million properties located in flood-prone areas in 2012 (Jongman et al., 2014). As a result, land use is intense, limiting flood management options, and placing great reliance on engineered flood protection measures (Wesselink et al., 2007). It is vulnerable to coastal flooding and large parts of the country are subsiding (van Stokkom et al., 2005). Spring ice melt from the mountainous region of the upper Rhine and Meuse rivers exposes the country to fluvial flooding, with major floods in 1993 and 1995 (Vis et al., 2003; Wind et al., 1999). The country has a millennial history of flood management including from the 14th century the building of dyke-rings around polders to protect land and settlements from flooding. Today more than a thousand polders are protected 65% in the Netherlands and some polders are located inland (Van Stokkom and Witter, 2008). Lately, the intense rainfall in July 2021 (13-15 July) with approximate 125-150mm/24hr accumulated precipitation over 24 hours for each of the individual days that particularly located in Limburg (E Netherlands) and neighbouring countries (e.g. Luxembourg, Germany and Belgium) and this event caused 184 casualties in Ahr catchment, Germany and 38 casualties in Belgium. The German Insurance Association (GDV) estimated the economic losses to exceed 350 million Euro (Krienkamp et al., 2021; Kotz et al., 2022).

The 1953 North Sea Flood, which caused 1,836 deaths, spurred the Netherlands to develop a high coastal flood safety protection standard. The country has the highest flood protection standards in the world, with 1-in-4,000 to 1-in-10,000-year flood return period infrastructure (i.e. coastal dike-rings), protecting populations and economic activities, especially in the West Coast cities of Rotterdam, The Hague, and Amsterdam (Klijn et al., 2004; Gerritsen, 2005). Despite the efforts of the Dutch government, the 1993 Meuse and Rhine River flood required over 200,000 people to be evacuated, with damage costs over 2.53 billion Dutch Guilders in 1993 flood and amounted 1.65 billion Dutch Guilders in 1995 flood (1 Dutch Guilder (obsolete is equivalent to 0.45 Euro as the currency was replaced by the Euro after 2002), which approximate costed about 1.88 billion Euros (at mid-1990s rate). The Dutch government understood it could not rely wholly on engineered flood defences to achieve an acceptable degree of risk (Wind et al., 1999) and in 1999 introduced a new water management policy, "*Room for the Rivers* (*Ruimte voor de Rivieren*)" (Böhm et al., 2004; Van Stokkom et al., 2005) (see Table 1). This required major changes in flood risk management, including that: (i) water had to be guided in the landscape following an explicit spatial planning process, and (ii) water had to be retained, stored and when necessary, the land had to be drained.

Table 1: Features and functions of the "*Room for Rivers*" policy in the Netherlands

Features	Functions
(i) Awareness	The Dutch government needs to improve communication on the nature and scope of risks and, in addition to its efforts, to offer all citizens the opportunity to contribute or participate in risk reduction e.g. floods preparedness.
(ii) Three-steps-strategy	The need for a robust and resilient approach to ensure safety and reduce water-related problems, based on the following principles: ➓ Anticipating instead of responding.

	➓ Not passing water management problems on to others, by following a three-step strategy (retention, storage, and discharge). ➓ Allocating more space to water in addition to implementing technological measures.
(iii) Giving rooms to rivers	Encourage water storage.
(iv) Spatial planning	Adapting the spatial zoning strategy to prevent any human activities in the floodplains to interrupt the river discharge capacity e.g. Nijmegen land management plan
(v) Knowledge exchange	Encourage social learning and public education relating to water and river management.
(vi) Governing responsibilities	The provincial and local municipal authorities and water boards all need to share their responsibilities and ensure water-related safety problems i.e. flood risk. All institutions need to ensure effectiveness in FRM.
(vii) Investments	It requires additional funds and investment in FRM systems for the projected climate change and land subsidence.
(viii) International or transboundary co-operation	Co-operation with other shared-river basin countries (i.e. Germany and Luxemburg) on FRM should be intensified.

Sources: Adapted from Klijn et al., 2008 and Van Stokkom et al., 2005

Along with the long history of flood management, Dutch water boards have an established engineering tradition which, it is argued biases them to management options with which they are familiar (Klijn et al., 2008). Some critics thus argue that the "*Room for the Rivers*" policy remains over-reliant on dike-rings, embankment construction, and other river regulation engineering (see Figure 1) (Hudson et al., 2008; Ten Brinke and Bannink, 2004). Nevertheless, the "*Room for the Rivers*" approach does represent a major shift in FRM, with strategies aimed at the integration of floodplain development and spatial land-use planning to meet socio-economic needs, ecological conservation and awareness of biodiversity, and wide stakeholder involvement. Collectively this novel approach is considered to represent a progression toward sustainable flood risk management (Van der Brugge et al., 2005; Van Stokkom and Witter, 2008). Lately, the Netherlands Government has established the Dutch Flood Protection Programme (DFPP), which aimed at improving flood protection structures with more resilient safety protection standards (expanded approximately 50% protection standard compare to the previous level) that co-produce between authorities i.e. the Dutch Water Authorities, Ministry of Infrastructure and Environment, Scientific Institutes, Consultancies and construction sectors (Jorissen et al., 2016), and that is a good strategy preparing the extreme climate and possible future impacts such as from the lesson on the lately July 2021 flood.

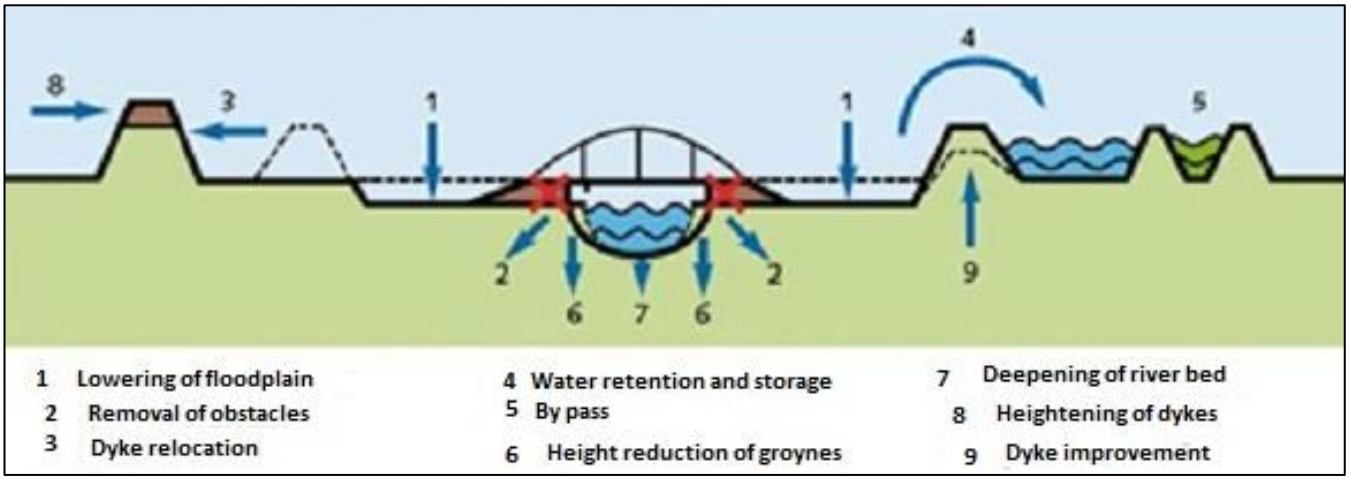

Figure 1: Measures of "*Room for Rivers*" in the Netherlands. Source: Room for Rivers Program office.

