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LIVING WITH FLOODS AND RECONNECTING TO THE WATER – LANDSCAPE PLANNING AND DESIGN FOR DELTA PLAINS

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Highlights

- We identify main technical means of nature-based solutions to delta plain floods on the landscape scale.
- We clarify flood type and its relationship to landscape planning and design.
- We review characteristics of different scales of flood control to landscape architecture.
- We propose a resilience strategy of landscape architecture for flood control based on the summarized experiences of typical cases.

Abstract. Although there is a consensus that landscape planning and design can play a positive role in flood mitigation, few specific reviews have explored how the strategies of landscape architecture could play a more effective and beneficial role in flood control. Focusing on the related knowledge about hydraulics, ecology, and practices of flood control, the paper explores the application of resilience theory on providing an improved theoretical framework for landscape planning and design for floods, especially for floods in delta plains, and highlights characteristics of different scales of flood control to landscape architecture. Three main types of technical means are discussed: water channel morphology and processes adjustment; riparian corridor and riparian buffer; and flood-specific landscape structural measures.

Keywords: flood control, flood resilience, landscape resilience, delta plain floods, landscape planning, landscape design.

Introduction

A flood can be defined as an event when the land is temporarily covered by water outside its normal confines (Commission of the European Communities, 2006), which is the most frequent natural disaster globally. According to the report of the human cost of weather-related disasters 1995–2015, about 2.3 billion people have been affected by flooding between 1995 and 2015 globally (Wahlstrom & Guha-Sapir, 2015). Among the 15 major natural disasters renounced and highlighted by the United Nations, flooding is one of the most severe natural disasters for its frequency, affected area, direct damage, and accounting for one-fifth of the global natural disaster loss (Munich Reinsurance Company, 2010).

Floodplain is an area that forms as the accumulation of fluvially derived sediment brought by floodwaters along the river. Floodplains have been important for humankind since it is extremely productive agricultural land fertilized by flooding. People tend to settle on the floodplain, despite the loss caused by periodic flooding. However, the dangers and damages have been outweighed by the economic and environmental benefits derived from the floodplain, such as food, transport, and irrigation. Urban densification and inadequate drainage design, coupled with climate change are primary drivers for flooding, which have been impacting more people with more negative effects on both life and property. The flood-prone area can be used effectively to coexist with the flood by sensitive landscape planning and design, which can be of help to mitigate the flooding damage and activate the greatest spatial extent possible. However, before adopting reasonable and effective measures, a complete and systematic knowledge framework of flooding is essential.

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It is necessary to analyze floods and classify them into different types. Floods can be classified according to their physical characteristics and causations of flooding. Pluvial flooding, fluvial flooding and coastal flooding are typically three main categories being classified on flood causative mechanism (Menne & Murray, 2013; Stevens et al., 2016). Pluvial flooding or surface flooding is generated by excessive rainfall directly in a certain area once the surface flow exceeds the drainage capacity, which is independent of an overflowing water body. Fluvial flooding or riverine flooding is caused once heavy rainfall results in a watercourse beyond its capacity which is independent of the rainfall duration. Besides, heavy snowmelt can also lead to serious fluvial flooding. Coastal flooding or tidal flooding that occurs in areas such as deltaic plains could be a result from various causes and closely coincides with the tidal conditions, which can be combined with the former two types of flooding. In some contexts, pluvial flooding and fluvial flooding are collectively referred to as terrestrial flooding.

Another standard, which is based on the duration of the flooding, broadly divides floods into flash floods (or torrential floods) and slow-onset floods (or plain floods) (Parker, 2014; Peden et al., 2017). In general, flash floods appear in the upper reaches of a river where excessive rainfall occurs over steep topography. As the localized nature of the heavy rainfall and other meteorological factors affect the spatial scale of the flash flood, it can be confined to a small area. The flash flood is characterized by rapidly rising floodwaters which could lead to a torrential response to water level and river discharge. With limited warning times, it leads to the highest average mortality rates per event. Flash floods are often accompanied by secondary disasters, for example, debris flows, landslides, debris dam failure, which may immensely damage river structures and result in loss to life and property further. On the other hand, slow-onset floods are to rise more slowly, cover greater spatial extent, last for a moderately long period time compared with flash floods. Slow onset floods are caused by a continuous and gradual process in which the ground is saturated and cannot absorb any more surface water runoff. Thus, this type of flood tends to give people sufficient time for assessment and to act (Jonkman, 2005). A relatively low mortality is likely, but such floods should also be considered as disasters regarding the actual damage or potential damage (Doocy et al., 2013).

