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Climate change & flood risk: challenges for the coastal regions of East Asia

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Abstract

Over recent years a body of evidence has grown to suggest that East Asia is experiencing the effects of climate change. Allied to this is that coastal populations and economic assets are becoming more vulnerable to flood hazards. Flood vulnerability has increased owing to the combination of a number of human and physical variables: a) rapid coastal urban growth, b) anthropogenic changes to the environment, such as land subsidence through natural resource extraction or the removal of natural protective barriers, and c) increase in frequency and magnitude of coastal hazards associated with typhoons, storm surges, and sea-level rise. East Asia's population is highly concentrated on low-lying coastal regions and deltaic cities are especially at risk. However, effective adaptation to climate impacts on many coasts is yet to develop. In this chapter, the drivers of coastal vulnerability are reviewed and examined in East Asia, exemplified by the Pearl River Delta (PRD), and its megacities of Guangzhou, Hong Kong and Shenzhen. The population of the PRD is expected to reach 120 million by 2050 and the delta is one of the most important economic centres in East Asia. Flood risk is substantial in the PRD, but flood-risk management appears to suffer from a lack of sufficient strategic planning to prepare for future climate extremes. Drawing on international experience of climate change adaptation and flood risk management, we suggest a path forward to develop adaptation strategies for deltaic and coastal cities in East Asia.

Keywords: Coastal Hazards, Pearl River Delta, Megacity, Vulnerability, Flood Risk Management

1. Introduction

Currently, more than half of the Asian population live in coastal areas, especially in vulnerable deltas and coastal cities (Fuchs et al. 2011, Woodroffe 2010). More than 325 million inhabitants are living in coastal low-lying flood prone areas in East Asia alone (McGranahan et al. 2007). Many of these areas are predicted to be vulnerable under near-future climate change (e.g. sea-level rise), with millions of people and their economic assets exposed to floods and storms (Ward et al. 2011). Seto (2011) projected that in the next few decades, most population increase will take place in the exposed deltas, estuaries, coastal zones and coastal cities of Asia (and Africa) due to better employment and education opportunities. Rapid socio-economic trends amplify the possible consequences of future floods, with increasing urban populations and greater financial capital invested in the flood-prone coastal zone. Hanson et al. (2011) found that more than twenty cities in East Asia's populations and economic assets will be highly exposed to coastal flood risks in the 2070s. Wilby and Keenan (2012) expect the frequency, intensity and duration of extreme precipitation events to increase as a result of climate change. Many Asian coastal areas are suffering from an increasing frequency of typhoons, rainstorms and storm surges from the West Pacific (Webster et al. 2005). At the same time, various deltas and coastal cities also experience (often anthropogenically-induced) land subsidence (Syvitski 2008).

In recent years, numerous coastal areas throughout Asia, especially deltas, have been impacted by severe floods. For example, Cyclone Nargis in 2008 inundated to 75 km inland in the Irrawaddy Delta in southern Myanmar (Terry et al. 2012), causing 146,000 casualties and economic losses over USD17 billion (Syvitski et al. 2009). Natural disasters also have huge global economic impacts: the central Thailand floods in 2011 caused serious economic damage of >100 billion baht (equivalent to US$4 billion) (BBC 2011), and together with the Tohoku earthquake and ensuing tsunami in northern Japan, had a cascading effect on global supply chains (Shibahara 2011). This chapter aims to understand the vulnerability to flood risk and to assess how current climate change adaptation and flood risk management might be improved in the East Asian region (China, Hong Kong) specifically. East Asia is of particular relevance to discussions of flood risk vulnerability due to high (and rapidly growing) coastal populations, historical evidence for coastal inundation events, and an expected increased vulnerability in the future associated with global climate change. The discussion focuses on the causes of coastal vulnerability and evidence of climate change impacts on coastal populations, and then presents an in-depth case study for the Pearl River Delta. Ultimately we ask the question, can international flood risk management experiences offer valuable insights to reduce coastal vulnerability in East Asia?

2. Causes of coastal vulnerability and evidence of climate change impacts on coastal populations

2.1. Geography and demographic change in East Asia

The deltas and coastlines of East Asia are home to large populations. Yeung (2009) reported how most of Asia's megacities (those with a population near or in excess of 8 million) are located on coastal or deltaic areas. In East Asia, the Yangtze and Pearl River deltas support populations of more than 75 million and 40 million respectively (Gu et al. 2011). These areas contribute an important proportion of national economic and industrial development, with manufacturing of electronics, automobiles and textiles. Rapid coastal urbanization and industrialisation has caused huge internal migration from rural to continental areas (Long et al. 2009) and resulted in a large and significant 'floating' migrant population (Bailey 2010).

