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Trends in flood risk management in deltas around the world: Are we going 'soft'?

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Flood-risk management (FRM) is shaped by context: a society's cultural background; physical possibilities and constraints; and the historical development of that society's economy, political system, education, etc. These provide different drivers for change, in interaction with more global developments. We compare historical and current FRM in six delta areas and their contexts: Rhine/Meuse/Scheldt (The Netherlands), Pearl River (China), Mekong (Vietnam), Ganges/Brahmaputra/Meghna (Bangladesh) Zambezi/Limpopo (Mozambique), and Mississippi (USA). We show that in many countries the emphasis is shifting from 'hard' engineering, such as dikes, towards non-structural 'soft' measures, such as planning restrictions or early warning systems, while the 'hard' responses are softened in some by a 'building with nature' approach. However, this is by no means a universal development. One consistent feature of the application of 'hard' FRM technology to deltas is that it pushes them towards a technological 'lock-in' in which fewer and fewer 'soft' FRM alternatives are feasible due to increased flood risks. By contrast, 'soft' FRM is typically flexible, allowing a range of future options, including future hard elements if needed and appropriate. These experiences should lead to serious reflection on whether 'hard' FRM should be recommended when 'soft' FRM options are still open.

Keywords: Flood risk management, Deltas, International comparison, Rhine, Meuse, Mekong, Pearl River Ganges, Brahmaputra, Zambezi, Limpopo, Mississippi

1. Introduction

Societies in delta areas have long taken advantage of the agricultural and transport opportunities offered by the presence of rivers, which provide water for irrigation, silt for soil improvement, and easy conveyance for shipping people and goods. On the other hand, flooding on these same rivers threatens lives and livelihoods. In addition, because of their coastal location, deltas are also prone to flooding from the sea due to high tides and/or storm surges, cyclones etc. In this paper we describe and compare the historical pathways by which societies in six deltas have protected themselves against both types of flooding, and we seek to understand why and how those societies have chosen as they did. We will look for common trends, and try to explain how they have arisen.

Societal responses to flooding may include infrastructure (technology), behavioural rules, and financial and administrative regulations (institutions). These are interdependent; for example, by comparing Dutch and German flood management practices Krieger (2013) shows how the technical understanding of 'risk' itself is institutionally shaped. We start with the assumption that societal responses to flood risk management (FRM) are shaped by local context as well as global developments. Local context includes a society's culture, including formal and informal institutions; the physical possibilities and constraints it faces; the historical development of its economy, political system, education, etc., and last but not least, the technical experience with FRM that a society has accumulated or to which it has access, for example through foreign consultants. In our Conclusion, we also situate the observed FRM histories in the global context of what has been labelled 'modernity'.

After Green, Parker, and Tunstall (2000) and Hegger et al. (2013) and akin to the so-called flood safety chain (Ten Brinke, Saeijs, Helsloot, & Van Alphen, 2008), we distinguish five types of FRM measures; a combination of these make up the FRM approach at any one time in one delta:

- *Flood risk prevention:* reducing the consequences of potential flooding through land-use planning: steering property investment in floodplains (allowing, preventing or removing); relocation of essential services, utilities and infrastructure.
- *Flood protection:* protecting existing assets through ‘hard’ engineering, e.g. dikes, dams.
- *Flood mitigation:* diminishing the flood volume and timing itself through reduced urban drainage, rural land management practices and upland retention; e.g. ‘room for the river’ initiatives.
- *Flood preparation,* including warning systems, disaster planning.
- *Flood recovery*, e.g. rebuilding, insurance.

We shall pay special attention to the current (re)emergence of ‘soft’ FRM, which includes prevention, mitigation, preparation and recovery. A ‘building with nature’ approach to flood protection (option 2) is a borderline case which could also be classified as ‘soft’ FRM, depending on the relative amount of engineering and control. We will show that in many countries the emphasis is shifting from protection through ‘hard’ engineering, such as dikes, towards non-structural ‘soft’ measures, such as planning restrictions, while the ‘hard’ responses are softened by ‘building with nature’ approaches. This is by no means a linear, unidirectional, or universal development.

We note that the current use of the term ‘flood risk-management’ itself is a sign of a shift in the discussions on floods: a few decades ago ‘flood defence’ would have been the term in use, which has a much stronger association with hard engineering (Butler & Pidgeon, 2011). On the other hand, ‘management’ still infers that control is possible; although the addition of ‘risk’ suggests that there is always a residual risk and that fail-free ‘defence’ is impossible. Most recently the notion of ‘adaptive’ or ‘strategic’ delta management is advocated in policy and research (Huitema et al., 2009; Medema, McIntosh, & Jeffrey, 2008), which connote a broader view on human habitation of deltas beyond flood risks alone.

Below, we provide (necessarily concise) descriptions of the history of FRM in six delta areas: Rhine/Meuse/Scheldt (The Netherlands), Pearl River (China), Mekong (Vietnam), Ganges/Brahmaputra/Meghna (Bangladesh), Zambezi/Limpopo (Mozambique), and Mississippi (USA). Overall these deltas share several socio-economic and water management characteristics, albeit at different scales and levels of detail. They are densely populated, house coastal megacities, and have great economic value because of international transport facilities, industrial development, and the investment in property related to both population and economic growth. They are located on low-lying plains and experience increasing flood risk from intense precipitation, (cyclonic) storm surges and high tides, global sea-level rise, and rapid urbanization and industrialisation. For each of these cases, we look into the history and current state of FRM and discuss the drivers for change.