The factors that induce and influence flood are multiple, complex, and interrelated. Generally, these factors could be classified into two types: source factors including weather factors, hydrology factors, pathway factors including river factors, land factors and topography factors (Schanze, 2006). Besides, human factors, including structural measures and non-structural measures, have profound influences on floods. Weather factors are the main factors that affect flood, which includes heavy or sustained precipitation, snowmelts, or other extreme weather events. Most intense floods are typically associated with extreme precipitation, spatial and temporal scales range of which could be from a large river basin and continue for several months to a confined reach of a single stream that just lasts for several hours. However, there are limits to what can be done other than to know more about its regularity and to predict them more effectively. Human factors affecting floods include structural measures of dams and levees, land covers, storage and drainage systems, and non-structural measures of flood risk management, source control (watershed/landscape structure management), laws and regulations, economic instruments, etc. (Kundzewicz, 2002). The characteristics of the three main flooding categories are as follow (Table 1) (Pender & Faulkner, 2010).

Although the variety of events and factors induce and affect floods, massive or sustained precipitation without efficient drainage is usually the main cause. The other common causes of flooding are storm surges, estuarine tides, sea-level rise, impervious surfaces, further exacerbating flooding. Excess water can then easily overwhelm outdated combined sewer and stormwater management systems, which gives rise to significant flood problems (Jones & Macdonald, 2007). Besides the features of floods, damage caused by flood mainly depends on the characteristics of exposed elements that are susceptible to be harmed (Sarewitz et al., 2003; Schanze, 2006).

To control and manage the flood, theories, and knowledge for practicing in a localization process are acquired. For example, floods on areas adjacent to mountainous

Table 1. Flood characteristics of fluvial flooding, coastal flooding, and pluvial flooding

Type	Main influencing factors			Features
	Source factors	Pathway factors	Human factors	
Fluvial Flooding	rainfall, snowmelt or ice jam, wind, waves	river factors, land factors	structural measures (dams and levees, land covers, storage and drainage systems) and non-structural measures (flood risk management, source control, laws and regulations, economic instruments)	long duration, large spatial extent, moderate dynamic
Coastal Flooding	tides, rainfall, wind, waves			moderate duration, moderate spatial extent, moderate dynamic
Pluvial Flooding	rainfall	topography factors		short duration, small spatial extent, highly dynamic

rivers can be grouped into different types of floods, which have different integrated specific time-space characteristics. Moreover, the floodplain of mountainous rivers of the southeast coastal area of China is frequently affected by cyclones or severe storms which intensify serious consequences of flooding. Therefore, instead of being confined in its local watershed, the study of the flood should extend the range to upstream and downstream of the river, an even broader catchment scale (Dixit, 2003; Grabs et al., 2007). Catchment modelling provides an alternative method of estimating floods and risk management. However, its practical value on practical applications has not been explored completely (Samuels, 2000). Using catchment modelling, the flood management plan could shift from a site-specific scale to a comprehensive catchment scale, which offers a valuable opportunity to gain further deep insights into flood risk (Evans et al., 2002).

1. Flood mitigation based on landscape resilience

1.1. Growing uncertainty by climate change

Flooding is a highly complex dynamic phenomenon caused by the interaction of multiple spheres on the earth, and its formations and changes are jointly affected by the atmosphere, hydrosphere, biosphere, and human socio-economic system (Kundzewicz et al., 2010; Parker, 2014). To assess the primary harm of natural disasters, several approaches have been adapted. One of the well-known approaches is the "risk triangle" approach which is based on the definition of risk proposed by Crichton (1999) and Kron (2002). According to this proposition, the risk can be modelled by three components: exposure, vulnerability, and hazard. Furthermore, all these components can be described in semantic and mathematical terms which are related to probability. Regardless of the efforts on developing more comprehensive approaches, nevertheless, knowledge on flood risk assessment and management and the impacts of flood control and intervention measures remain insufficient. Therefore, it is crucial for deliberations of the uncertainty of flooding. The uncertainty of flood control and management results from the limited knowledge, of the elements and processes of the flood risk system (Wallingford, 2002; Apel et al., 2004; Faulkner et al., 2014). This turns into a clearer fact that mostly only quantifiable data are looked upon in flood analysis. The system constructed on a limited heuristic basis unavoidably leads to restricted views and conclusions to the real flood problems.