National economic policy has driven the rapid urbanization of East Asia's coastal regions, for example China's "open door [economic] policy" in 1979, transformed its previously agrarian coastal regions into industrial economies, catalysed by the establishment of Special Economic Zones (SEZs) (Yeung 2010). SEZs are mainly located in three major deltaic areas in China, such as the Bohai economic zones in the Yellow River Delta and periphery, the Yangtze River Delta and the Pearl River Delta. Pudong in Shanghai and the Suzhou development zones in the Yangtze River Delta are both success stories of the last few decades. The Pudong New Area (PNA) had a population of 1.5 million with a GDP of about RMB6 billion during the 1990s (Yeung and Sung, 1996). Now the PNA is the symbol of China's economic reform, with GDP exceeding RMB92 billion in the 2000s. At an annual growth rate of >18%, it helped Shanghai become the most important economic hub in East China (Zhang et al. 2012). Similarly, Suzhou also exhibits accelerated development as a high-tech industrial zone (Wei et al. 2009). The city has attracted more than 7,500 foreign enterprises, with investments totalling some RMB210 billion in the 2000s. Recent figures suggest the GDP of Suzhou has reached over RMB670 billion (Gu et al. 2011), and is now one of the most rapidly growing cities in China. These examples illustrate how economic reform and urbanization influence rapid demographic change in the region.

Several countries in SE Asia are following similar development policies and economic reforms. The Vietnam and Myanmar governments have adopted SEZs in the Mekong, Red River and Ayeyarwady deltas, with resulting rapid urbanization in their coastal cities (Seto 2011). Yangon on the Ayeyarwady delta recorded a population growth of at least 22% every decade since the 1960s (United Nations 2010). While Tokyo was the only megacity in Asia during 1950s, eight megacities have emerged in East Asia during the 2000s, seven of which are located in coastal areas (Osaka-Kobe, Shanghai, Jakarta, Manila, Seoul, Guangzhou, Shenzhen and Hong Kong). It is projected that other coastal megacities will emerge in the region by 2015 (Yeung 2009).

2.2. Consequences of Climate change – flood risk in East Asian coastal areas

2.2.1. Climate change and flood risk

East Asian coastal regions already experience a high incidence of extreme events such as typhoons and storm surges (Mendelsohn et al. 2012), the negative effects of which are generally more prevalent in coastal areas than inland (Ericson et al. 2006). Climate change will worsen flood risks from both landward and seaward directions. Landward influences on flood risk relate to higher rainfall from large storms. The frequency and intensity of storms and other extreme events in the West Pacific region has increased from the 1970s to 2000s, a trend which may continue further owing to climate change (Wilby and Keenan 2012, Hanson et al. 2011, Prudhomme et al. 2010). There is strong and clear evidence that elevated greenhouse gas concentrations will contribute to greater volumes and intensification of precipitation events (Min et al. 2011). This is expected to significantly increase annual mean river discharge and annual maximum monthly discharge, equating to a higher annual probability of the 1-in-a-100-year flood event for many large drainage basins (Milly et al. 2002). Studies elsewhere have already quantified the links between increased human greenhouse gas contributions and heightened flood risk; for example, greater precipitation and runoff directly attributable to climate change increased flood occurrence in England and Wales by up to 90% in the year 2000 (Pall et al. 2011).

From the seaward side, a rise in global mean sea level is escalating the flood risk for low-lying coastal areas. While predictions vary widely, recent estimates suggest a possible global sea-level rise of 150 cm to 190 cm by the end of the century (Vermeer and Rahmstorf 2009). Rising seas cause a range of effects that are factors in flood risk, such as coastal submergence, erosion and ecosystem loss (Nicholls et al. 2011). A rising sea level also raises the baseline for storm surges driven ashore by extreme meteorological events (Ericson et al. 2006), which may result in more frequent inundation or overtopping of sea defences that are designed for lower-level scenarios. Moreover, for the western North Pacific Ocean, annual and decadal cycles in the genesis points, migratory paths and maximum intensities of typhoons should be anticipated (Terry & Feng 2010; Feng & Terry 2012), which in turn influence the likelihood of coastal inundation by systems that eventually make landfall along East Asian coastlines.

Of course it is important to remember that the physical impacts of climate change are just one component of overall “flood risk”. Risk may also increase owing to anthropogenic land uses (section 2.2.2) and socio-economic factors relating to rapid urbanization and population densities in coastal zones (section 2.1), as well as by the fluvial and coastal consequences of climate change already mentioned.

2.2.2. Climate change, human influences and outlook

Anthropogenic land use exacerbates the magnitude of sea-level rise, and thus overall coastal vulnerability. Today, many coastal and deltaic regions in East Asia are confronting land subsidence in response to declines in fluvial sediment loads reaching the coastal zone (caused by upstream river damming), land compaction and resource extraction (e.g. petroleum, gas and groundwater). On the east coast of China, annual rates of land subsidence in Tianjin exceeded 11 cm during the 1980s owing to groundwater extraction, with cumulative subsidence rates exceeding 1 m in the last decade alone. Subsidence affected an area of 60,000 km^2, with a maximum subsidence of 3.9 metres recorded at Tianjin since the 1950s (Xu et al. 2008). Tang et al. (2008) reported that much of central Shanghai is now 2 m below mean sea level, with the CBD area now reliant on structural flood protection measures. Recent research has revealed that the city is the most vulnerable to coastal floods compared with 8 other global coastal cities (including Rotterdam, Osaka, Manila and Dhaka) (Balica et al. 2012). Bangkok faces similar issues. Over-extraction of groundwater in the Chao Phraya

Delta has caused subsidence of >2m since the 1970s, with an annual subsidence rate of 10 cm/yr. Partly in consequence, the shoreline of Bangkok has receded by several kilometres (Chen and Saito 2011).