2. FRM in six deltas around the world

In the deltas under scrutiny, flooding originates from different sources: the ocean, rivers, rainfall, or groundwater. Depending on their origin, flood events have different characteristics: salt or fresh water, speed, spread and volume of deposited water, etc., which in turn affect their impact on society. In any flood event, multiple sources may be involved. Technically, it is possible to prevent all but the most extreme floods happening, as illustrated by the extensive drainage and flood defence system in The Netherlands, but the extreme scale of tropical rivers pushes engineering to or beyond its limits (Lahiri-Dutt, 2015). The usual FRM strategy to prevent flooding consists of (partly) surrounding land by embankments, or dikes, that prevent river and sea water from flooding the land some or all of the time. Excess rainwater and groundwater is either drained by gravity, which is possible as long as the land is above the level of the sea and/or river at least some of the time, or pumped out by mechanical means. We start with the Rhine/Meuse/Scheldt Delta in The Netherlands, showing an extreme of technical prowess but also its consequences. Whether the Dutch system should be taken as an example to be followed, as many Dutch experts like to think, is a question we will raise in our Discussion.

2.1. Rhine/Meuse/Scheldt Delta (The Netherlands)

With a combined catchment area of 244,000 km^2 and an average discharge of 3370 m^3/s, the delta of the Rhine, Meuse and Scheldt in The Netherlands has a relatively modest size. The first embankments in The Netherlands were constructed in the 10th century (Huisman, 1998; Te Brake, 2002; Van de Ven, 1993). Over time they had to be heightened and strengthened at regular intervals because an absence of regular flooding causes the land level to drop relative to the water level due to compaction of unconsolidated floodplain sediment. In natural deltas this is largely compensated by fresh sedimentation, but when the land is enclosed by dikes (Figure 1), continuing subsidence renders protection ever more difficult in the long run. The result is known as ‘technological lock-in’: past choices made to protect the land lead to a vicious cycle of investment in ever more advanced technology in order to keep the water out (top half of Figure 1) This is precisely what happened in The Netherlands.

Despite the relatively advanced Dutch protection system being in place, the 1953 flood disaster in the Rhine/Meuse/Scheldt delta caused severe damage and nearly 2000 deaths. Subsequently, exceptionally high flood protection standards were incorporated in law, protecting most of the country to return periods of 1250 to 10,000 years[1]. A large flood defence programme, the Delta Plan, was initiated, including the construction of large dams to close off estuaries and the reinforcement of dikes where access to the harbours of Rotterdam and Antwerp had to be guaranteed (Bannink & Ten Brinke, 2006).

[1] Recently, the calculation of flood protection norms was changed from being based on the return period of design discharges to being based on the risk of inundation. For the sake of being able to compare Dutch figures with other countries, we mention the old norms here. In the new system, protection levels are maintained or increase compared with the old system (Deltaprogramma, 2014).

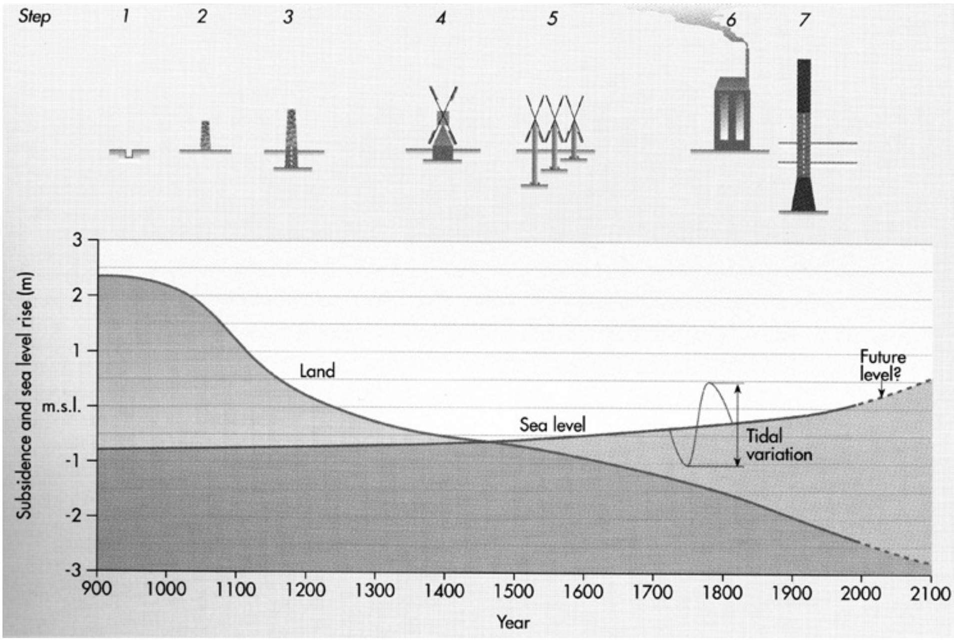

Figure 1. History of FRM technology and subsidence in The Netherlands (source: Huisman, 1998)

The 1970s marked the start of an 'ecological turn' in Dutch water management (Disco, 2002). Societal pressure, but also the growing professional doubts about environmental impacts of large-scale engineering, were instrumental in a decision not to close off the last estuary, the Oosterschelde (Bijker, 2002). Instead, civil engineers rose to the challenge of designing a storm surge barrier which would provide flood protection when necessary but which is usually open to maintain the existing ecosystem dynamics. This can be considered a precursor of 'softer' protection, though still based on very 'hard' engineering. In response to river flooding in 1993 and 1995, a second Delta Plan (Deltacommissie, 2008) developed a new FRM strategy to respond to new economic conditions and climate change (cf. Tol, van der Grijp, Olsthoorn, & van der Werff, 2003). This is still mainly based on protection, even increasing return periods to 100,000 years, but including moves towards 'soft' FRM as described below (Wiering & Arts, 2006; Zegwaard, Petersen, & Wester, 2014). The subsequent Room for the River programme includes these changes towards 'soft' FRM. In this programme the river channel and floodplains are widened where necessary and possible, and floodplains are re-connected to river channels in order to 're-naturalise' the river and increase storage capacity (Van Staveren, Warner, Van Tatenhove, & Wester, 2014; Warner, Van Buuren, & Edelenbos, 2013). These floodplain modifications also have a spatial planning element. However in practice, cost considerations and inhabitants' protests often mean that 'hard' protection measures are implemented rather than 'soft' FRM (Roth & Warner, 2007).