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2.4 The United States

The United States (US) regularly experiences severe flooding. According to the US National Weather Service (NWS), there has been an average of 87 deaths per year from flooding between 1989 and 2018 (National Weather Service, 2018) and 29 flood events during the same period that resulted in over $1 billion in economic losses, with an average event cost of $4.3 billion. This does not include flooding caused by tropical cyclones (42 during the same period with an average event cost of $21.9 billion). (National Atmospheric and Oceanic Administration, 2019).

Tropical cyclones are low-pressure systems that form over warm tropical waters. They typically form when the sea-surface temperature is at or above 26.5°C. Tropical cyclones can continue for several days, or weeks, and follow an erratic path. A cyclone will dissipate once it moves over land or cooler oceans. The differences between tropical cyclones (i.e. storms, cyclones and hurricanes) are varied from the wind speed in ascending order, and "typhoon" is a term that used the same feature as a hurricane (Bureau of Meteorology, 2021). Not all cyclones (typhoons) bring intensive rainstorms that cause heavy rainfalls to enhance fluvial and pluvial floods. However, storms (cyclones and hurricanes) are often evolved with rainstorms and generate storm surges as a combined effect to enhance the "compound flood", and enhance the riverine floods because of extreme precipitation. The most disastrous events in this period are Hurricanes Katrina in 2005; Sandy in 2012; Harvey, Irma, and Maria in 2018; and Florence in 2019; along with flooding in the Midwest in 1993, 2008, and 2019, as these events significantly occurred as coastal or combined floods with coastal and pluvial floods (Chan, 2004; Link, 2010; Xiao et al., 2011; Vance, 2012).

In the US, large populations are located along the banks of watercourses, lakes, and coasts. In coastal flood-prone areas of Florida, California, Texas, Louisiana, and New Jersey, populations have expanded greatly since the 1980s (Niedoroda et al., 2010); the US Census projects an additional 82 million residents by 2030, an increase of 29% of the current population in

coastal areas such as Florida, Virginia, New York State and New Jersey on the East Coast, Mississippi in the Midwest and California in the West Coast (Hamin et al., 2019; Maantay and Maroko, 2009). Demand for development land remains high, and along with climate change, is likely to increase flood risk, especially in coastal areas (Bagstad et al., 2007; Aerts et al., 2013; Burgess et al., 2007).

The federal government has controlled the main flood management institutions since the 1920s when it took responsibility for managing floods, primarily through flood control structures. However, at that time flood legislation was unclear, particularly concerning the relationship between federal, state, and local government. Notably, the federal government sought to share the financial burden of flooding and flood protection with state governments and local communities, and the percentage to be covered by state and local governments has increased over time (Arnell, 1984).

Even as more funds were committed to flood control works, there was no decline in flood losses leading to calls for flood management rather than flood control (Wright, 2000). As a result of this, the National Flood Insurance Act was signed into law in 1968, which had a carrot and stick approach with the carrot being the provision of flood insurance in communities that regulate the development of the 100-year floodplain. This was followed in 1977 by Executive Order 11988: Floodplain Management, issued by President Carter, which directed federal agencies to take the flood hazard into account when planning, funding, and implementing developments in flood-prone areas (Arnell, 1984). Further, the Federal Emergency Management Agency was established in 1979 to coordinate all of the tasks associated with emergency management, including mitigation and the National Flood Insurance Program (NFIP).

Even with all of this, the federal management strategy maintained a focus on hard-engineering solutions. Eventually, an impetus to review the approach was seen in the 1993 Mississippi River flood, which led to the river flooding over 1,200km of the river's length and about 840,000 km^2 in area (Figure 2), resulting in over $15 billion in economic damages. The subsequent "*Galloway Report*" in 1994 proposed that development in the floodplain should be avoided unless no alternative locations existed (Galloway et al., 1999), similar to the "*MSW in the UK and Room for Rivers in the Netherlands*" in the UK and Dutch approaches to described above. Yet, while the report was in preparation, reconstruction of damaged and breached levees was ongoing. However, the Galloway report indicated that whilst embankments and levees are important in protecting urban areas, they are insufficient on their own. Floodplains should be managed as part of the natural ecosystem, with risk-based forecasting used to inform flood management. These practices encouraged sharing of flood risk information with the public and improved awareness of and preparation for flood risk. From the mid-1990s there were improvements in practices of (i) hydrological data collection during and after floods; (ii) development and installation of better instruments to evaluate coastal and river flood risk (e.g. Use of GIS, remote sensing, and GPS to identify and understand flood hazards in various locations); and (iii) development of hydrologic models for more precise flood monitoring and prediction (Changnon, 1998). Since then, among other publicly available risk information sources, the NWS provides river level data with maps showing potentially flooded areas through its Advanced Hydrologic Prediction System (AHPS; https://water.weather.gov/ahps/) and the United States Geological Survey (USGS) monitors river levels and discharges for thousands of rivers nationwide (water.usgs.gov).