Rapid urbanization also causes negative geomorphic impacts on coastal and deltaic areas. Sediment input has declined due to the diversion of river channels and the construction of levees, artificial riverbanks and upstream dams (Syvitski and Kettner 2011). These practices limit the sediment supply needed to maintain deltas and associated wetland habitats (Yang et al. 2006) hence aggradation, the natural increase in surface due to sediment deposition is reduced. Syvitski and Saito (2007) estimated that sediment loads have reduced by >70% in the deltas of the Yellow and Yangtze rivers and >90% in the Pearl River Delta. Most of East Asian deltas are therefore sinking in response to these human and natural influences (Syvitski et al. 2009).

All of the above exacerbates flood risks from storm surge and sea-level rise for East Asian coastal cities, 16 of which are ranked in the top 20 from 136 global port cities at risk (Hanson et al. 2011). Moreover, coastal megacities cities will continue to experience rapid socio-economic growth. For example, Qingdao on the east coast of China will continue developing as a technological hub (Yeo et al. 2011) and economic assets there may increase to USD 600 billion. However, Gu et al. (2011) cautioned that the Yangtze River Delta has insufficient flood protection infrastructure, and populated East Asian coastlines all need better preparation for the future (Nicholls 2011). There is an important and urgent need for appropriate flood risk management strategies to be developed for East Asia.

Table 1 is about here

3. The case of East Asian mega-deltas

3.1. Current challenges of mega-deltas in East Asia – the PRD case

The PRD is located in southern Guangdong Province of China, covering 11 cities including the Hong Kong and Macau Special Administrative Regions. The agricultural delta before the 1980s has now been transformed into China’s major industrial and economic hub. For example, the fishing town of Shenzhen has grown into a megacity with over 15 million people (Yeung 2009). Other PRD cities have similarly recorded a 5 to 10-fold growth in population within the last three decades (Vogel et al. 2010). Remarkably, the PRD covers <1% of China's landmass (41,698km^2) (Yang 2006), but contributes 20% of its national GDP, being called the 'World's Factory' by economic commentators (Yeung 2010). Reforms and huge investments have attracted international trade and a large labour force through migration (Bailey 2010). The PRD now has a population of some 60 million (Marsden 2011) and is the world's most densely populated delta with >7,500 people per km^2 (Syvitski and Saito 2007). UN-HABITAT (2008) projected that the population may increase to over 120 million by 2050. This extraordinary growth has led to rapid urbanization and concomitant vulnerability to both inland and coastal flooding.

3.2. Climate change and flood vulnerability in the PRD

3.2.1. Inland floods

The PRD catchment is mostly characterised by steep hills and floodplains, comprising >20% and 70% of the land area respectively (Cheng 2005). Inland floods in the PRD occur in summer from May to September (Dou and Zhao 2011; Zhang et al. 2010), when 80% of the annual rainfall (2200 mm) arrives, often as intense precipitation associated with Pacific typhoons. The Hong Kong Observatory (HKO) noted that both the peak intensity and frequency of rainstorms in the PRD region have increased during the last century, a trend that is likely to continue in the near-future (Lee et al. 2010). Particularly, the frequency of heavy rainfalls (>100 mm in 24 hours) may increase the risk of flash flooding, particularly in the flood-prone Guangzhou, Shenzhen and Hong Kong megacities. The PRD has also experienced flooding of the main Pearl River during the wet season. Guangzhou has experienced significant inundation twenty-four times since the Ming dynasty (1368 AD), with ten large flood events 1911 and 1983 (Weng 2007). The 1915 flood of the North and West Pearl Rivers was the most severe, a 1-in-200 year event that displaced some 6 million people, and caused 100,000 deaths and injuries in the western PRD (Zhang and Wang 2007). More recently, over 8-17 June 1994, flooding after >600 mm precipitation from Typhoon Russ caused 102 deaths, 2000 injuries, the inundation of more than 9000 villages, 230,000 houses and 100,000 ha of farmland. The total economic loss stood at RMB 3.2 billion (Wong and Zhao 2001). Many embankments and dikes along the North Pearl River were breached and collapsed; prompting questions on whether existing flood protection structures will meet future needs (Huang et al. 2004).

A projected increase in extreme events is exacerbated by rapid urban development in the PRD, which increases surface runoff. The urban land cover of 30% in the delta in 1982 is now >80%, mostly on the floodplains (Yeung 2010). Consequently, maximum urban flood discharge in Shenzhen has increased by nearly 13% in 10 years Shi et al. (2007). Similarly, Typhoon Chanthu in July 2012 highlighted vividly how urban drainage systems in Hong Kong, designed for the 1-in-50 year flood, may not be able to cope with future peak discharges (Chui et al. 2006). Fuchs et al. (2011) therefore questioned the appropriateness of further urban expansion in exposed Asian deltaic and coastal areas in the face of unpredictable climatic regimes.