More recently, ‘greener’ strategies have also been incorporated in coastal zone management (Studio Coastal Quality, 2013). several ‘Building with Nature’ pilot projects are being implemented to learn how coastal flood protection measures can be developed that benefit from, and are supported by, existing coastal ecosystem dynamics (De Vriend & Van Koningsveld, 2012). The Sand Engine project combines a ‘hard’ measure (artificial sand addition) with ‘soft’ natural processes (sea currents gradually spreading this sand along the Dutch coast) to offset coastal erosion over a period of 10-12 years (Janssen, Van Tatenhove, Otter, & Mol, 2014).

The most recent shift in the Dutch FRM is represented by the multi-layer safety (MLS) concept (Government of the Netherlands, 2009). It recognises that flood management is not only an engineering affair (i.e. protection, possibly including ‘soft’ versions), but that land-use planning, early warning and evacuation should be integrated in FRM. The ubiquitous flood insurance opportunities in the USA and elsewhere are a no-go topic in Dutch FRM, with minor exceptions (Botzen & Van den Bergh, 2008). The scope for improvement in early warning communication and evacuation plans is large, considering the low levels of flood awareness in Dutch society generally (Kolen, Hommes, & Huijskens, 2011; Terpstra, 2009). However, local pilots found that the economic feasibility of investing in existing structures is generally higher than for new interventions in spatial planning (Tsimopoulou, Vrijling, Kok, Jonkman, & Stijnen, 2014), illustrating the technological lock-in in Dutch FRM.

Increased prosperity, collective organisation, and the accumulation of technical knowledge enabled the Dutch to reduce individual and societal risks with increasingly costly and technologically complex interventions. However, the success of ‘hard’ protection severely limits the possibilities for testing ‘soft’ FRM options due to the lock-in created by enclosing the land by dikes: the dikes are ‘hard’ boundary conditions for Dutch FRM (Wesselink, 2007). Developments towards ‘soft’ FRM remain ‘add-ons’ as Dutch FRM remains locked-in into doing FRM by protection.

2.2. *Mississippi River Delta (USA)*

The Mississippi River drains 3,300,000 km^2, or 41% of the USA (excluding Alaska and Hawaii) into the northern Gulf of Mexico (Kemp, Day, & Freeman, 2014). The modern delta, which began forming about 7,000 years ago, is a classic ‘bird’s foot’ delta, in which sediment flux exceeds erosion by tidal and near-shore processes, building elongate distributary arms into the ocean. These natural processes, as well as recent human interventions, have created unique flood risks to the human population now occupying this area. Subsidence is the first cause of flood risk. Sediment deposition loads the earth crust in the delta, and causes it to subside due to its weight. Prior to human modifications, this subsidence was counterbalanced by sediment accumulation, but protection by levees (dikes) now precludes sedimentation over large delta areas. In addition, the suspended sediment load to the Gulf of Mexico has declined by over 70% since 1850 (Kesel, 1988; Meade & Moody, 2009) due to upstream dams and other human modifications (Jacobson, Blevins, & Bitner, 2009). Sand and gravel load, which is important for the initiation and maintenance of delta and coastal shoals, has declined even more (Meade & Moody, 2009). Subsidence is further compounded by compaction and oxidation of recent sediments and by groundwater and oil and gas extraction. Total subsidence is 5-6 mm/y near New Orleans, increasing to over 20 mm/y in the coastal area (Dixon et al., 2006). Some occupied areas now lie 3 meters below sea level (Dixon, 2015).

Alongside subsidence, the other major contributor to flood risk in the Mississippi Delta is degradation of coastal wetlands. The construction of 15,000 km of canals to facilitate navigation and oil and gas production caused the remaining sediment to be deposited in the Gulf of Mexico rather than the delta (Kemp et al., 2014). The resulting cumulative wetland loss is now over 25% of historic Mississippi Delta wetlands (Couvillion et al., 2011). Shrinking delta land and degraded delta ecosystems significantly increase risk of storm-surge-driven coastal flooding. The Mississippi River Delta is among the most vulnerable to catastrophic flood damages worldwide, a threat however that is broadly mitigated by US wealth and investment in flood control (Tessler et al., 2015).

In contrast to Dutch FRM, the USA has long emphasised prevention through land-use planning and recovery through insurance. In this domain, reform bills were recently discussed that tended towards risk-based insurance rates. This would generate sufficient revenue to cover future flood losses and better address the individual responsibility of floodplain occupants (Bergsma, 2015). The fact that this discussion takes place at all is an indication of a fundamentally different view of whose risk FRM is dealing with: one that requires collective action (Netherlands) or one where taking risks is seen as individual choice (USA) (Bergsma, 2015). However, the 2005 storm surge during Hurricane Katrina re-focussed FRM towards ‘hard’ protection. The surge breached the flood-control system protecting New Orleans and surrounding areas, killing 1322 people and causing US$83 billion in property damage (Kron, 2015). Johnson, Fischback, and Kuhn (2015) propose that the disaster was as much due to decades of indecision, errors in design, and insufficient funding as the storm’s intensity at landfall. In fact, the history of US FRM largely matches the history of flood disasters on the Mississippi River. Floods in 1849 and 1850 sparked two sweeping scientific and engineering studies (Ellet, 1850; Humphreys & Abbot, 1876), leading to the first national US FRM strategy of ‘levees only.’

Prior to 2005, many US experts had argued for the need to include other, ‘softer’ FRM approaches. Already in the 1940s the ‘levees-only’ strategy was rejected in favour of a comprehensive toolkit including land-use planning and insurance schemes (e.g., Arnold, 1981; White, 1945), and some of these were indeed initiated. One such measure was the US National Flood Insurance Programme (NFIP), enacted in 1968 to curtail flood damage through government subsidized insurance and land-use limitations (albeit with porous controls on its implementation) (Bergsma, 2015). Another example of ‘softer’ FRM is the 1990 Coastal Wetlands Planning, Protection and Restoration Act through which up to US$1 billion was invested in over 100 coastal restoration projects in Louisiana. A number of such forward-looking projects can be identified across the USA, but the national strategy for river, delta, and flood management remains overwhelmingly and unequivocally focused on engineering structures.