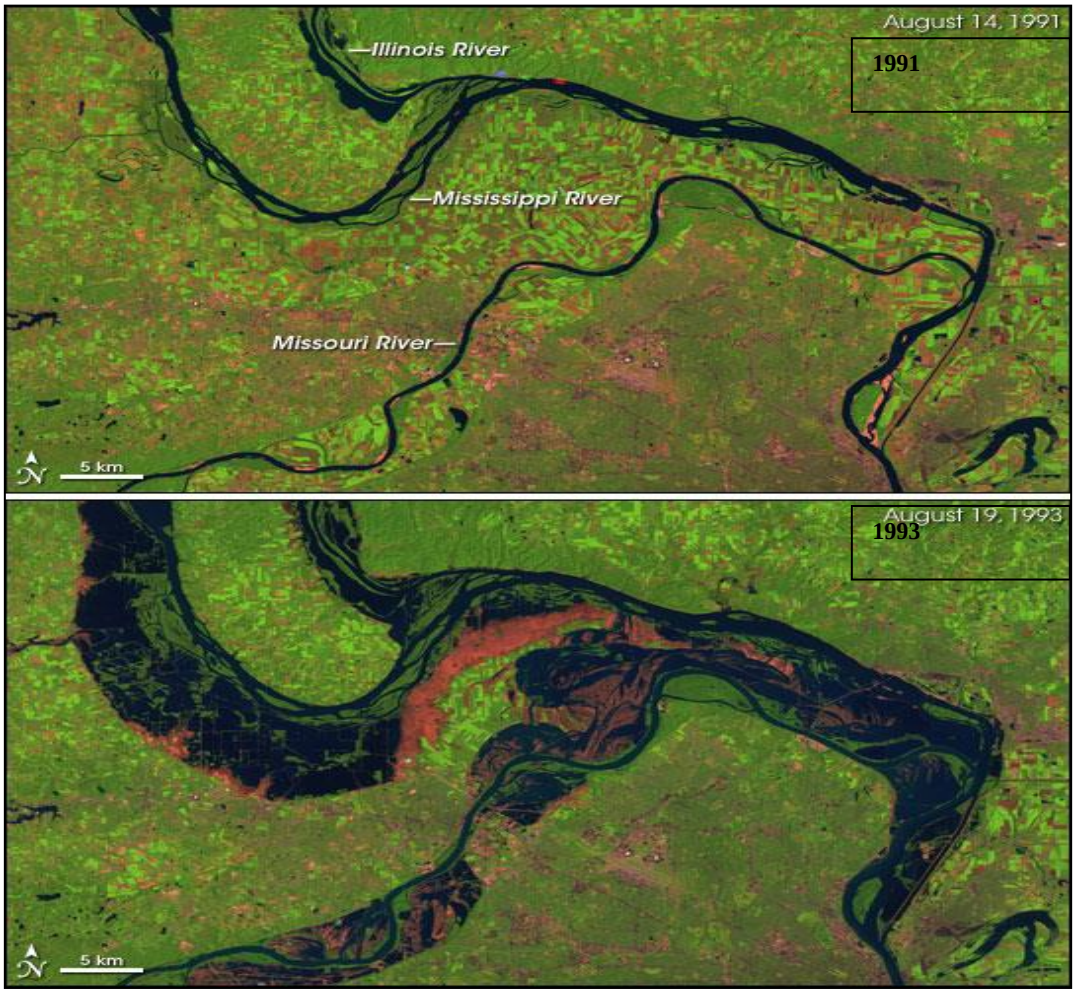

Figure 2: The lower image of the 1993 flood condition compares to the normal condition in the 1991 upper image in the lower Missouri, the Mississippi River. Source: (Allen J, NASA).

The NFIP marked a particularly significant development of flood management in the US. The scheme, the world's largest national flood insurance program, provides short- and long-term financial assistance to residents in flood zones (Arnell, 1984). The program enables property owners to purchase insurance protection, administered by the Federal government, against losses from flooding and requires flood insurance on all properties in the designated 100-year floodplain as shown on "*Flood Insurance Risk Maps*". Despite the requirement for flood insurance and the potential sanctions for not having it if flooded (ineligibility for other federal disaster assistance), only approximately 50% of properties in the designated 100-year floodplain have flood insurance (National Association of Insurance Commissioners, 2017). This may reflect several factors, including a misunderstanding by property owners of their flood risk and an expectation that disaster relief will be forthcoming despite the requirement.

The NFIP aims to provide flood protection for property owners and discourage development in substantial risk areas by limiting access to insurance. The NFIP is sponsored by the federal government which also provides insured residents with access to emergency financial relief aid should they suffer flood damage (Longenecker, 2008). The program was designed to be financially self-supporting, but the US Government Accountability Office reports that losses cost the taxpayers about USD 200 million annually and that since 1978, the NFIP has paid more than USD 51 billion in flood claims (Bagstad et al., 2007). Congress originally intended that the NFIP program be supported by premiums, but this has not happened for various reasons including subsidised insurance rates for pre-existing structures and repetitive loss claims for many structures with no action to reduce their risk.

Further, sufficient funding from Congress for flood insurance risk maps updates has not been forthcoming even though many of the maps were created in the 1980s and thus do not reflect floodplain changes over time, whether from upstream development or climate change. Insurance is one means to mitigate flood risk but designing and delivering successful schemes are difficult, with issues arising relating not just to affordability, but also to cost-sharing, the sacrifice of very high-risk areas, and insurance industry returns and expertise (Ball et al., 2013; Crichton, 2008; Michel-Kerjan and Kunreuther, 2011). In fact, the UK has also introduced flood insurance similarly in the early 2000s as the flood risk mitigation approach, and establish the flood risk mapping by addressing the postal code from the households and locations for riverine and coastal floods, as a planning instrument for informing the stakeholders (planners), investors (developers) and communities the flood risk information (Lamond and Penning-Rowsell, 2014).

As is the case in many places, attention to flood risk increased with an event that forces communities to recognize the nature of the risk it faces. For example, following Hurricanes Katrina and Sandy, US authorities responded with flood-sensitive strategic plans. In the aftermath of Sandy, New York City adopted a "*rebuild by design*" coastal master plan that integrates climate change into an adaptive development planning process, such as the implementation of climate adaptation plans merged with the long-term master plan for the New York City (Rosenzweig and Solecki, 2014). This includes the production of flood risk maps to increase public awareness; the development of an emergency contingency plan for all city districts with specific attention on vulnerable social groups (e.g. minorities and the elderly); and raising flood protection for particularly vulnerable (Aerts et al., 2013). These strategic actions, together with those described above, indicate the US has adopted a "mixed" options approach to dealing with rising flood risk. However, the devastating Houston flood following the 2017 Hurricane Harvey highlights that not all US cities are adequately prepared. Houston has exacerbated its flood risk through fast, sprawling development that has led to substantial loss of wetland storage, expansion of impermeable surfaces, and lack of related investment in flood defence infrastructure. This is reflective of the need for better planning and coordination between federal, state, and local governments. While flood management in the US has historically been a federal responsibility, the NFIP is only successful as a shared responsibility. However, with this change, insufficient attention has been given to who bears the cost of flooding. In Houston's case, the residents and federal government have borne the costs while the benefits of development have gone to the city's tax base and private developers (Berke, 2017). Thus, while the US has made important and successful strides toward SFRM, more is needed to achieve its goals.

2.5 Japan

Japan covers approximately 378,000 km^2 of which 70% is hilly or mountainous terrain, hence low-lying flood-prone areas have been preferentially developed for settlement. In the past decades, across the country, more than, 60 million people (49% of the population), reside on floodplains (Huang, 2014). The country, unfortunately, has frequent flood hazards and disasters records as the topographic feature of Japan tends to have short steep rivers with little upstream storage. Hence, flash and pluvial and combined types of floods, in particular, occur often. Over the last 30 years, intensive rainfall events (>50mm/hr) have increased in frequency by about 50%, and those >100mm/hr have more than doubled (Yamada et al., 2011) and this trend is expected to continue with climate change. Japan has flood hazards arising from typhoons, torrential rains, snowmelt, and tsunami; and past floods have been associated with major impacts (Fujita and Hamaguchi, 2012). For example, in 2000 at Tokai city in Nagoya, pluvial flooding killed 18 people and injured 115, and economic losses were about 978 billion JYP (c. USD 9.57 billion). Another example, in 2004 during the Niigata-Fukushima flood, a result of torrential rain, killed 20 people, and inundated 26,000 properties, making 5,800 homeless. In the same year, four strong typhoons (Songda, Meari, Ma-On, and Tokage) hit the East coast of Japan between September and October causing sea surges, with 180 killed or missing and over 23,000 properties destroyed (Zhai et al., 2006).