3.2.2. Coastal floods

Whilst preparing for, and managing inland flood events, East Asian megacities are also vulnerable to coastal flooding. Vulnerability is caused, in part, by anthropogenic changes to the coastal zone. In the PRD more than 3,720 km^2 of coastal land has suffered subsidence, especially in Macau, Zhuhai, Zhongshan, Shenzhen and Guangzhou cities. Much subsidence is triggered by construction on Mollisol soils, which are often unstable with an organic rich profile, a calcareous base and become saturated easily (Xu et al. 2009). At the same time, rapid urbanization causes land scarcity and municipal governments have favoured land reclamation to meet demands, such as the large Shenzhen Bay reclamation project along the Shekou Peninsula (Li and Damen 2010). In some areas, reclamation has extended coastlines over 1 km seawards during the last decade (Hay and Mimura 2006). Unfortunately, most reclaimed lands were converted from coastal wetlands such as mangroves and saltmarshes, which can provide seawater storage or hydrodynamic attenuation during regular tidal cycles (e.g. Möller 2006, Lacambra et al. 2013). Reclamation activities also modify estuarine morphology, by introducing dry land where previously only wetland existed, which may likewise affect tidal dynamics in the PRD (Zhang et al. 2009).

Recent research showed that mean sea-level rise in the PRD has risen with the rate at twenty six mm per decade from 1954 – 2009, and noted a significant upraise during the 1990s (Figure 1) (Zhang et al., 2011b). Woo and Wong (2010) projected sea-level would rise a further 200 mm in the PRD by 2050, exposing more than 2,000 km^2 of coastal low-lying areas to tidal inundation (Huang et al. 2004).

Figure 1 is about here

Since the PRD is located within a subtropical monsoon climatic zone, typhoons and storm surges are common during the wet season, as previously mentioned. For example, storm surges driven by typhoons Hagupit and Koppu in 2008 and 2009 inundated the low-lying coastal areas of Tai O town, flooding 100 properties (Figure 2). From 1991 to 2005, 41 storm surges of 2-3 metres occurred in the PRD as a whole (Zhang et al. 2011a), while the HKO recorded over 10 surges higher than 1.5 m from 1954 to 2009 in Hong Kong alone (Lee et al. 2010). Typhoon Wanda in 1962 was a particularly severe event that generated a surge reaching 4 metres average mean sea-level (Yim 1996). Historical events like this, which could recur again, underscore the vulnerability of Hong Kong and other PRD cities to future typhoon-generated surges and associated coastal floods.

Figure 2 is about here

3.3. Current governance in climate change adaptations and flood risk management

In spite of the contextualisation of flood risks facing the PRD as mentioned earlier, flood risk management (FRM) and climate change adaptation (CCA) are receiving little attention. More than 86% of the PRD coastal area relies on flood protection infrastructures (dikes and embankments); although only a limited proportion could withstand a 1-in-100 year event (Cai et al. 2011). Moreover, if a projected sea-level rise of 30 cm occurs by 2030, then a 1-in-100 year storm surge would inundate 80% of the delta, with an estimated 1 million homes flooded, and economic losses exceeding RMB 232 billion (Zhang 2009). Notwithstanding these estimates, however, improving the current flood protection standards in diverse deltaic and estuarine areas would be costly (Woodroffe 2010).

Alarmingly, a recent governmental report on PRD strategic regional planning (Guangdong Province Housing & Urban – Rural Department 2011) addresses neither existing flood risks nor the possible effects of climatic change. Ng (2012) criticised the fact that regional CCA remains at the public consultation stage (EPD 2010), with limited consideration of implementing FRM. Past events have also shown that no institutions are specifically responsible for coastal flood mitigation. In Hong Kong, for instance, the Drainage Service Department (DSD) mainly deals with urban flood problems and their Stormwater Manual illustrates ad-hoc approaches that are not based on strategic long-term plans that take into account climate change projections (DSD 2000). Similarly, Zhou and Cai (2010) noted how numerous land reclamation and development plans with the Shenzhen Bay area do not include coastal flood vulnerability, and it is more than apparent that the PRD and other Asian coastal cities need to address projected climate change extremes within CCA (Fuchs et al. 2011). Lack of central coordination of flood management may be an issue for many regions globally, though this has particularly dire consequences for a heavily urbanised and vulnerable area such as the PRD.