The IPCC Fourth Assessment Report of Climate Change 2007 illustrates the consensus that climate warming is unequivocal by scientific evidence, and its impacts on the globe and regional hydrological cycle are already underway and to be expected in future (Intergovernmental Panel on Climate Change [IPCC], 2007). Climate change increases the uncertainty about the frequency and destructive power of floods. Theoretically, climate change alters surface evapotranspiration, accelerates the water cycle process, causes sea-level rise, warmer temperatures, and increases the probabilities of extreme precipitation, and events of a flood (Trenberth, 2011; Church et al., 2013). But locally, rather than globally, effects are often more subtle (Milly et al., 2002).

Uncertainties occur in the process of flood control and management that partly can be attributed to inadequate understanding of the flood phenomenon and limitations of the models used (Hall & Solomatine, 2008; Teng et al., 2017). Moreover, as long-term prediction is mainly based on data of past floods, while changes of climate and land-cover can make such historical data unreliable, and prediction becomes unreliable. In general, the required scientific knowledge on flood control needs comprehensive insights into flooding to reflect its internal mechanism in the system and to verify the assumed effects of human factors. To respond to future flood disasters, requires more robust flood management methods to cope with greater uncertainty or adapt to future possibilities.

1.2. Synthesis and complexity of flood problems

Coupling with ever-changing environmental conditions, rivers will continue to be changed by interacting human and natural processes, which make flood forecasting and control difficult. Facing the synthesis and complexity of flood problems and the change and uncertainty of the future for human beings with extreme events to happen more frequently, flood mitigation activities, i.e. control and management of flood water movement to reduce potential damage need comprehensive and continuous means. Resilient strategies should be integrally applied in flood control to deal with uncertainty innately (De Bruijn, 2004).

Despite attaining additional knowledge on a certain domain, integration becomes the key challenge. Integration can be interpreted as the combination of various means in a comprehensive understanding of the whole flood event and response with an appropriate way to minimize negative effects of floods, from physical processes forecast, structural measures design, decision-making to flood management. Due to the synthesis and complexity of the issue on flood mitigation, several different dimensions should be taken into consideration about "integration". One refers to the horizontal aspects related to the flood event, which are related to spatial planning and flood risk management (Sayers et al., 2013). Given the former dimension, flood mitigation should be combined with various human interventions to source factors and pathway factors, namely integrate structural measures and non-structural measures to eliminate the risk of flooding (Hooijer et al., 2004; Shah et al., 2018). Another dimension is related to the temporal stages. Considering the occurrence stages of flooding, the "integration" could also be interpreted as temporal integration, i.e. a combination of human interventions across three stages of the flood event, i.e. before, during and after a flood event to eliminate risk (Deutsches Komitee für Katastrophenvorsorge e.V., 2003; Azizat & Omar, 2018).

For the discipline of landscape architecture, its flooding-related research is of great significance for comprehensive flood risk management, which mainly involves near-natural or semi-natural means or alternative approaches, such as constructed wetlands (Zhai & Lange, 2021), the natural buffer zone, waterfront parks, living shorelines etc. (Watson & Adams, 2012). However, as the strategies on flood control changed orientationally in the last few decades, the study on the form, structure, function of all landscape elements combined with the green and blue infrastructure for different types of floods now is the frontiers of landscape architecture.

1.3. Strategy from resistance to resilience

The flood coping strategies could be divided into two major categories, one is the resistance strategy, namely building up the riverbank, forcing the flood down through the channel; the other is the resilience strategy, which is to drain the floodwater into lakes, ponds or wetlands and depressions on the flood peak period, while the accumulated water slowly returns to the original river channel naturally (Liao, 2012). Resilience strategy is an effective way to help to understand the uncertainty of complex systems and reduce system vulnerabilities, and it cross-scale links social and environmental systems in a co-evolved way (Berkes, 2007). Compared with that shift the flood from one point to another of resistance strategy, the results of resilience strategy are mitigating the flood indeed.