In the initial years following Hurricane Katrina, governmental investment focused on 'hard' protections for New Orleans and surrounding delta areas. As of the 10-year anniversary of Katrina, US$14.5 billion has been spent on repairs, expansion, and/or (remedial) construction of over 250 km of levees, a large new storm-surge barrier, pumping stations, and canal closing structures. Recent modelling confirms that this Greater New Orleans Hurricane and Storm Damage System now provides protection against events with a return period of over 100 years (Johnson et al., 2015). However, with the initial surge of engineering construction came the recognition that these structures alone would not provide adequate or long-term protection. Following Katrina, governing US agencies including the US Army Corps of Engineers and the Federal Emergency Management Agency (FEMA) have reportedly 'adopted a flood risk management paradigm' (Galloway, 2012) – as opposed to flood control only. Even the American Society of Civil Engineers, long an advocate for infrastructure investment, professes that 'since Katrina struck, the nation has begun to shift from a mind-set of controlling floods to one of recognizing that absolute protection against these natural hazards is not possible'.

More tangibly, the 2012 Comprehensive Master Plan for a Sustainable Coast (Coastal Protection and Restoration Authority of Louisiana [CPRA], 2012) calls for a further US$50 billion to be spent on the Mississippi Delta and coastline over the next 50 years, split approximately equally between further 'hard' protection and a broad range of 'softer' measures. The latter include sediment diversions, pumping of dredged sediment to establish and maintain delta and coastal shoals, closure of hydrologic conduits such as the Mississippi River Gulf outlet and some of the delta canals, and additional mitigation measures such as the elevation, flood-proofing, and relocation of individual homes and other buildings (CPRA, 2012). Detailed risk modelling suggests that this US$50 billion investment reduces total average annualized flood damages in the Mississippi Delta region from US$21 billion to US$4.85 billion (Johnson, Fischback, & Ortiz, 2013), a residual risk that is considerably reduced but still substantial. 'Softer' FRM in the Mississippi Delta significantly outstrips other such efforts elsewhere in the USA. Costs are high, but fundamental questions are now being addressed, such as the relative importance of sand vs. silt for wetlands restoration (Kemp et al., 2014), and options for gradual physical and social retreat of barrier island systems in the face of coastal erosion and sea-level rise (Campbell, Benedet, & Gordon, 2005). Despite these efforts, the Mississippi Delta remains a very hazardous place to live and work, with long-term challenges from subsidence, sediment starvation, and climate-driven sea-level rise.

2.3. *Pearl River Delta (China)*

Over the last two millennia, successive Chinese empires have gained extensive experience with FRM. The 'hard' engineering approach (i.e. dike building) has been utilized since the Tang Dynasty (around 8th century AD). Later the Chinese also constructed embankments to make polders and reclaimed marshy land so that, 'by the twelfth century the whole Yangtze Delta was covered with polder fields' (Lewis, 2009, p.134). The population density of Chinese deltas increased significantly during the Tang Dynasty due to trade and employment opportunities, accelerating southward and eastward population migration (Zeng & Huang, 1987). Increasing populations placed stress on food production in the low-lying deltas; dikes were built to protect cultivation and guarantee agricultural production there, with paddy cultivation, sugarcane and fish ponds doubling as rice paddies (Zong et al., 2013).

Until recently, FRM in the Pearl River Delta was not as technically advanced as in the Yangtze Delta. Weng (2007) reports that about 433 dikes were built on the Pearl from the time of the Tang Dynasty to the Qing Dynasty (19th century), at a total length of 1897 km. However, since the 'open-door' policy in the late 1970s, economic growth has spurred economic development. World-class container ports (i.e. Hong Kong, Shenzhen and Zhuhai) and foreign investment mean that the delta now accounts for over 20% of China's GDP. Rapid economic growth boosted migration, and the population increased more than tenfold within three decades. The delta has become one of the world's most urbanized deltas. Municipal authorities have to find plenty of new land to satisfy rising demand, and coastal wetland reclamation was initiated recently (Chan, Wright, Cheng, & Griffiths, 2014). Over 86% of the Pearl River Delta coastal area currently relies on 'hard' infrastructure, such as dikes and sea walls, for flood protection (Cai, Huang, Tan, & Chen, 2011). However, the protection standard remains low: from 10 to 50-year return periods. Some scholars predict that by 2030 over 80% of the Pearl River Delta's low-lying area would be flooded by a 1-in-100 year storm surge if the sea level were to rise by 30 cm. Such flooding would impact about 1 million homes and cause over 40 billion US$ in economic losses (Chan, Adekola, Mitchell, Ng, & McDonald, 2013b; Zhang, Xie, & Liu, 2011).

There remains little sign of strategic FRM in the Pearl River Delta, with much *ad-hoc* construction of levees, embankments, and sea walls; extensive new infrastructure is being constructed in the Pearl River Delta (Zhou & Cai, 2010). Decision-makers and practitioners focus on their designated separate roles, disregarding overarching issues such as environmental sustainability, for which 'soft' FRM approaches would be considered. The Ministry of Water Resources (at national, provincial and municipal scales) is the government institution that manages all kinds of flooding in China (Chan, Adekola, Mitchell, & McDonald, 2013a). The majority employed at this 'Bureau' are water engineers, preferring engineering solutions (Cosier & Shen, 2009). They are not required to consider wider approaches that may address the socio-economic, environmental and climate change issues (e.g. spatial planning and land use, flood-proofing of infrastructure, emergency evacuation plans, financial tools for flood recovery, flood insurance, etc.).

In the last two decades, Hong Kong and Shenzhen municipal flood authorities spent over US$5 billion on flood protection engineering, regulating the river so as to increase the return period of floods from 5 to 50 years, and 200 years in urban areas. In rural areas, where no such work has been undertaken, return periods are in the region of 0.5 to 2 years. The limited view on FRM is exemplified by the recent governmental strategic housing plan to 2050, which does not consider existing flood risk and climate change issues (Guangdong Province, 2011). Planning authorities at all levels (regional, municipal, districts and towns) are disconnected from FRM institutions such as the Guangdong Water Bureau (provincial) and the Drainage Service Department in Hong Kong (municipal).