Regarding inland and river flood management, the PRD region has a long history of protection measures. Dikes and river channel diversion have been used for centuries since the Ming Dynasty (Weng 2007). In modern times, local governments continue to depend on hard engineering approaches. Hong Kong and Shenzhen authorities for instance rely mainly on river regulation through construction of artificial channels and embankments for flood protection against 1-in-50 year events. Protection is aimed at economic assets such as railway terminals, luxury properties and government buildings (Chui et al. 2006). However, the channelised river silts up without frequent dredging, so reducing flood protection by 50% (Chan and Lee 2010). This demonstrates that engineering defences are insufficient, and that integrated FRM approaches incorporating ‘soft’ protection measures such as flood warning and risk mapping are necessary for urbanised cities (Ma et al. 2010). Hong Kong and Shenzhen authorities have applied flood risk modelling in the Drainage Master Plan (Chui et al. 2006), although certain aspects of the planning process cannot take advantage of this important information until it is released into the public domain. Overall, the PRD and most Asian coastal regions currently face tough challenges, with a lack of holistic FRM policy existing against a canvas of rapid socio-economic growth and emerging climate change threats.

4. European experiences in Flood Risk Management offer important lessons for East Asia

Growing threats of climate change in East Asia, particularly risks of more frequent floods affecting populous deltas and coastal cities within existing constraints to effective mitigation, suggest that it may be wise to learn lessons from wider international experiences.

In the Netherlands, the Dutch people have lived with floods for centuries, as most of the country, including the large cities of Rotterdam and Amsterdam, lie near to or below sea level (Van Koningsveld et al. 2008). Consequently, Dutch authorities have learnt to use dikes to protect against high tides, windmills to pump water from floodplains, and have successfully reclaimed agricultural land from the sea since the 13th century (Wesselink et al. 2007). Nonetheless, unprecedented floods events still occur. The 1953 flood during a storm surge in the North Sea breached 900 dikes, inundated more than a million properties and caused 1,835 deaths (Vis et al. 2003, Gerritsen 2005). Afterwards, the Dutch government recognised that coastal measures to cope with the 1-in-10,000 year return period event were needed (van Stokkom et al. 2005). The 1953 storm surge led to an unprecedented national-scale engineering works involving a complex system of dykes and surge barriers, requiring investment of €13 billion to date (Kabat et al. 2005). Indeed, the 1953 storm surge led to wholesale changes in coastal flood risk management throughout North West Europe. More recently, floods in the Rhine and Meuse rivers during 1993 and 1995 winter rainstorms (Tol et al. 2003) indicated how inland river floods are still a concern, and the government realized by the mid-1990s that flood protection standards would not be able to cope with expected changes in flood events due to climate change. Consequently, the "Ruimte voor de River" ("Room for the River") policy has: 1. encouraged provision of more space for water storage, 2. restricted further developments on floodplains, and 3. begun to manage flood risk strategically by planning within sustainable frameworks (van Herk et al. 2011). Some have voiced criticism over continued infrastructure building on risky areas and a reliance on engineering-based flood management approaches, though more recent policies such as "Living with Water" and "Living in a Dynamic Delta" are promoting resilience against flood risk through the better conservation of floodplains and wetlands (Wesselink et al. 2007). Hall and Penning-Rowsell (2010) support such practices as they also help to sustain nature and biodiversity, and promote good quality of watercourses, thus delivering multiple benefits consistent with the European Water Framework Directive (2000). This policy commits EU member states to achieve a good status, in both qualitative and quantitative terms, for all water bodies by 2015. Van Stokkom and Witter (2008) highlight that the latest Dutch FRM policy is still in a transitional state, and aims to address social justice by ensuring that all citizens benefit equally from flood protection measures. Importantly, the Dutch public have a right to understand their flood risk. This means that relevant risk and hazard information can be publically accessed (e.g. data on flood return periods, flood histories and locations), which raises awareness and improve preparedness (Gersonius et al. 2011). As such, these practices fulfil requirements of the European Floods Directive (European Union 2007) that all EU member states openly provide relevant flood risk information to their citizens by 2015.

The 1953 North Sea floods that impacted the Netherlands also caused severe damage to South East England, with some 300 deaths and widespread inundation, including central London, and most notably Canvey Island in the Thames estuary (Penning-Rowsell et al. 2006). London is another megacity, with a population around 10 million, and Lonsdale et al. (2008) estimated that an area of >345 km^2, 480,000 properties, 1 million people and 2,000 km of transport links are exposed to flood risk. As a measure against storm surge threats to London, the current Thames Barrier began operation in 1983 (31 years after planning commenced), designed to protect up to a 1-in-1000 year event, a standard that at the time was greater than most flood defence measures in the UK. However, although the barrier may provide sufficient protection to meet 2035 climate-change projections, flood vulnerability remains high owing to continuous population increase and economic growth along the Thames estuary: this area has been slated for major development and redevelopment in the coming decades. Worryingly, the design life may well be reached sooner, as the original design in the 1950s-60s did not adequately account for accelerated sea level rise (Lonsdale et al. 2008).