According to the relationship with natural processes, the interventions to flood control could be categorized into the following three main types (Ngai et al., 2017):

- Resist natural processes – interventions designed for resisting natural processes (mainly process of erosion), including seawalls, revetments, etc. man-made structures.
- Manage natural processes – interventions designed for managing natural processes (mainly processes of sediment accretion and movement), including water channel, beach profiling, groyne, dam, etc.
- Work with natural processes – interventions designed for stabilizing or reinforcing natural processes, mainly including assisted recovery, restoring functioning natural processes measures. Sometimes focusing on no interference with the natural process.

Some interventions overlap the above three types. However, an effective strategy should be integrated into these different intervention ways, rather than simply boil them down to good or bad. In addition, the latter two types of intervention can be included within the “sustainable water cycle” concept. Forepassed practices have proved that resistance strategy is only applicable to flood control on small watersheds and key regions. It is a feasible, economical, and effective flood control measure to extend flood storage and detention areas along rivers with severely inadequate flood discharge capacity in low-lying areas. However, the strategy on flood control changed from simple resistance to resilience combined resistance in recent decades (De Bruijn, 2004; Liao, 2012). It stressed the importance of biomimicry and working with nature, and focused on responsiveness, flexibility and multifunctionality in design (Lennon et al., 2014).

The formation of the delta plain has a direct relationship with sediment brought by the flood (Hehl-Lange & Lange, 2019). Due to its low elevation, fertile soil, and convenient transportation, typically it is highly populated and it forms the basis for the development of economic hubs such as London, Shanghai, Rotterdam, Hamburg, Guangzhou, Cairo, and Dhaka. Therefore catastrophic floods would bring a massive loss for the economy and loss of lifes. Thus, sufficient attention should be given to delta plain floods. For the delta plain and megacities on it, the resilience strategy is more valuable than the rigid, passive resistance strategy. In an area where population and wealth are concentrated, limited land resources should be used efficiently to make room for multi-functional flood storage and detention areas, such as wetlands, ecological protective belt, natural buffer zone and other measures to provide ecological benefits and other benefits to the delta plain as well as to mitigate the flooding damage. These flood detention areas can also be of use for other purposes under permitting conditions, for example as sports, leisure, or parking purposes. Besides, rainwater harvesting can be considered as one of the most fundamental ways to help mitigate flooding of urban areas as part of a sustainable urban drainage system. It can also supply supplemental sources of water to toilet flushing, irrigation, laundry, or domestic being utilized with proper treatment, which can also attribute to water conservation. At the same time, if new construction in a flood risk area is well planned, the cost of the flood control design will be lower during phases of construction or reconstruction while reducing operating costs. This helps to incorporate resilience design into plans with a potential return on investment.

1.4. Concepts of landscape resilience

“Landscape resilience” is not a strict definition. It provides us with broad framework. The concept of landscape resilience derived from the resilience concept of United Nations International Strategy for Disaster Reduction (2009), that is the capacity of a system, community, or society potentially exposed to hazards to adapt, by resisting or changing, to reach and maintain an acceptable level of functioning and structure. Landscape resilience is a synthesis of thinking across ecological studies and social-ecological resilience theory to create a system robust to persist and adapt in the long term (Beller et al., 2015).

Some related concepts or ideas contribute to landscape resilience. As an approach of making natural ecosystems an integral part of sustainable development, Nature-based Solutions (NBS) (Zhai & Lange, 2020) have been widely adopted as living and adaptable tools to bring landscape resilience to practical design, which enables built landscape to face critical environmental, economic, and social challenges (Lafortezza et al., 2018). NBS-based landscapes should be nature-sustainability-oriented, helping in designing and managing new human ecosystems. Blue-green infrastructure, or green infrastructure, is a combination of multiscale networks with multi-functional ecological systems around and between urban areas, which can signify both living and vital landscapes resilience in a socio-ecological system context (Berg et al., 2013). Networks of urban green spaces with a blue-green-infrastructure-based landscape can bring functions of recreation, biodiversity, ecosystems services, cultural identity, etc. into resilience-based design. As a significant part of a flood resilience paradigm, Sustainable Drainage Systems (SUDs) were increasingly promoted in the quest for flood resilience in urban areas. Compared with the broad concept of NBS, SUDs focus on specific techniques to manage flood risk. With the implementation of SUDS, adaptive, integrated, and multifunctional landscape design with considerations of landscape resilience should be carried out based on no or low regret solutions (Woods-Ballard et al., 2007). In pursuit of bringing great challenges to planning and managing urban green spaces for sustainability, planners must form strong relationships with key actors, especially landscape architects to bring greater integration and "multi-functionality" of SUDS into the resilient design of public open spaces. The common strategies related to landscape resilience are listed in Table 2. The core concepts of these strategies are similar, though with different focuses.