Historically, flood management policy was not coordinated in Japan, and it was not until the 1961 "*Disaster Countermeasures Basic Act*" that legislation provided the basis for an integrated disaster management strategy and clearly defined responsibilities across the government. Specific laws relevant to flood prevention, such as the "*River Law*" followed in 1964 which reorganised river administration and improved flood governance. The Water Law was the catalyst for the 1977 "*Comprehensive Flood Control Measures*" policy that specifically focused on flood prevention, flood control, and response to flood events (Takahasi, 2009). Under this policy, rivers are divided into three classes (A-C); Class A rivers, the largest in terms of area, length, and significance of their assets (economic and population in their basins) are managed by the Ministry of Land, Infrastructure, and Transport (MLIT) River Bureau which reports directly to the Japanese Central Government. Flood risk in the smaller Class B and Class C rivers are managed at municipal and local government levels, with MLIT support (MLIT, 2008). Ikeda et al. (2008) note that whilst flood fatalities fell after 1960 as new flood protection policies took effect (including an MLIT policy that 1% of national income be invested in flood measures from 1960–1990), economic losses from flooding have not fallen and remained high.

Kundzewicz and Takeuchi (1999) illustrated that since the River Law was enacted, the MLIT and related institutions employed a hard engineering flood protection approach, with the main flood control strategy being to transport water quickly to the sea. Super levees, divergent canals, floodways, and bypasses were constructed. This approach was questioned after the 1977 Nagasaki flood where 375 people in the unprotected upstream area died following a 180mm/hr rainfall event. Two problems were particularly evident: (i) flood control or hard flood protection measures did not cover all parts of the river, due to the cost of such defences; and (ii) Class A rivers and Class B/C rivers were managed by different institutions with inadequate

communication between them and a lack of integrated flood risk appraisal (Ueno, 2002). Afterwards, in the 1990s, the River Law recognised the complex nature of integrated catchment management, with the law seeking to address objectives related to flood risk, water resources, and environmental quality and legislated in 1997.

"*Article 1. The purpose of this Law is to contribute to land conservation and the development of the country, and thereby maintain public security and promote public welfare, by administering rivers comprehensively to prevent the occurrence of damage due to floods, high tides, etc., utilize rivers properly, and maintain the functions of the river water by conserving the fluvial environment*".

This amended River Law reflected that the government was advocating a more sustainable approach to flood risk, with the integration of social and environmental issues into FRM, as well as wider public engagement (MLIT, 2008):

"*When river administrators intend to draft a river improvement plan, they shall consider opinions from persons with experience or an academic background when necessary*" (Article 16-2-3), and "*In connection with the previous paragraph, river administrators shall take necessary measures, such as public hearings, etc., to reflect the opinion of the people concerned whenever necessary.*" (Article 16-2-4).

In the 2000s, the MLIT issued their "*Effective Flood Management including Basin Responses*" policy, which emphasised that flooding was unavoidable and accepted the ability of flooding in water-prone areas (e.g. wetland) to enhance ecological value (Ikeda et al., 2008). This policy not only focused on the areas with high assets (e.g. urbanised floodplain), but extended to cover the rural areas in the river basin (i.e. upstream) (MLIT, 2008). Key to this policy is the integration of hard and soft flood protection measures, rather than reliance on traditional engineered defences. The Japanese authorities understood flood protection measures and practices are necessarily considering flood consequences in Japanese cities, because of their substantial populations and affiliated economic assets. The "*Act on Countermeasures against Flood Damage of Specific Rivers Running across Cities*" (legislated in 2003) targeted reducing flood risk for various sized rivers that run across the cities and towns in Japan (MILT, 2003). The Act was further amended in 2004 and further legislation passed through the "*Flood Fighting Act*". These two ensure that municipal governments understand their roles in delivering according to FRM practice explicitly (Yamada et al., 2011). For example, informing residents for increased awareness by issuing a "*flood warning*" for the communities to understand potential flood spots. Further, the legislation also provides emergency services (e.g. temporary shelters, evacuation medical services, etc.) for enhancing emergency response and recovery practices (OECD, 2006). Lately, towards the 2010s, the Japanese authorities further addressed flood resilience approaches.

"Flood Resilience" refers to the ability of communities and sectors to withstand a flood event and the ability to recover from the disruption of floods (Environmental Protection Agency, 2014). In Japan lately, the government especially tackled the perception via issuing flood hazard maps (MILT, 2008). The MILT was further concerned about the intensive rainstorms that enhanced urban floods and legislated specific measures to reduce flood risk during heavy rainstorms (MILT, 2013). After the Tsunami and coastal floods in the early 2010s, the MILT has further implemented the "*Act on Special Measures concerning Urban Reconstruction*" in 2018 to strengthen flood resilience, particularly tackling the prevention, emergency response, and recovery processes (see Figure 3). This is used to support decision making by land-use planners by setting up the land use

regulation zone system; directing the floodproofing of existing urban facilities (e.g. the underground, railways, public services facilities); raising flood awareness amongst the at-risk public (via flood warning system, hazard map, and future flood projection); and informing the emergency response and evacuation procedures (via relocation practice) of the civil emergency services (MILT, 2018).