In response, the Environment Agency (EA), the UK government agency responsible for CCA and FRM, has devised a strategic regional flood risk and development plan in the Thames Estuary, namely the ‘TE2100’ project (Environment Agency 2009) (Figure 4). This project is designed to address flood risk holistically, by applying integrated river basin management that includes 1. land-use planning (e.g. restriction of new development in high-risk areas), 2. surface water management and soft FRM measures (e.g. improved emergency response, flood warning systems, and enhanced public participation), and 3. conservation of natural marshland areas (e.g. at the Thames River mouth) (Dawson et al. 2011). The plan deliberately takes a proactive and long-term approach, looking forward 80 years to the end of the century, and importantly considering both “hard” and “soft” flood protection measures. As the EA recognised, in order to deal effectively with emerging climate change impacts over coming decades, it is no longer sufficient, or cost effective, to rely on engineered flood defences and ad-hoc solutions (Environment Agency 2009). Importantly in the context of climate change, TE2100 was one of the first large-scale projects to recognize and appreciate uncertainties in climate projections, and incorporate them into the decision-making process (Kiker et al. 2011).

A third international example, also from the UK, may also have important implications for coastal flood risk management in East Asia. This example is primarily concerned with issues of coastal erosion and CCA, though provides important lessons for how a holistic FRM framework should operate. With an increasing appreciation that coastal processes cross administrative boundaries and can operate over large scales, the UK Government embarked on a series of large-scale Shoreline Management Plans (SMPs), designed as a "large-scale assessment of the risks associated with coastal processes [that] helps to reduce risks to people and the developed, cultural and natural environment" (DEFRA 2006, Winn et al. 2003). SMPs are novel in that they were some of the first management plans where management boundaries were based on a 'behavioural systems approach', incorporating geomorphological characteristics (such as sediment movement and currents), as opposed to purely administrative boundaries. Therefore, they encompass processes and impacts of management decisions that may cross borders and affect neighbouring areas. SMPs advocate a combination of four management decisions along the coast, namely

(i) **advance the current defence line** by building new (hard) defences further seaward

(ii) **hold the current defence line** by maintaining current (hard) defence standards

(iii) **no active intervention,** where current defences are not actively maintained, and

(iv) **managed realignment,** where the coastline is (actively) allowed to move landwards

A key aspect of SMPs is their use in attempting to predict a) future land uses, and b) the consequences of these various management interventions. Similar to the EU Water Framework Directive described previously, the results of the SMP process are publically available, and public participation in this process is encouraged.

To summarise the Dutch and UK experiences, integrated, large-scale and holistic approaches have been developed that are transforming flood risk management in coastal areas experiencing growing threats from climate change and internal growth. However, to date, such approaches do not appear to have been coherently adopted within East Asian cities experiencing similar pressures. A number of important lessons should be learnt from this international experience, and lead to a set of key considerations for improved FRM in the PRD:

1. Planning. FRM must be an integral part of urban and economic planning. For example, DEFRA (2006) describe the close interplay between SMPs and the land use planning process. SMPs may recommend limited development in areas at risk from erosion or flooding, areas where managed realignment is likely to be implemented, or restrict development that may interfere with coastal processes. Like the TE2100 and SMP process, a mechanism for frequent review and update must also be included. In Europe, Directive 2007/60/EC (European Union 2007) (known as the 'Floods Directive') is driving such a review. The directive requires members states to produce a preliminary flood risk assessment, considering impacts on health, economic activity, cultural heritage and the environment. This preliminary assessment then guides more detailed modelling of areas at significant risk, considering the extent and depth of flooding under low, medium and high probability event scenarios. Flood Risk Management Plans must then be established, by 2016, which communicate the flood risk to policy makers, developers, and the public, with a view to developing prevention, protection and preparedness measures.

2. Participation. This is an essential requirement if people and organisations are to make informed decisions about flood risk. Participation is evident in the UK and Dutch flood risk management cases described above (e.g. the Thames Gateway Partnership, TE2100 public consultation, publically-available information in The Netherlands and publically-available and searchable online flood risk mapping tools in the UK (Environment Agency 2012). Similarly the EU Floods Directive recognises the importance of participation in the development of Flood Risk Management Plans, which needs community support if they are to be effective. It does not, however, prescribe how this should be achieved, and it is worth noting that participation comes in many forms, ranging from tokenistic information provision, through to true partnership with full interactive dialogue between parties, perhaps involving citizen juries or community champions (Arnstein 1969).

3. Spatial scale. The Delta Plan in The Netherlands required a national-scale approach to FRM; a municipal or county-level planning approach would be substantially less effective as floodplain and coastal zones are not closed units, but management changes in one locality may have knock-on impacts further along. The Delta Plan and UK SMPs are effective precisely because they take a large-scale approach. The EU Floods directive promotes a coherent approach to spatial scale, by requiring a preliminary flood risk appraisal for each member nation, which informs more detailed local level assessment for identified at significant risk areas.
4. Temporal scale. For example, SMPs identify a combination of management interventions that may be required over the next 100 years (DEFRA 2006). Such a long-term viewpoint allows a proper treatment of issues relating to cost and uncertainty.
5. Integration. FRM must not solely focus on hard engineering works, but integrate other aspects such as soft defence methods, including vegetation (riparian, coastal). Large-scale shoreline management planning (such as in the UK) provides a planning framework to highlight areas where different management approaches (hard defences, soft defences) may be most appropriate. A holistic approach to FRM is required.
6. Uncertainty. Uncertainties inherent in climate change scenarios must be incorporated into the decision-making process. This is explicit in the Floods directive, where low to high probability events must be modelled. The financial (and political) cost of building defences for a scenario that may not occur is high; this approach requires long-term management plans that can absorb these 'sunken costs' (Kiker et al. 2011).