The current disjointed governance of the Pearl River Delta is the major barrier to achieving ‘softer’ flood management (Chan et al., 2013b). However, recently Chan et al., (2013a) found that authorities such as the Drainage Service Department in Hong Kong have shifted their visions towards ‘softer’ FRM[2]. They realised that there was a lot of dissatisfaction from the public about previously built hard engineering measures (Chan et al., 2013b). Environmentally friendly measures were initiated in the early 2010s, for example in the development of ‘soft’ FRM in the Shenzhen River Regulation Project Stage IV, where the authorities adopted a ‘building with nature’ approach to regulating the last part of the Shenzhen River. This project preserves the existing meanders and river-bed level and uses in situ natural river bed materials. It also constructs large flood storage ponds for FRM by preparation. This pioneer ‘soft’ FRM project could become the model for other cities in the Pearl River Delta. For the first time, green groups (e.g. World Wide Fund for Nature and Bird Watching Society) responded positively to FRM plans, because damage to local habitats has been greatly reduced. In another recent example, the Drainage Service Department in Hong Kong is working on a mangrove scheme for a ‘building with nature’-type FRM (Chan, Ching, & Erftemeijer, 2011).

2.4. Mekong River Delta (Vietnam)

While large-scale hydraulic projects including dikes started in the 11th century in the northern Red River Delta, such schemes did not exist in the southern Mekong Delta until recently, due to less intensive settlement (Devienne, 2006). The physical dynamics of the Mekong River are unique, with large-scale seasonal flooding in the upper Delta. These floods have made the inhabitants of the Mekong Delta world-famous for their capacities for ‘living with water’ and ‘living with floods’. The land was long managed for paddy cultivation, with 1-2 harvests a year. Infrastructure consisted of small drainage canals, low ‘August dikes’ that protect the land until August, then allow monsoon peak flows to flood the land and fertilise it. This system survived largely intact until reunion with the North in 1975, with significant shifts in FRM thereafter (Evers & Benedikter, 2009). Regions that used to be subject to seasonal flooding now have been diked. Relative sea-level rise has meanwhile increased flood risk in coastal regions (Syvitsky et al., 2009). The following analysis puts the current revival of a ‘soft’ FRM approach for the Mekong Delta in a historical context.

The Mekong Delta has been the arena for global and regional geo-political struggles for a long time, with profound impact on FRM (Biggs, 2012; Sneddon, 2012; see also Scott, 2012). The first large-scale interventions in the Mekong Delta took place in the late 19th century under French colonial rule. French engineers set out to ‘pacify’ the region, extending navigable canals and building permanent settlements on the reclaimed land to attract investors from Europe (Biggs, 2008). Later most of their reclamation work took place to fight nationalist groups who were able to hide in unreclaimed reed beds. The idea of ‘casiers’ was imported from the North Vietnamese Red River Delta: a piece of land

[2] http://www.dsd.gov.hk/EN/Flood_Prevention/Ecological_Enhancement/Introduction/index.html

protected by surrounding dikes (like Dutch 'polders'). When Americans took control over the region from the French, they continued with these 'nation building' activities, stimulating economic development to politically stabilize the region (Biggs, Miller, Hoanh, & Molle, 2009; Sneddon, 2012). In this light the Chief of the Tennessee Valley Authority, David Lilienthal, was commissioned in 1966 to come up with a plan for the Delta. This was a novel shift from a regional to a Delta scale (Käkönen, 2008). This Delta Planning exercise was repeated in 1974 by a Dutch-led team (Biggs et al., 2009). During the Vietnam War (1955-1975), irrigation and water-control infrastructures were poorly maintained, yet still the Delta as a whole produced an increasing amount of rice thanks to land-redistribution to farmers and the introduction of high-yield rice varieties (Pingali & Xuan, 1992).

After the country was reunited in 1975, the drive to collectivize the economy dramatically decreased rice production. In response, a goal was set in 1986 to make the Mekong Delta Vietnam's rice bowl producing three harvests per year. The 1990s saw improvements to the canal system as well as increased economic liberalisation. From 1996 dikes were constructed to protect urban areas from flooding with recurrence periods up to 100 years, and to fight salinity intrusion in the coastal areas. From 1996 to 2000 a new round of construction of embankments, high dikes, and sluice gates to control the Mekong River took shape (Biggs et al., 2009). Operation and maintenance of these structures requires large government expenditure (Evers & Benedikter, 2009).

Around 2000, negative effects of this protection-oriented FRM started to be discussed: increased salinity, reduced sedimentation, reduced fertility, impaired fisheries, and increased flooding downstream. In all, the Mekong Delta highlights how local FRM reflects global and regional politics (Biggs et al., 2009; Dore & Lazarus, 2009; Käkönen & Hirsch, 2009;), culture (Zink, 2013), and economic (Biggs, 2008, 2012). This historical path has resulted in a situation where, as Käkönen (2008) suggested, the Mekong is at a crossroads between continuing on the infrastructure-intensive strategy (FRM by protection) and switching to more 'soft' and adaptive ways. In the light of uncertain future developments upstream in the Mekong and relative sea-level rise, this is addressed by the most recent Mekong Delta Plan (MDP) (2013), in which Vietnam and The Netherlands collaborate. The MDP suggests the revival of the traditional system of living with floods in the upper delta as a realistic possibility, implying a move away from triple rice harvests towards a controlled flooding season and a renewed interest in August dikes. In locations where hard defences have already been constructed, sluices can be added to allow flood water in at the appropriate times.