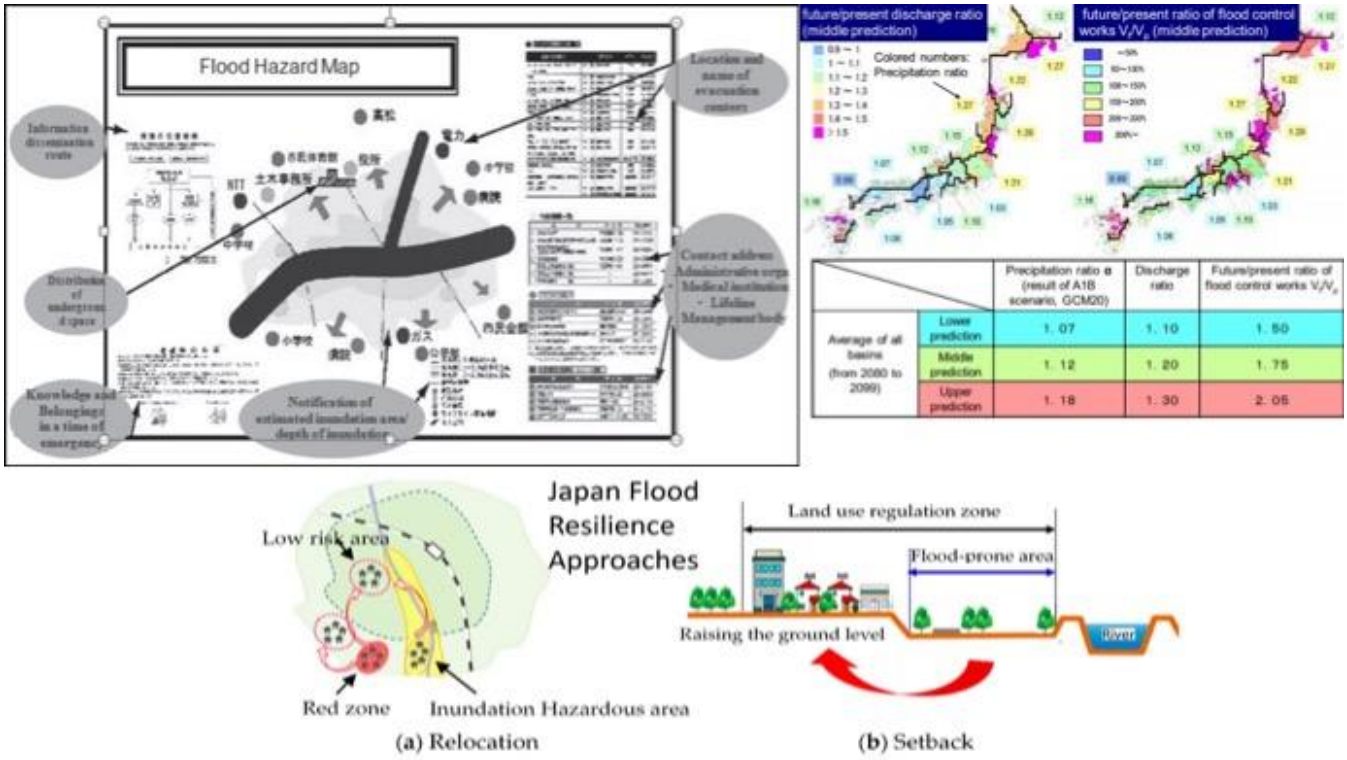

Figure 3: Flood resilience approach in Japan – Upper: Flood Hazard Map and Fluvial Flood Prediction with future Climate Projection; Lower: Japan Flood Resilience approach for a. relocation and b. setback strategies to protect residents (adopted from MILT 2008;2014; Fan & Huang, 2020).

3 Discussion

3.1 Sustainable flood risk management (SFRM) – where are we now?

"*Sustainable Flood Risk Management* (SFRM)" evolved during the 1990s, when the concept of Sustainable Development became prominent (Brundtland, 1987). The three pillars of sustainability (social, economic, environmental) are widely recognised and they have influenced sustainability policies (UNCED, 1992). Sustainable Development strategies seek to ensure economic development is conducted in a manner that respects environmental limits and values and considers the distribution of all costs and benefits of development through time (inter-generational equity) and across social groups (intra-generational equity) (Pearce et al., 1996; Sneddon and Fox, 2006; Morse, 2008). An additional imperative is the development

of strategies through open and participatory mechanisms. These sustainability principles apply to all types of development, including the development of FRM strategies, through Sustainable FRM (SFRM) (Evans et al. 2004; Hooijer et al., 2004). Table 2 illustrates how SFRM is interpreted differently across the four countries in this study and reveals that whilst SFRM is not a contested concept, it does lack a widely accepted definition. Similarly, De Bruijn et al. (2007) suggest that SFRM could be understood simply as the ability of society and ecosystems to cope with several types of flood risk whilst maintaining the level of well-being, whilst Chan et al., (2013b) attempt to characterise SFRM practice within a more explicit sustainability framework. Nevertheless, for the four countries we discussed above, progress from flood control to FRM, and now towards SFRM is evident (Lawson et al. 2020) (see Figure 4).

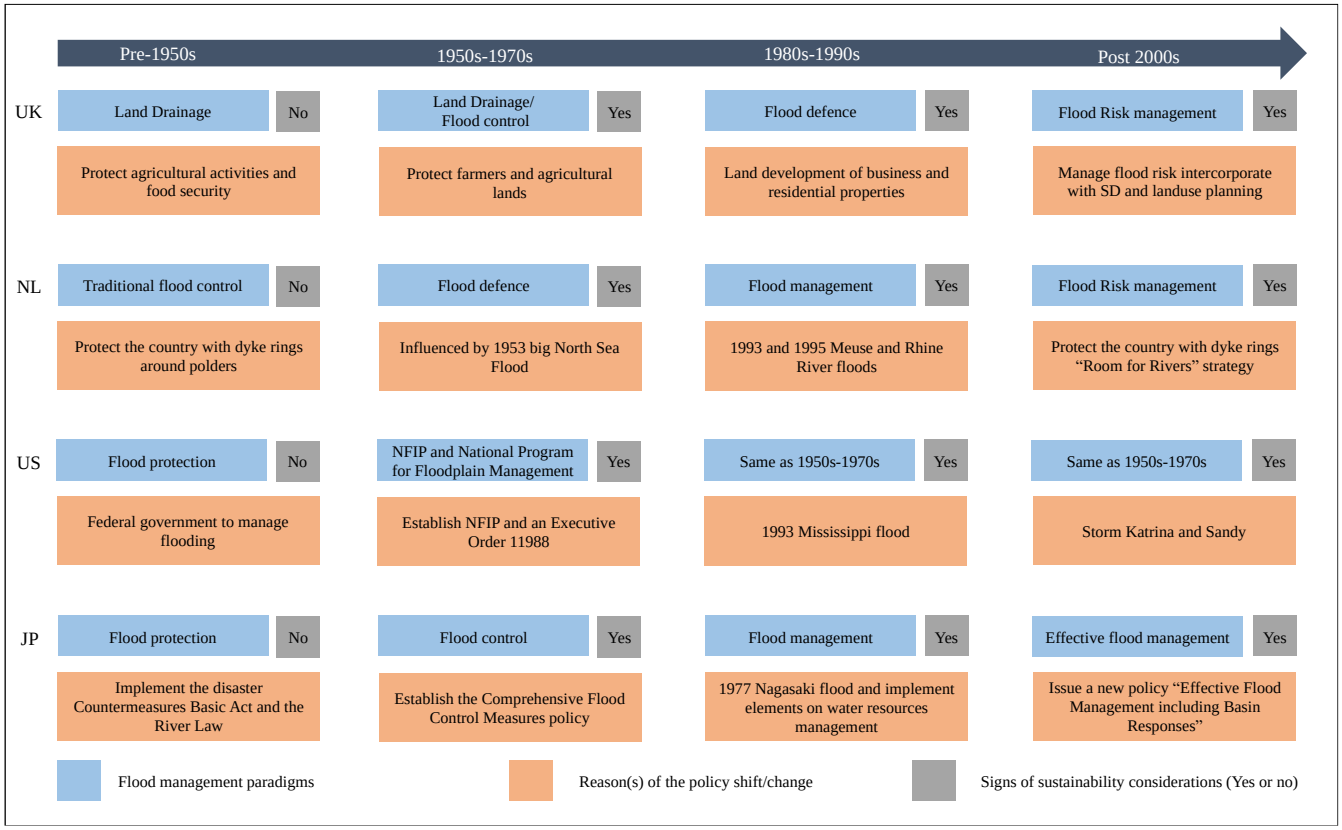

Figure 4: Flood management paradigms and major changes towards SFRM.

Examples of action taken towards SFRM include the open provision of flood risk information to aid participatory planning (post-2000); which has been implanted in the Netherlands and the UK refer to the EU Flood Risk Directive - *"Floods Directive - 2007/60/EC"* (European Parliament, 2007). For example, the local authorities (e.g. Local Planning and Water Bureaus) to deal with flood mitigation measures that considered addressing wider social-economic assessments and appraisals. The authorities extended the Cost-Benefit Analysis and similar benchmarking practices that assess economic impacts; social values;

perceptions and opinions; cost-sharing through national flood insurance schemes, environmental consideration, natural capitals and design of flood mitigation with nature. Similarly, the United States has also considered these factors during the same era, considered to protect the natural environment, and to recognise its value in mitigating flood risk (e.g. via sustainable drainage systems, wetlands, and reintroduction of river meanders) (Butler and Pidgeon, 2011; Green, 2014; Porter and Demeritt, 2012; Scott et al., 2013). From our review, it is apparent that no country has FRM that comprehensively addresses sustainability concerns (see Table 2).