Many of the recommendations listed here require an overarching FRM institutional framework, which provides opportunities to consider multiple management and policy instruments over varying temporal and spatial scales. Previous experiences in Europe, prompted by natural disasters such as the 1953 North Sea storm surge, provide important lessons for the shape such a framework should take.

Figure 3 is about here

5. Conclusions

Across East Asia, coastal regions (deltas and cities) with large populations and have become global hubs of socio-economic activities. The PRD is a primary exemplar. Unfortunately, recent histories demonstrate how the region faces significant flood risks, while rapid economic and population growth continue at astonishing rates. At the same time, current climate change and sea-level rise enhances the likelihood of intensive rainstorms and storm surges delivered by western Pacific typhoons. Consequently, low-lying coasts and East Asian megacities in particular face magnified exposure to severe flood risk.

In spite of this, the East Asian coastal region suffers from limited implementation of holistic strategies that address CCA and FRM. Evidence suggests a tenacious devotion to traditional 'hard' (engineered) flood protection measures, practised in a piecemeal manner. Such approaches are costly and not economically sustainable; more strategic 'soft' management options have yet to be adopted. In this regard, lessons may be learned from experiences in The Netherlands and the United Kingdom where FRM has embraced multiple aspects of CCA, land-use planning, awareness building and pubic engagement.

These EU practices may encourage the testing of similar approaches to improve flood resilience in East Asia. Although the EU is unlike East Asia in many ways, Asian nations should nonetheless strengthen regional collaboration in order to promote CCA within FRM policies. This seems a reasonable recommendation since most East Asian nations are facing similar challenges of balancing coastal development with adequate protection against inundation. Thus, heightened exposure to flood risk on East Asian coasts and deltas, against the backdrop of unabated rates of population and economic growth, emphasises how integrating climate change adaptation and flood risk reduction is an imperative best tackled sooner rather than later.

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Table 1. Selected East Asian coastal megacities ranked top 40 globally in 136 port cities in terms of population and economic assets exposed to coastal flood risk at present and in the 2070s. Data Source: Adapted from Hanson et al. (2011)

Coastal megacities	**Country**	**Located on the deltas (yes/no)**	**Current population exposed on flood risk**	**Future (in the 2070s) population exposed on flood risk**	**Rank in exposed population (in the 2070s)**	**Current exposed assets (USD$ Billions)**	**Future exposed assets (USD $Billions)**	**Rank in exposed assets (in the 2070s)**
Guangzhou	China	Yes, Pearl River Delta	2,718,000	10,333,000	**4**	84.17	3357.72	**2**
Ho Chi Minh City	Vietnam	Yes, Mekong Delta	1,931,000	9,216,000	5	26.86	652.82	16
Shanghai	China	Yes, Yangtze River Delta	2,353,000	5,451,000	6	72.86	1771.7	5
Bangkok	Thailand	Yes, Chao Phraya Delta	907,000	5,138,000	7	38.72	1117.54	10
Yangon	Myanmar	Yes, Irrawaddy Delta	510,000	4,965,000	8	3.62	172.02	39
Hai Phong	Vietnam	Yes, Red River Delta	794,000	4,711,000	10	11.04	333.70	26
Tianjin	China	No	956,000	3,790,000	12	29.62	1231.48	7
Khulna	Bangladesh	Yes, Ganges – Brahmaputra	441,000	3,641,000	13	4.41	177.86	38
Ningbo	China	Yes, Yangzte River Delta	299,000	3,305,000	14	9.26	1073.93	11
Shenzhen	China	Yes, Pearl River Delta	701,000	749,000	**18**	21.7	243.29	31
Tokyo	Japan	No	1,110,000	2,521,000	19	174.29	1207.07	8
Jakarta	Indonesia	No	513,000	2,248,000	20	10.11	321.24	27
Osaka-Kobe	Japan	No	1,373,000	2,023,000	21	215.62	968.96	13
Qingdao	China	Yes, Yellow River Delta	88,000	1,851,000	23	2.72	601.59	18
Nagoya	Japan	No	696,000	1,302,000	27	109.22	623.42	17
Hong Kong	China	Yes, Pearl River Delta	223,000	687,000	39	35.94	1163.89	**9**