Most of the presented benefits can be considered as Ecosystem Services. Ecological Services aim at guaranteeing the urban ecological functions to enable continuous ecological functions available to citizens. Enhancing the qualities of ecosystem services can improve better risk management and resilience in landscape architecture.

2. Landscape planning and design to address floods on delta plains

2.1. Flood resilience and landscape architecture

We divide landscape architecture approaches for floods on delta plains into two categories. Landscape planning mainly addresses general macro-level issues, such as the hydrological connection of the river network within a catchment, integrated measures related to flood resistance and resilience measures of upstream and downstream. Landscape design solves the micro-scale specific problems, such as the type, form and structure of flood resistance and resilience measures. However, either of these two categories of means needs to be combined with different discipline knowledge and measures which could mitigate the intensity of floods, increase in-channel water storage capacity, and distribute high flows into desired areas of the floodplain. Therefore, the flood mitigation of delta plain needs integration of the above two means and focus on the characteristics of delta plain floods. Furthermore, the study on landscape planning and design to flood control should pay attention to relationships between hydraulics and landscape architecture on a variated spatial and temporal scale. With the different subjects of concern from hydraulics, the corresponding scale on landscape architecture is different. At the macroscale i.e. regional scale,

Table 2. Strategies related to landscape resilience

Strategy	Definition	Main types of practices	Application area
Nature-based Solutions (NBS)	Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience (European Commission, 2016)	Combine technical, business, finance, governance, regulatory and social innovation, including established ecosystem-based approaches	European Union, North America, Africa, India
Blue-green infrastructure	A network for solving urban and climatic challenges by building with nature (Pötz & Bleuzé, 2011)	Urban forests, constructed wetlands, green and blue roofs, rain gardens, downspout disconnection, bioswales, green alleys, green stormwater infrastructure	US, UK and EU
Sustainable Urban Drainage (SUDs)	A range of techniques for sustainable utilization of water resources respecting both social, economic, and environmental interests (Maksimovic & Todorovic, 1996)	Bioswales, permeable pavement, wetlands, detention basins, green roof	UK
Low Impact Development (LID)	A principle for guiding sustainable urban planning and building design to better simulate the natural water cycle (Dietz, 2007)	Rain gardens, cisterns and rain barrels, green roofs, permeable pavement, bioswales, commercially manufactured stormwater management devices	North America and New Zealand
Water Sensitive Urban Design	A land planning and engineering design approach which integrates the urban water cycle, including stormwater, groundwater and wastewater management and water supply (Wong, 2006)	Bioretention systems, infiltration trenches and systems, sand filters, permeable pavement, sedimentation basins, constructed wetlands, swales and buffer strips, ponds and lakes, rainwater tanks, aquifer storage and recovery (ASR)	The Middle East and Australia
Sponge City	Solutions to manage urban flood risk, purify stormwater, and provide water storage opporunities for future usage (Qi et al., 2020)	Eco-friendly measures for collection, management, and reuse of urban water, including sustainable structural and non-structural measures	China

the subject focused on the spatial scale is a basin, in which hydrologic cycle period is taken as reference on a temporal scale. At microscale i.e. local scale, the reach of a river is the subject on spatial scale, in which a single event is taken as a reference on a temporal scale.

It is widely assumed that the resistance to delta floods should rely upon the landscape resilience approach. The landscape resilience approach regards the flood as a natural phenomenon of the ecosystem and adopts a comprehensive control method that adapts to the natural process of flood and regards floods as the functioning of the ecosystem meantime (Watson & Adams, 2012). As divergencies exist in different spatial scales of flood control, the corresponding characteristics of a certain spatial scale should be comprehended completely by planners and designers. For the objects concerned, related theories, and key technologies can be totally different. Thus, to learn the relationship between different scales is crucial to solving the problem comprehensively (Table 3).

Through restoring the buffer zone, increasing fluvial longitudinal connectivity, creating adaptation pathway of small-scale flood and other means, not only can re-naturalized sites restore the river channel, recover the riverside habitats but also can reduce flood threats and damages caused by a flood.