2.5. Ganges/Brahmaputra/Meghna Delta (Bangladesh)

The Ganges/Brahmaputra/Meghna delta encompasses 280 rivers, covering most of the country of Bangladesh. It is the largest delta in the world draining almost all of the Himalayas, the most sediment-producing mountains in the world. The combined flow of the Ganges, Jamuna (the downstream continuation of the Brahmaputra), and Meghna Rivers are delivered to the Bay of Bengal through the Lower Meghna River (Akter, Sarker, Popescu, & Roelvink, in press), a total of 1 trillion m3/year of water and 1 billion tonnes/year of sediment. With 170 million people living in a vast, low-lying coastal plain, the delta is perceived to be at great risk of increased flooding and submergence from sea-level rise (Auerbach et al., 2015). In the upstream delta, riverine floods are common. Traditionally, seasonal dikes maintained by tenant farmers' collectives keep water out during the dry season, but are overtopped in the monsoon season, a system resembling the August dikes in Vietnam. Normally, 25-30% of the delta area is inundated by the seasonal monsoon. These floods are valued by rural people, because they are beneficial to land fertility, fisheries, ecosystem services, and transportation (Huq, 2014). Flooding due to high sea levels, induced by storm surges or monsoon wind, occurs in the coastal areas. Sometimes extreme flood events are caused by a combination of high sea level and high discharges in the major rivers systems. In extreme flood events, 50-70% of Bangladesh can be inundated.

Bangladesh has received much international attention regarding its vulnerability to flooding. After devastating floods in 1954/55, the then East Pakistan government (ruling over what is now Bangladesh) asked the United Nations for help. Plans were established mainly focussing on protecting agricultural lands from flooding, with World Bank, USAID and Dutch funding and input. Plans included large dams upstream (in India), principally for hydropower generation but the buffering effect would also benefit FRM. The plans also proposed the large-scale construction of embankments that would protect areas to a 20-year return period (East Pakistan Water and Power Development Authority, 1964). Since then, FRM has gone through several cycles of learning from the problems triggered by successive solutions (Chowdhury, Rahman, & Salehin, 1997; Hossain, 1994; Huq, 2014). In the 1960s, severe river erosion caused the newly constructed embankments to fail year after year. In addition, lack of sedimentation lowered the enclosed land, causing drainage to fail and create water logging (Auerbach et al., 2015). The 1970s saw the introduction of sluices to remedy water logging. Again, problems arose because siltation of the rivers resulted in blockages, preventing the inflow of irrigation water and outflow of drainage water. Farmers started to draw groundwater instead, but pumping increased subsidence, lowering of the water table, and aquifer depletion. This happened at a time when modernisation of agriculture in general was taking place (the Green Revolution).

The 1980s saw a scaling-up of engineering projects. Following devastating floods in 1987 and 1988, a Flood Action Plan (FAP) sponsored by the World Bank and the Asian Development Bank was formulated. This multi-year effort expanded the engineering measures begun in the 1950s (Rashid & Rahman, 2010) but also recognised that the construction of river and coastal embankments to provide full flood protection was not feasible (Brammer, 2010). The FAP was presented as an interdisciplinary assessment of water risk and vulnerability. It included FRM as part of integrated water management, and proposed more inclusive decision-making. However, overall the 'hard' FRM strategy was not challenged. The FAP faced extensive criticism (e.g. Brammer, 2010), not least because the integration promised was difficult to achieve in practice (Cook & Wisner, 2010). The overall result of these several decades of FRM planning and implementation is a system where some rivers are now dead because they have become disconnected from the network. Land levels continue to decrease due to subsidence and salinity continues to increase, for lack of freshwater leaching. Continuous rehabilitation of the system is required, but the project-oriented donor assistance favours the building of new infrastructures over long-term maintenance, re-engineering, or ‘soft’ FRM measures.

Counteracting these top-down approaches, in recent years some tenant-farmer collectives have taken the initiative to ‘soften’ the polders by illegally and temporarily cutting embankments to again allow siltation and restore tidal movement. This increased land levels and scoured the river to regain its earlier shape (Shampa, 2012). This approach, labelled ‘Tidal River Management’, has now been adopted as in national policy and NGO discourse (Haque, Chowdhury, & Khatun, 2015; Shampa, 2012). In the meantime, the Bangladesh government developed plans to address sedimentation and braiding of rivers through dredging coupled with partial river training work so subsequent erosion can be minimized. This also has an element of using the dredged sediment in reclaiming or redevelopment land in industrial zones.

In parallel to protection-type FRM projects, ‘soft’ measures were also developed because it was realised that ‘hard’ protection would not be enough, or could be constructed soon enough, to alleviate human suffering and damage to the economy and the environment. Starting in 2010, Bangladesh is implementing the Comprehensive Disaster Management Programme for protection of the Ganges Delta from flooding and cyclones. Incorporating ideas on access (Sen, 1981) and disaster risk reduction, the public and agencies made great advances in reducing the toll from floods and cyclones. For example, a flood forecasting and warning system was developed and provisions were made for use of new school buildings as temporary flood shelters (as described already in IBRD, 1972). Also, construction and planning guidelines were issued to reduce flood risks: to build all structures of strategic importance above the flood levels with a 100-year return period and to control developments in the floodplains and wetlands by zoning, the latter of which was less successful.

In retrospect, FRM in Bangladesh was often planned and implemented without sufficient consideration of institutional capacity and financial resources for maintenance. Rather, every major development was the result of *ad-hoc* response to major flood events (Sultana, Johnson, & Thompson, 2008). To address this, the current National Water Policy in theory provides an institutional framework in which local stakeholders’ platforms are formally established as an independent institution. This enables local residents to manage their own affairs and incorporate their ideas in FRM, although it is not clear whether they will have sufficient means and expertise to implement them. Bangladesh’s continued dependence on external donor resources (Sultana et al., 2008) and the heavy reliance on foreign experts (Warner, 2010) could impede this move to localism. Overall, the adoption of a protection strategy by constructing dikes and polders is moving towards the same technological lock-in as seen in The Netherlands.