Table 2: Strengthens and weaknesses of current FRM practices towards SFRM across 4 countries

Pillars	Strengthens of practices	Practices	Facts/examples	Weaknesses of practices	Arguments and reasons
Social-economic	Social justice	**UK:** Pitt (2008) reported to address social justice and equity issues in FRM	Defra research (projects FD2605 and FD 2606) has looked at issues of inequity of FRM in England	Social injustice and inequity	**UK:** No exact implemented guideline to address issues of inequity of FRM, but most of the poor live in the flood zone (Johnson et al., 2007) **US:** Ethical minorities - A research showed the minorities in NYC mostly are not insured by the NFIP flood insurance scheme (Maantay and Maroko, 2009)
	Flood risk information	**UK, NL**: Flood risk mapping in *EU Flood Risk Directive* (EU, 2007; Environment Agency, 2014abc); **US:** Interactive flood information map (NOAA, 2014ab); **JP:** Flood hazard map (MILT, 2008)	Increase understanding of flooding, preparedness, and awareness; assess potential economic impacts (the UK and NL); showing flood histories (hazards), types of flooding, current flood risk, and level of protection (US); showing the post-flood emergency routes and contingency plan (JP)	Analysis and reporting of potential flood risk on possible social-economic impacts	**UK, NL:** Flood risk mapping – may be too technical for the public to understand (Porter and Demeritt 2012). Absence of the detailed information (e.g. protection measures) on the flood maps in UK and EU cities
	Cost-benefit analysis in flood infrastructure investment (CBA)	**UK, NL**: Adopted CBA in NPPF and Room for Rivers (Carter et al., 2009; Eijgenraam,2005)	Maximising the cost and value, and creating economic justification on the FRM process	Cost-benefit analysis (CBA)	**UK, NL:** Difficult to evaluate environmental and social aspects in the CBA
	Flood insurance	**US:** NFIP (Arnell, 1984)	Most residents (who live within 1-in-100 years flood zone) are covered in the NFIP scheme	Flood insurance	**US:** Poor people and minorities are mostly not insured by the NFIP scheme (who live outside the insurance coverage boundaries - the risk is higher than 1-in-100 years) For example, some residents were the poorest community in New Orleans lived in the Lower Ninth Ward, which was flooded by a catastrophic breach (during Storm Katrina) without NFIP coverage) (Chamlee-Wright and Storr, 2009; Burby, 2006)
	Apply sustainable flood management practices (e.g. blue-green	**UK:** Adopted Sustainable urban drainage systems (SuDs) (Mitchell, 2005; Coupe et al., 2013)	Reducing flood risk, surface water pollutant level, the pressure of the surface runoff discharge,		

	infrastructure, Nature-Based Solutions, etc.)		improving amenity and environmental values (e.g. improving wildlife habitats)		
Other issues	Governance	**UK:** Better FRM governing structure		Complex institutional arrangement	**UK:** Time consuming and not cost-effective (Green, 2014)

For example, Maantay and Maroko (2009) show how in New York City, the national flood insurance scheme does not effectively reach some social groups, particularly ethnic minorities, who tend to be exposed to above-average flood risk. Social equity issues tend also to be underrepresented in SFRM studies, although researchers and practitioners are increasingly alert on how resilience to flooding varies spatially, temporally (Yang, et al., 2021) and socially with low-income households a particular concern. Similarly, economic appraisal of flood strategies recognizes environmental impacts, but ecosystem service values and the wider benefits of nature-based flood management (Dadson et al. 2017) are nowhere routine in such economic appraisal. Concerning flood management, the Pitt Review into a series of major floods in England (Pitt, 2008) highlighted that flood governance can be a major problem. Pitt observed that so many organisations had responsibilities for FRM, and at a variety of geographic scales and flood types, that a high degree of institutional complexity resulted which acted as a barrier to effective FRM. This problem is also seen in the US (Rosenzweig and Solecki, 2014). Local authorities have since been given the lead role in FRM. Porter and Demeritt (2012) commend the openness and transparency of flood risk mapping but raise concerns over the degree of technical expertise needed for the public to understand and act appropriately on the information conveyed. These examples indicate that in the four countries reviewed in this paper, challenges to SFRM exist. However, these tend to be challenges of an operational rather than philosophical nature, challenging the delivery of SFRM but not the principle. That is, there is now widespread recognition of the need to address sustainability concerns and embed sustainability principles into FRM policy and practice.

3.2 Implementing SFRM in Asian coastal megacities

Currently, many Asian coastal megacities are operating predominantly within the flood control and defence paradigms, including Guangzhou, Shenzhen, and Hong Kong (Chan et al., 2013; Yang, et al., 2018), Shanghai (Balica et al., 2012), Bangkok (Keokhumcheng et al., 2012), Ho Chi Minh City (Storch and Downes, 2011; Nguyen, et al., 2021), Jakarta (Texier, 2008; Wannewitz and Garschagen, 2021) and Singapore (Chan et al., 2018; Chan et al., 2021). These cities all feature in the top coastal cities at risk by the 2050s (Hallegatte et al., 2013). Because of their rapidly growing populations, economies, developmental pressure, but also rising flood hazards from climate change (i.e. more frequent storms and intensive rainfall, etc.). Limited room to expand has resulted in the development of floodplains, wetlands, and reclaimed coastal areas (Chan et al., 2014; Ji, et al., 2021), a practice common in Asian coastal cities (Fuchs et al., 2011). In table 3, we illustrate the flood management practice in Asian cities relative to the dominant flood paradigm in the West, as we discuss the progress of their flood management strategies as we start with the era before the 1990s – "Flood protection (control and defence)"; and further discuss their progress in the 2000s "Flood risk management (FRM)" era and "Post-2000s Sustainable flood risk management (SFRM)" era, we also discuss further for the evidence and examples for these practices among the selected Asian coastal cities further below in this section.

Looking at the past (before the 1990s), there are many coastal cities that suffered from severe floods in Asia. Taking Singapore as an example, as Singapore has developed rapidly with tremendous socio-economic growth, but has been inundated by severe

floods because of the rapid urbanisation since its independence in 1965 (Chan et al., 2018). The Drainage Department of Singapore was established in 1972 to prevent floods. The Government of Singapore invested heavily to construct dense networks of drains and canals as the major approach for flood management before the 1990s (Lim, 1997) and this reduced flood-prone areas from 6900 ha in the 1960s to 207 ha in the 1990s (Lim and Lu, 2016). Owing to economic development, Singapore adopted a Low Impact Development (LID) approach (similar to SuDs in the UK) in the 1990s in line with the changes made in other countries. This included constructing stormwater retention ponds for stormwater storage and reuse at Kallang district (Lim and Lu, 2016).