2.2. Nature-based solution types

As a widely used tool in the practical design of landscape resilience, nature-based solutions include the following types:

- Fully nature-based solutions – preserving and sustaining naturally occurring features of the delta plain ecosystem, such as floodplains, woodlands, saltmarshes, mudflats, dunes, marshes, etc.
- Partially nature-based solutions – restoring and establishing artificial features of delta plain ecosystem, such as water channel morphologies and processes, recreated habitats, etc.
- Environment-friendly structural engineering – combining hard engineering structure with natural features, such as marsh–levee systems or dune–dyke systems, etc.

Among these type, perhaps the toughest challenge to landscape architects is partially nature-based solutions, that is to analyze site status, distribute flood flow into desired areas with the natural or designated watercourse, and adjust water features such as detention, retention, and percolation, in rational means based on river hydrologic modelling. Thus, high flows inundate the floodplains and interim buffers to store water during the flooding period. Meanwhile, the storage and retention processes of flooding runoff help to increase vertical water connectivity between different soil layers and supply the groundwater.

2.3. Main technical means of NBS to floods in delta plains

In the following part, nature-based solutions for delta plain areas to flood events based on a landscape architecture perspective will be discussed. The main technical means are as follows (van Wesenbeeck et al., 2014; Prominski et al., 2017):

1) Water channel morphology and processes adjustment

The morphological characteristics of water channels include the plan form, cross-sectional characteristics, and channel longitudinal gradients. Based on the naturalized river channel design theories, morphology adjustment should be incorporated as part of the floodplain management, and the following aspects of adjustment should be included generally: straightening or remeandering, enlarging or diminishing, embanking or de-banking and reinforcing or weakening, etc. (Ollero, 2010; Vietz et al., 2016). The specific adjustment scheme for the water channel morphologies depends on the goals, available land spaces, funds, physical site constraints, vegetative covers, and other constraints. There is no "one-size-fits-all" approach for water channel adjustment. However, increasing lateral connectivity among the rivers, streams and floodplains can bring benefits to flood control. According to the observed and the expected water level, flood and tide

Table 3. Characteristics of flood resilience to landscape architecture on different scales

	Regional scale	Scale between regional and local	Local scale
Objects concerned	elements of landscape planning (hydrological system, aquatic ecosystem, land use system)	elements of landscape planning and design	elements of landscape design (aquatic environment, revetment, vegetation, pavement)
Related theories	fluvial landscape ecology, landscape ecology	river hydraulics, hydraulic engineering, landscape architecture	ecological engineering, landscape architecture
Key approaches and technologies	spatial planning, ecological planning, river hydrologic analysis, hydrologic cycle analysis, hydrologic risk analysis, functional coupling of each subsystem in the macrosystem	reservoir system analysis, flooding analysis (flood simulation model), water channel morphology and process adjustment, means of evaporation, relationship of detention, retention and percolation, relationship of erosion and sediment	technology optimization: site-specific landscape design optimization, ecological function optimization, engineering technology optimization: multi-porosity space, continuous space, and diversified space

control standards, the buffer zone and inundated areas, the channel morphologies and control point elevations of levee top are determined and integrated with hydrophilic activities, land use patterns, landscape elements and land-use types. Water storage and retention capacity of the river can be improved in several ways, in water channels or outside water channels such as on floodplain levels. In popular semi-natural river harnessing or river restoration projects, setting back flood defences or removing other obstructions from the main river channels is regarded as an effective method to increase the cross-sectional areas of floodplains. Another treatment method is to reconnect isolated channels and connect the river with floodplains, from widespread small-scale storage and detention buffers to large-scale flood reservoirs (Guida et al., 2015). The storage capacity of high flows is important, for as the larger the storage capacity, the lower the peak discharge and runoff velocity would be, which could directly mitigate flood damages. In urban areas, the water storage and retention capacity are strengthened by means such as Sustainable Urban Drainage (SUDs), Low Impact Development (LID), Water Sensitive Urban Design, Sponge City, etc. Generally, they reinforce the rainwater infiltration, retention and storage through permeable material used in urban underlying surfaces, effective subsurface storage, and drainage systems. In rural areas, the conditions are better than in urban areas in general, as soils of cultivated lands have relatively better capacities of water-holding and penetrating than urban underlying surfaces.