2.6. Zambezi and Limpopo River Deltas (Mozambique)

Mozambique hosts fifteen major river basins, most of which cross national boundaries and all of which drain at the Mozambican coast into the Indian Ocean (Consultec and Salomon [CS], 2013). More than 50% of the Mozambican territory is part of international river basins, the largest two among these being the Zambezi River with a catchment size of 1,200,000 km^2 and the Limpopo River having a catchment size of 412,000 km^2 (Alvaro Vaz, 2000). Some 50% of the water in Mozambique's rivers comes from outside the country. Flooding in the deltas is due to the concentration of excessive catchment rainfall, often associated with cyclones that originate off the East-African coast in the Southern Indian Ocean. For example, in January 2015 a cyclone that made landfall in Mozambique caused heavy rains in and around the Licungo basin in central Mozambique, caused more than 150 fatalities, estimated damage to infrastructure amounted to US$155 million and to the agricultural sector in terms of crops losses and damage to irrigation systems about US$100 million (Dutch Risk Reduction Team, 2015).

The Mozambican deltas are relatively sparsely urbanised or industrialised, and dikes were primarily constructed to protect farmland. In the late 1800s, following the rise of commercial agricultural schemes in the Zambezi delta, the first embankments were constructed. Over the years, some of these embankments have been incrementally raised in response to specific flood events (Beilfuss & Brown, 2006; Carmo Vaz, 2000). Before the 1880s and continuing alongside the constructed dikes, smaller-scale farming activities in the floodplains adapted to the natural hydrological cycle of the river, using different crops in different parts of the floodplains to ensure food security year-round in a 'living with floods' approach (Isaacman, 2005). However, after the 1950s, flood characteristics drastically changed due to large hydropower dams constructed upstream in the Zambezi, Limpopo and other river basins. This was a deliberate effect, flood control being among the advertised benefits of these hydropower dams (Radmann, 1974). Medium-size flood events no longer occurred on a regular basis, diminishing the area of frequently inundated floodplain. As a result, previously fertile lands dried up, driving agricultural activities to zones closer to the river and to intensified irrigation. However, large dams did not eliminate major floods. Subsequently, the increasingly valuable irrigated farmlands required flood protection, leading to the building of dikes.

The construction of dikes proved a mixed blessing. The dikes protected against most high flow events, but by constricting flow area in the floodplains the dikes also cause increased flood levels in the river, exacerbating flood risk at locations elsewhere and increasing potential damage due to violent flood flows in case of dike breaches, but this trade-off is not considered (as, for example, proposed in Van Ogtrop, Hoekstra, & van der Meulen, 2005). Dike breaches with devastating impacts occurred in 1978 in the lower Zambezi and in 1977, 2000 and 2013 in the Limpopo (CS, 2013) Construction and maintenance of dikes in Mozambique was, and in many regions remains, poor. Still today, there is no registry of existing dikes and no consensus on who owns and should maintain them.

Water management, including FRM, falls under the responsibilities of the Ministério das Obras Publicas, Habitação e Recursos Hídricos (MOPHRH), where the Direcção Nacional de Águas (DNA) coordinates water management activities nationwide. Operating in parallel to DNA and under supervision from MOPHRH, five regional water boards were created by the national Water Law of 1991 (Boletim da República, 1991). An Administração Regional de Águas (ARA) carries out monitoring and operational water management activities. In recent decades, several foreign aid and World Bank programmes have provided technical assistance, financing of programs and capacity building to the national and regional agencies. The large amount of foreign FRM support from various parties at both national and regional levels brought with it the risk of uncoordinated activities. For example, DNA and some of the ARAs now possess flood forecasting and warning tools and have staff that were trained in the application of these, but for lack of coordination, these new methods, procedures and tools have not yet become part of operational practice.

In this context the development of an integrated, holistic approach to FRM remains a huge challenge. Land-use planning activities and building and construction practices in the Mozambican basins do not generally take into consideration the probability of flooding. For example, railroads and roads are transecting river basins and pose significant obstructions to floodplain flows (e.g. Beilfuss & Brown, 2006; Tinley, 1994). During past floods, damage to infrastructure has contributed greatly to overall losses. While the new National Plan for Management of Water Resources (Ministério das Obras Públicas, Habitação e Recursos Hídricos, 2015) aims to focus on sustainability and to make spatial planning an integral component in FRM, the common response to flood damage is still to reconstruct or recover what was damaged, if needed stronger than before. Where ambitions for sustainable approaches exist, they easily fail when the next flood calls for swift repair actions, leaving insufficient time to rethink the overall approach. At the moment, changes to FRM can still be made in Mozambique that would avoid technological lock-in, but this requires the development and acceptance of broad long-term visions.

3. Discussion: similarities and differences

Comparing FRM trajectories across the world, the similarities between the six deltas reviewed here are striking. First of all, the initial human response to the agricultural potential of deltas was the same: protect the land from flooding in the low-flow season, and in some cases allow it to fill (with fresh water[3] and sediment) during the seasonal flood season. This strategy prevailed for centuries in the Mekong, Pearl, Ganges/Brahmaputra/Meghna and Zambezi-Limpopo deltas, until the 1950s. When tracts of delta land are permanently enclosed to create polders, several adverse impacts start to kick in: subsidence due to sediment compaction and other mechanisms (Syvitski et al., 2009), salinization due to salt water intrusion (groundwater or marine surface water), loss of fertility due to lack of new sediment deposition, siltation of drainage channels and hence perennial water logging due to failed drainage, etc. These adverse effects were triggered with the 1000-year history of creating polders in the Rhine/Meuse/Scheldt Delta, and in the Ganges/Brahmaputra/Meghna Delta since the mid-20th century; in the Mississippi Delta subsidence is mainly caused by starving

[3] The caveat ‘fresh water’ is important, because no flooding with salt water is desirable unless the land is used for fisheries or shrimp farming. Inundation with salt or brackish water makes the land unusable for all but a few crops (salt-tolerant vegetables and pasture are notable exceptions), and it takes several years of rainwater leaching before the salt levels are sufficiently reduced to re-allow agriculture. This means that land that is flooded by seawater with a frequency of even less than once a year is only suitable for grazing or fish farming.

the delta of sediment by diverting it elsewhere. The resulting large-scale subsidence in turn require ever-increasing protection and drainage works.