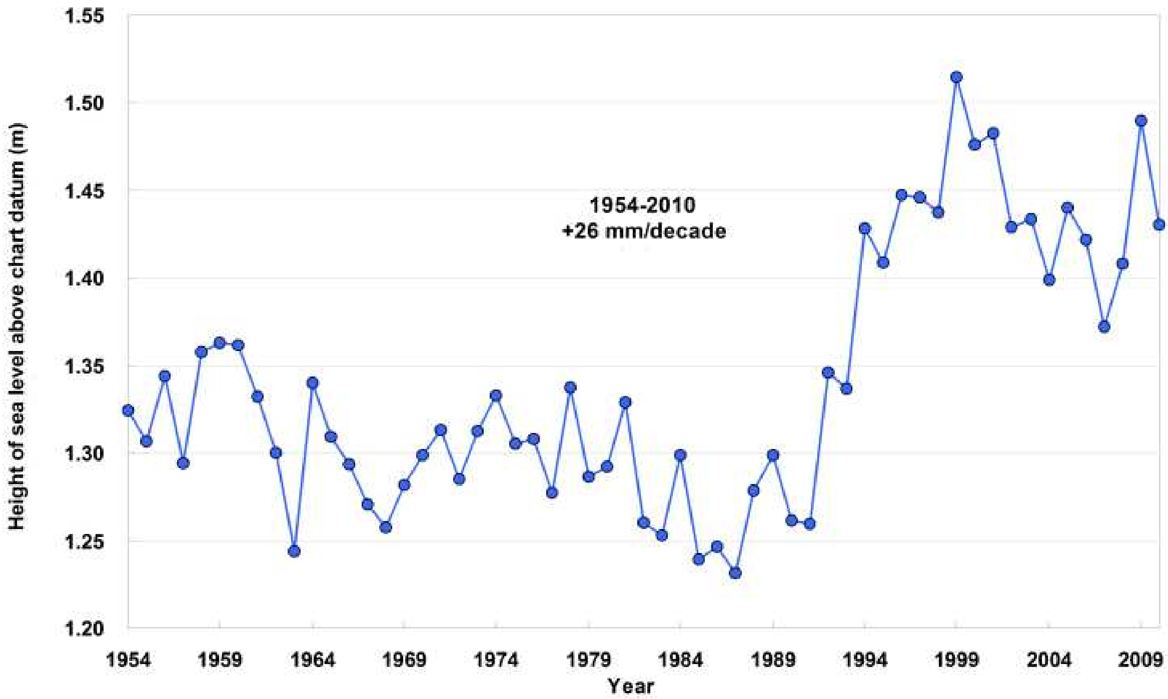

Figure 1. Annual mean sea-level at North Point/Quarry Bay (1954–2008). Source**:** Adapted from Zhang et al. (2011)

Figure 2. Tai O town flood in 2008 after Typhoon Hagupit. Source: TVB

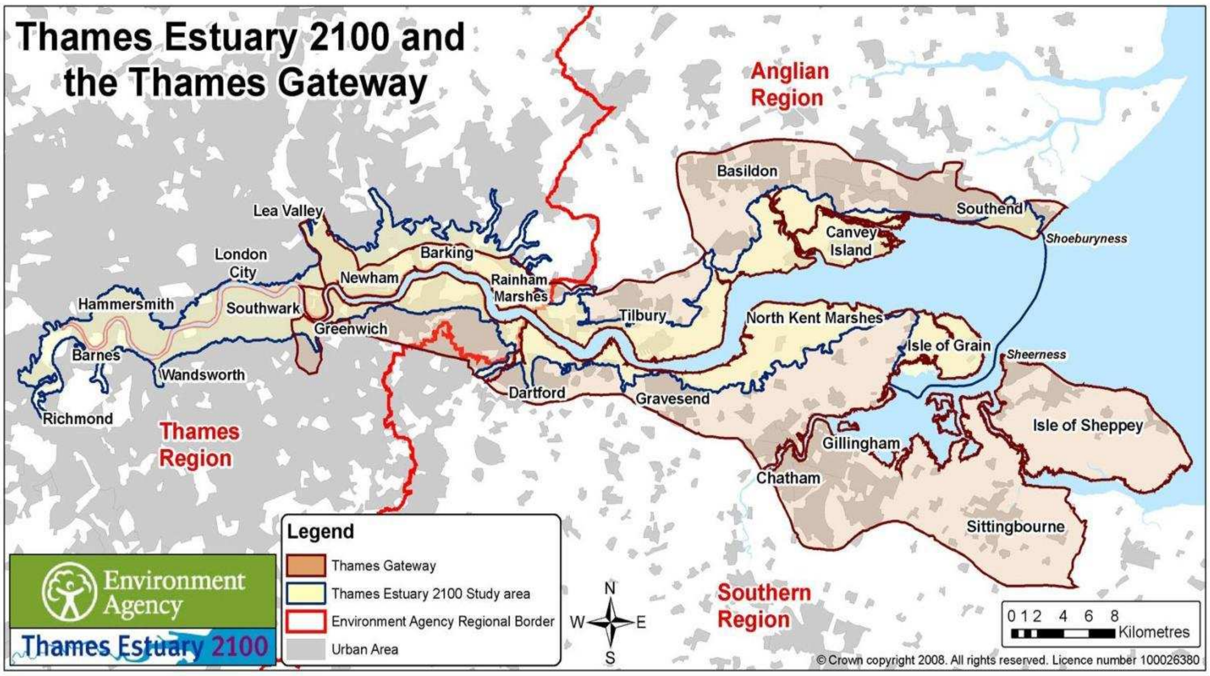

Figure 3. Thames Estuary 2100 project study area. Source: Environment Agency (2009)