2) Riparian corridor and riparian buffer

System-based design strategies are far more critical for flood control than local adjustments. This system consists of protected and strengthened ecosystems that can also be used as natural corridors and buffers. According to the principle of landscape resilience, the rainwater and runoff of surroundings can be filtrated and intercepted by the designed riparian buffer, which plays an important role in protecting water quality and aquatic ecosystems from the impact of adjacent land-use patterns and extreme rainfall or surface runoff. As one kind of landscape type of aquatic-terrestrial ecotone, riparian areas in the terrestrial ecosystem have close interactions with the aquatic ecosystem. In addition, a riparian buffer is an indispensable component of a river basin, primarily due to its vital role in bank stabilization, habitat support, runoff stagnating, sediment depositing, water quality regulation and flood prevention. Setting riparian buffer as a flood control measure is confirmed by both effective function and economic feasibility. However, its role in flood storage and detention is conditional. Buffer vegetation increase surface roughness which slows down surface flows and regulates the quantities of water in different watercourses, thereby minimizing the negative effect of floods. However, with land reclamation, some riparian areas are transformed into fields, golf courses, pasture, and residential communities, simultaneously accompanied by ecological degradation. The restoration of the riparian buffer is necessary and urgent and to recover native vegetation first, and then to recover a robust ecosystem.

It is critical to design the riparian buffer appropriately, though the process is complex for being affected by the topography, hydrology, and land use in surroundings. The design includes its location, vegetation species, structure, and so on (Johnson & Buffler, 2008). The design of riparian buffer is necessary for the entire river, especially in special sites such as small tributaries and watersheds in the upper reaches of rivers. Given the topography, riparian buffers generally located at the descent adjacent to streams, lakes or reservoirs could absorb surficial runoff. In terms of vegetation, different species have different ecological functions. The well-developed roots of the trees can stabilize the shoreline against erosion as well as provide diversified habitats for wildlife. A herbaceous buffer strip can enhance the infiltration capacity, retard surface runoff, and enhance sedimentation (Rose et al., 2002). The structure of a riparian buffer affects its functions. Even with the same buffer width, the nitrogen removal capacity of herb vegetation buffer or forest-herb vegetation buffer was better than other types (Mayer et al., 2007). Also, a buffer with a certain degree of complexity in the structure makes the system more stable. The width of a riparian buffer is mainly determined by the river basin size and river width, the height of trees, riparian ecological processes, and range of lateral influence of habitats (Gregory, 1997).

3) Flood-specific landscape structural measures

As mentioned above, strengthening the connection between rivers and floodplains is an effective way for flood control. Areas deviated from the main watercourse to flood storage and detention belongs to floodplain areas which act as a secondary defence system to adjust higher-intensity floodwater in an intended way. The floodplain defence system usually requires constructing flood bunds, namely, one specific type of water storage dam which increases the water storage capacity of the floodplain. Structurally, for better regulation of the system, inlet, outlet, and spillway mechanism is required. Regularly, different types of flood detention reservoirs are distributed in the floodplain, including washland, wetland or other flood detention reservoirs. Washland is usually human-made and may have functioned as agriculture, amenity or recreational, etc. While wetlands are more dynamic, water levels would be either high seasonally or permanently, with natural or artificial characters. There are also other types of human-made flood detention reservoirs. These human-designed flood-specific landscape structural measures can be classified into varieties of hydrologic modes. However, they can be ascribed to the same mechanism for flood management and flood storage during times of high flow to mitigate flood. Factors being considered for flood-specific detention reservoirs can be summed up as follows: topography, catchment area, expected water quality, predicted stormwater flows, design storm event return period, and the current surrounding environment and proposed development. These types of flood detention reservoirs are not mutually exclusive. On the coasts of delta plains, tidal flats are another important type of structural measure for flood defense. Such wetlands between land and sea include two main types: vegetated saltmarsh and non-vegetated mudflat. Benefitting from the material exchanges between land and sea, tidal flats can provide many crucial ecosystem services such as provide defense against storm surges, which can prevent the invasion of floods further. Its design resembles the ones of wetlands. Also, factors such as tides, typhoons, should be taken into considerations.

The adoption of landscape structural measures brings benefits to flood defense and management systems. The extent of effectiveness will vary by site characteristics and the design and operation of the structural measures. In most cases, the change is likely to include mitigation in flooding frequency, duration, and depth of flooding.