The technical potential for controlling the river, as well as the relative importance of the adverse effects, depend on the physical characteristics of the individual deltas; for example, salinization is particularly severe in the Ganges/Brahmaputra/Meghna Delta. However, due to the similarity between physical responses in deltas, we can predict that the sustained and widespread application of protection technology will push deltas towards the same technological lock-in as experienced in the Netherlands, where fewer 'soft' FRM alternatives become feasible over time. Continued investment in protection infrastructure requires high levels of sustained investment in maintenance and in expertise (Stijnen, Kanning, Jonkman, & Kok, 2014). In less prosperous countries, donor assistance leads to increased debt and dependence on outside assistance. The construction and maintenance of the extended flood defence system in Bangladesh is only possible through foreign aid or contracts and imported expertise, adding a 'debt lock-in' to the developing technological lock-in. While more than half of the deltas surveyed perform strategic FRM resulting in policies and laws, it is also clear that many of the protection structures are constructed as ad hoc response to a catastrophic flood event due to politicians heeding the population's calls for protection, rather than in the context of a carefully planned and well-thought through FRM strategy.

The adverse effects of 'hard' protection are now also recognised in all six deltas. However, the range of proposals for adding soft FRM measures of prevention, mitigation and preparation, and 'building with nature' forms of protection developed in the last decades, they can never do more than soften the edges of 'hard' FRM because of advanced subsidence (Van Staveren et al., 2014; Wesselink, Bijker, De Vriend, & Krol, 2007). Moreover they often prove more costly than 'old-fashioned' engineering, either in construction or land claims, and less popular with citizens. In Bangladesh and Vietnam initiatives have emerged to return to the traditional system of seasonal flooding by opening up the embankments. However, in many areas in Bangladesh subsidence has proceeded beyond the stage where this is possible. In China the 'hard' edges of engineering may be 'softened' in future projects, but the focus is otherwise on protection, while land-use planning in urban areas could prevent increased flood risk.

Finally, the existence of a dynamic and well-funded pool of expertise in itself can be a driver for changes in FRM. New knowledge is also disseminated through conferences and foreign advisory missions. However, this time the learning has a potential to be reciprocal, since other deltas have more recent extensive experience with these 'soft' FRM approaches. In addition, spaces for experimentation are greater in deltas where protection has not advanced to such an extent that few other options are open any longer.

4. Conclusion: underlying currents

While trajectories from one set of FRM options to another are neither linear nor universal, and trajectories can fragment, halt, or fold back on themselves, the local histories of human approaches to FRM show many similarities. Looking at these six deltas, we see a development from modest seasonal embankments in the service of agriculture ('living with water'), to ambitious plans and/or engineering works to fully protect land ('flood defence'), to a 'softening' and broadening of the types of measures that take account of a residual risk of flooding, for example appropriate building construction, changed land use, retention, warning, and insurance ('flood risk management'). This development is not just a matter of changes in the choice of measures due to learning processes. Instead, it should be seen as part of broader societal changes which have been labelled 'modernity'. These developments ultimately have implications for 'flows of power' as well as 'flows of water' (paraphrasing Molle, Mollinga, & Wester, 2009), which we will briefly touch on below.

The idea of full flood control is an expression of (high) modernity. Modernity can be summarised as 'the ideal of grasping the future before it happens, and thus controlling its course and its nature in order to prevent disasters' (Nobert, Krieger, & Pappenberger, 2015, p. 247). In order to achieve this, modernity quantifies, predicts, and optimises possible behaviours and responses, by applying what is seen as universal knowledge. Top-down state-led initiatives and responsibility are the logical extension of modernity's control principle. This transcends political ideology: for example in the 1990s, an unquestioned baseline of developing centralized modernist solutions at large scales was transferred from the American advisors to the Vietnamese socialist leadership. Regardless of their ideological differences, they shared a similar posture of dominion over the natural world' (Käkönen, 2008, p. 206).

Molle et al. (2009) identify several developments since the 1980s that contributed to a shift away from state control of water resources: the financial squeeze, neoliberal critiques, environmental movements, calls for democratisation and participation, decentralisation, and the emergence of supra-national institutions. Nobert et al. (2015) argue that the shift from 'defence' to 'risk management' is a further development of modernity, with the individualisation of risks (cf. Beck, 1992) and an emphasis on risk communication rather than engagement with the risks. Put differently, 'the 'object' to be governed has to some extent shifted from actual flood waters, to citizens at risk of flooding, and the agencies or organisations with designated responsibilities. This has serious consequences in equity terms because 'soft' FRM options of preparation and recovery are often made the responsibility of citizens rather than the state, despite doubts that citizens have the capacity or willingness to take on this responsibility. FRM through land-use planning is usually the responsibility of local rather than national authorities, who need to take many more interests into account aside from flood risks. 'Soft' FRM options are therefore implemented primarily through actors' change of conduct at individual or local level, while their power to act is highly limited. Butler and Pidgeon (2011, pp. 541–542) judge that these 'contemporary trends in non-coercive technologies of governance are potentially not adequate to deliver change, particularly not change of the scale and kind that issues like flooding are seen to demand'. These limits to the potential for citizens and private parties to take responsibility is a serious limitation for initiatives to 'soften' FRM.

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Managing Flood Flows for Crop Production Risk Management with Hydraulic and GIS Modeling: Case study of Agricultural Areas in Shariatpur Pakistan: lai Nullah Basin Flood Problem Islamabad â€“ Rawalpindi Cities Ahmed Kamal. V 1 23 33 41 49 67 73 95 103 113 121 127. 145.Â Background Paper Flood Risk Management in South Asia. Mriganka Ghatak1, Ahmed Kamal2 , O.P. Mishra1 1 SAARC Disaster Management Centre, New Delhi, India 2 National Disaster Management Authority, Islamabad, Pakistan.Â According to the recently published 2011 World Risk Report, countries like Bangladesh, India, Nepal and Pakistan exhibit a high level of vulnerability as demonstrated by their lack of coping capacities and adaptive capacities.