Indeed, neighbourhood coastal cities such as Bangkok, Jakarta and Ho Chi Minh City also face similar issues (on urban floods), particularly in their fast urbanisation and the developmental period during the early 1980s. Rapid land use changes transform green spaces (e.g. agricultural and farmland, forest, wetland, etc.) into an urban area, but land drainage and flood measures were unable to cope with the urban runoff (Takeuchi, 1993; Jha et al., 2012; Huu, 2011; Katzachner et al., 2016). Mostly, the flood management practices before the 1990s in these cities were mainly driven by flood control and defence measures. Jakarta was under Dutch influence for flood engineering in the early 1920s, which is demonstrated by the East Flood Canal Project which was constructed during the Dutch Colonial period in 1924 and that was an extension of the Western Floodway at the city of Jakarta to alleviate urban peak discharge (Jha et al., 2012). Bangkok was dominated by the engineering approaches such as engineering works for agricultural irrigation, embankments, reservoirs, and drainage systems in the 1980s and 1990s (Bouriboun, 1998). Across the Mekong, Ho Chi Min City has also been dominated by agricultural engineering works for agricultural production (e.g. rice and poultry, etc.) and crop protection during the storms (e.g. typhoons) before the 1990s (Huu, 2011). Likewise, Chinese coastal cities faced urban floods that were enhanced by urbanisation and rapid development during the "*Open Door Policy*" established in the late 1970s, such as urban floods in Shanghai during 1981, and later events in 2020 and 2021 because of typhoons (Chan et al., 2021, Dou, 1991). Guangzhou experienced frequent urban floods due to increased population density in major areas such as Tianhe, Baiyun, etc. (Zou, 2012). Engineering approaches (e.g. flood walls, dykes, drainage canals, pumping stations, and dredging engineering works) were particularly popular and applicable before the 1990s in both cities (Zou, 2012; Meng and Dubrwoski, 2016).

During the 2000s, these coastal cities gradually moved to consider wider aspects of socio-economic risk and health issues in communities and these have started to be considered in the FRM policy implementation. For example, in Jakarta, the municipal authorities initiated non-structural measures including an early warning system, health service capacity building, and contingency planning including relocation and compensation schemes after the 2002 and 2007 floods, having realised that engineering works were insufficient (WHO, 2007; World Bank, 2009). In Bangkok, the Thai government still preferred using engineering works to further strengthen flood defence (e.g. dykes, drainage system, canals, and retention area) that focussed on improving the engineering technology of flood mitigation but also established emergency response measures such as evacuation areas in Bangkok Metropolitan districts (Chen, 2007; Phamornpol, 2011). In Ho Chi Minh City, socio-economic implementation (i.e. Master development plans, investment plans, etc.) was initiated in the late 1980s. The Vietnamese authorities opted for rapid urban expansion and deforestation due to the pressure of economic growth. During that period, the

authorities have a limited consideration on urban floods and rely on engineered measures on flood issues (Krystian and Nguyen, 2005; Labbé, 2010), and later in the 1990s started considering flood relocation and relocated over 1 million people away from frequent flood zone (Danh and Mushtaq, 2011).

Across China, taking account into Shanghai, for example, the authorities started to recognise a "risk-based" flood management strategy. FRM approach has been recognised as a step-ahead as the municipality government understood the importance of learning "flood risk" analyses and information to evaluate the hazards and responses on measures (Lu, 2010). For example, the Shanghai authority acted to raise the flood protection level of coastal defence from 1-in-100 to 1-in-1000 year protection level during the early 2000s (Yin et al., 2015; Zhou et al., 2016). In Guangzhou, the municipality government similarly reacted after frequent floods in the late 1990s and adopted flood risk measures (Wong and Zhao, 2001). The authorities then promoted green infrastructure (e.g. via "*Green-blue network*" in Nan Sha District) to protect ecology and recognised cultural value by conservation of heritage out of flood impacts (Timmeren, 2014; Han et al., 2015).

In the last two decades, these cities have experienced more floods bringing greater urgency for governments to progress and consider wider socio-economic and environmental pillars in flood risk management, whilst also being influenced by global FRM practices. For example, Jakarta established a Comprehensive Flood Management Plan that recognized higher risk (e.g. populations, flood locations, etc.) (JICA, 2013). The authority adopted land use planning measures to avoid development increasing flood risk and implemented micro-insurance schemes and relocation contingency plans to improve resilience (Jha et al., 2012). Similarly, in Bangkok, the Thai Government established a flood resilience strategy based on catchment management after the severe 2011 flood. This was the worst flood since 1942 with 46.5 billion USD damages and 680 deaths (Poaponsakorn, 2015) and recorded insurance losses solely from Japanese factories (e.g. Toyota, Honda, and Nissan) of 10 to 15 billion dollars. This enhanced global insurers' and governments' understanding of the chain effect of large floods (Meehan, 2012). The Government initiated a flood risk zoning policy and restricted developments in high-risk areas (Water Resource Management Strategic Committee, 2012; Berkowitz, 2013; Supachai, 2016). In Vietnam, the authority has also established integrated flood management strategies (Eckert and Huynh, 2016), but the municipal governments still focus on engineered flood measures (Katzschner et al, 2016).

In China, Shanghai and Guangzhou governments have moved forward in alignment with the National Climate Change strategy. For example, Guangzhou has followed the National 12th Five Year Plan included a National Adaptation Strategy (NAS) for climate change (UNDP China, 2012), and established a scientific warning system based on accurate flood risk information (Lyu et al., 2016). Shanghai was identified as one of the most vulnerable Chinese cities under climate change (Hallegatte et al., 2013; Francesch-Huidobro et al., 2017; Yuan et al., 2017). The authority further established the flood monitoring and forecast systems and the Meteorological Office worked with the IPCC on climate projections to further improve public emergency warning, planning, and preparedness (Li, 2015). Singapore is transforming from a "*City in a Garden*" to a "*City of Gardens and Water*". The Government is also further implementing the "*Active Beautiful Clean*" (ABC) Waters Program for delivering sustainable and climate-resilient measures on urban stormwater management and adopted the "*source-pathway-receptor*" (SPR) model to address flood risk and climate change (Chan et al., 2018; Liao 2019).

Climate change is raising sea levels making storm surges more hazardous (Nicholls, 2011), and is increasing the frequency, intensity, and magnitude of storms (typhoons), intense rainfall events, and sea surges (Basconcillo and Moon, 2021; Chan et al., 2021; Ku et al., 2019; Webster, 2008; Webster et al., 2005). Natural resource extraction is also increasing flood hazard through the land subsidence it causes; for example, in the coastal area of Bangkok groundwater extraction has resulted in subsidence of two metres since 1970 (Syvitski et al., 2009). The cities that are selected in this review rely upon hard-engineered defences and their previous ways to deal with flooding, but these structures offer a relatively low degree of protection (e.g. under 1-in-10 years). For example, the major urban drainage systems in Singapore have been improved from 1-in-50 years up to 1-in-100 years, whilst Guangzhou and Shenzhen only have a 1-in-20-year return period protection against typhoon and sea surges (Chan et al., 2012; Chan et al., 2018). Further, fatalities occurred in Hong Kong in 2010 when pluvial flooding overwhelmed the 1-in-50-year protection level defences, whilst Shenzhen only has a 1-in-20-year return period protection against typhoons and sea surges (Chan et al., 2012).

Confront with Climate Change, the existing levels of protection are not enough. There is an urgency improving flood protection standards with heavier investment financially, but we also need to address social and environmental perspectives altogether for reducing future flood risk. That said it is sensible to encourage Asian coastal cities to move further towards SFRM. We have been using other global lessons and experiences (from 4 countries) that destined ways forward on flood management.

Table 3: Development of flood management practices in selected E. and S.E. Asian cities

City and their country	Flood management practice in Asian cities relative to dominant flood paradigm in the West		
	Before the 1990s Flood protection (control and defence)	**2000s Flood risk management (FRM)**	**Post-2000s Sustainable flood risk management (SFRM)**
Jakarta, Indonesia	Solely engineering response with Dutch colonisation influence (Jha et al., 2012).	FRM practice develops after the 2002 and 2007 floods. Non-structural measures were implemented in the Urgent Flood Mitigation Project (WHO, 2007; World Bank, 2009).	Improving resilience e.g. established the Coastal Defense Strategy (JCDS) in 2014 (Hidayatno et al., 2017).
Bangkok, Thailand	Practice focused on engineering solutions (Takeuchi, 1993; Bouriboun, 1998).	Improved flood engineering technology (e.g. dykes, drainage system, etc.) and identified evacuation areas at the Metropolitan Administration (Chen, 2007; Phamornpol, 2011).	Established the community resilience plans, recognised flood risk after 2011 big floods (Berkowitz, 2013; Supachai, 2016).
Ho Chi Minh City, Vietnam	Irrigation canals and agricultural engineering works dominated to protect crops (Huu, 2011; Katzschner et al, 2016).	Doi Moi social market economy reforms and dominated engineered measures (Krystian and Nguyen, 2005; Labbé, 2010). In the late 1990s, initiated flood relocation scheme in flood zones (Danh and Mushtaq, 2011).	Integrated flood management was established (Eckert and Huynh, 2016).
Guangzhou, China	Engineered measures to protect settlements (Zou, 2012; Meng and Dubrwoski, 2016).	Combat flood risk in various practices (Wong and Zhao, 2001); Promote ecological and cultural value (Timmeren, 2014; Han et al., 2015).	Guangzhou improved the flood warning system and adopted a Climate Change resilience plan (Lyu et al., 2016).
Shanghai, China	Flood management focused on engineering works (Dou, 1991; Ke, 2014).	The municipal government extended flood risk analysis and raised the level of protection to 1 in 1000-year flood (Yin et al., 2015; Zhou et al., 2016).	Shanghai Meteorological Office worked with the IPCC on climate (e.g. sea-level rise) projections and improved resilience measures (Li, 2015).
Singapore, Singapore	Singapore government invested in engineering works to alleviate floods in 1972 (Lim, 1997; Lim and Lu, 2016; Chan et al., 2018).	Pioneered in SE Asia to establish the LID practices after the 1990s (Lim and Lu, 2016).	ABC Waters Program was launched that based on BGI and LID in 2006 (Liao, 2019). Addressing climate change with the SPR model (Chan et al., 2018 and Liao 2019).

575 A key impetus of the shift in practice from the flood protection and defence paradigms, to SFRM, has been a recognition that the costs of traditional hard engineered flood defences are increasingly unaffordable, and that a wider package of measures is needed to address flood risk. As learned in the aftermath of the Hurricane Katrina disaster in New Orleans, FRM also requires

better development of non-engineered measures, ranging from strategic land use planning with substantive public participation (Neville and Coats, 2009), specific attention to the most vulnerable communities (including insurance to aid recovery) (Chamlee-Wright and Storr, 2009; Burby, 2006), and well-prepared emergency and evacuation plans for when floods strike (Niedoroda et al. 2010). All of these should be considered through a Multi-Criteria Decision Analysis of alternative strategies). Experience with Hurricane Harvey in 2017 suggests that even if these lessons have been learned, flood risk may remain high due to a legacy effect of past land-use planning and investment decisions.

Hard engineered flood protection measures will always be important in the defence of Asian cities, but whilst these defences can be more coherently planned (Francesch-Huidobro et al., 2017), evidence indicates that the level of protection needed is unaffordable (Jongman et al., 2014). Despite the apparent limitations of relying solely on structural defences, few efforts have yet been made to adopt a wider set of measures that incorporate non-structural protection measures, pre-emptive strategic and land use planning, risk awareness and communication, emergency planning, and post-event recovery and learning.

Current approaches also tend to focus on potential economic losses, neglecting the role and value of the natural environment and social considerations, such as impacts and recovery potential of different social groups, and participatory planning. Indeed, most Asian cities (even those with high flood risk) remain focused on hard engineering solutions (refer to Table 3) and lack a sufficient range of climate change adaptation guidance and practice (Nguyen, et al., 2021), which may prove problematic as sea-level rises, and extreme storms, surges, and typhoons become more frequent. Given the lack of affordability of the level of engineered defences necessary to mitigate rising flood risk, Asian coastal megacities may find it advantageous to recognise the wider international experience and develop coping strategies that reflect a greater acceptance of options of '*Living with flood risk*' rather than assume that all such risk can be engineered away. Such coping strategies combine traditional engineering, soft engineering (e.g. SuDs), land-use planning, working with rather than against nature, and social strategies that recognise vulnerable communities, and engage stakeholders in the co-production of responses to flood risk. The international experience clearly shows that the SFRM approach is more complex than control or defend, hence significant operational and procedural challenges can be expected, with good governance needed to engage stakeholders effectively whilst avoiding undue institutional complexity.

4 Conclusion

In Asian coastal megacities, flood risk is high and rising, and defending against flooding effectively using traditional approaches is becoming financially unsustainable. Coping with flood risk, as illustrated by 'Room for River' concepts, and through 'soft measures', as discussed above, is in some countries increasingly considered a necessary and more sustainable alternative to hard-engineered defences alone.

The policies in 4 countries as case studies demonstrate important lessons for achieving long term SFRM to deliver flood management practices consistent with socio-economic and environmental concerns. We accept that different countries and

cities have their interpretation of SFRM but recommend that policymakers adopt “mixed options” for long term sustainability with social, economic, and environmental considerations.

However, this is a philosophy that has had relatively little influence on practice in the coastal megacities of Asia. There is, of course, no prescriptive template for developing coping strategies, and each country and city will need and wish to develop measures appropriate to their specific contexts - physical, socio-economic, environmental, and cultural. Specific local knowledge (i.e. circumstances, contexts and constraints) in Asian coastal cities/megacities will need to be considered.

For very dense coastal megacities ‘making space for water’ opportunities may be rather more limited than they are elsewhere in the world, such that coping strategies will develop with different emphases and we are not trying to make this ground for urban or rural areas, which even urban areas should be re-considered their long-term land-use planning (i.e. Master Plans) that coping with the climate extremes and nature. Once the limitations of hard-engineered defences are recognised and understood, sustainable development principles and tools can be used to shape coping strategies and help deliver more flood resilient cities.

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