3. Case studies of landscape planning and design across flood types

3.1. Rationale

In various reports and publications, a range of cases of flood mitigation has been presented. These include national scale, regional scale, or urban scale. Cases with large scale usually adopt more planning and management means, while small-scale projects are more likely to focus on the design means, though means of management would also be combined with. Having recognized the concept of landscape resilience as one of the most comprehensive approaches for developing flood resilience, governments and scientific communities are currently faced with the challenge of moving from general pronouncements to practical applications. We propose a framework of a technical route for establishing the cities through the implementation of landscape resilience (Figure 1). The key knowledge includes hydraulics, ecology, meteorology, environmental science, etc.; the fundamental technologies include: spatial planning, hydromechanics, civil engineering etc., and methods for planning and architecture are applied as linking knowledge, technologies and application.

Moreover, a qualitative research methodology was also adopted in four selected cases. These cases represent different countries with different contexts and a range of landscape planning and design methods. An analysis was undertaken of the applicable principles and ideas affecting flood mitigation implementation, and how this was framed in terms of landscape resilience. The analysis has been used to gain an insight into their ability to respond to flood. These cases are selected for analysis in this paper, rather than introduction and review the latest developments in the field, due to the complexities of the flood problem in the world.

3.2. Adaptive urban transformation in the Yangtze River Delta

The resilience concept is utilized for the Wuxiangba Riparian Wetlands Project of comprehensive adaptive urban waterfront transformation in Xitiaoxi river, Anji County, China, situated in the Yangtze River Delta (YRD) of China. As one of China's most important economic regions, YRD has been the fastest developing delta in the world for the past four decades. However, YRD is facing great challenges in its long-term economic development posed by climate change and environmental degradation, such as floods. During annual monsoon rain season and typhoon season, i.e. from June to September, cities in YRD are straining to fight in flood control and emergency rescue, which not only interfere with the standard economic operation of the relevant areas but also push up the cost of running the economy with rising costs of flood control. Reservoirs have been constructed along the middle and upper reaches of the river to reduce the flood threat, but the risk will be magnified a hundredfold by the floods exceeding the designed capacity of reservoirs or extreme abnormal weather. The more advanced the economy, the more urgent the prevention of potential risk will be. During the super long period of heavy rainfall in the YRD in 2020, over 410,100 people in Zhejiang Province were affected by flooding and the direct economic loss was up to CN¥ 3.84 billion yuan. However, Zhejiang Province is only part of YRD, other data of flood-affected areas are not yet available.

Since 2017, several strategies have been put forward on flood control in YRD from the perspective of landscape architecture via a series of comprehensive adaptive urban innovation projects. These projects focus on injecting more resilience into the urban waterfront and adaptations being made to face the increasing flood risk of the area. The multi-scale approach is introduced in design and planning, which enables a multi-scale systemic understanding of urban landscape dynamics and solves complex problems of different scales, especially by integrating landscape infrastructure and flood management measures. Due to the high land cost in YRD and the high-standard flood control, the compound multi-function waterfront

Figure 1. Framework of the technical route from landscape resilience to flooding resilience

has been adapted to replace the single function hydraulic engineering project to improve the city's flood capacity and adaptability.

With principles of compromise from the scale of flood water level to normal water level, guiding restoration and minimum intervention, Wuxiangba Riparian Wetlands Project encompasses an ecological river habitat and a constructed wetland, including functions of leisure, sightseeing, education, etc. To respect the natural in-situ conditions and the hydrological characteristics of the river, different planting and site designs are applied at different water levels (normal water level and flood water level (5-year return period, 20-year return period, 50-year return period). One key point of the Wuxiangba Riparian Wetlands Project is to construct ecological infrastructure for river ecosystem restoration, such as zonal vegetation and ecological embankment (see Figure 2). Several approaches have been adapted to preserve zonal vegetation and native plants as much as possible and combine them with the conditions of the site. For the natural design of the shoreline, uniform sections are abandoned for the entire project. According to the characteristics of the river regime and the processes of erosion and sediment of the shore, different types of sections have been adopted in design (see Figure 3). The landscape resilience concept was adopted in Wuxiangba Riparian Wetlands Project, as a trade off between flood control and ecological restoration. Permeability and connectivity between water-land phases and water cycles are enhanced and offer suitable habitats for diverse wildlife by practicing methods of ecological improvement as a solution to the multi-objectives problem. As this project has only been accomplished in July 2019, further assessment is needed after several years of the evolution of a new ecosystem.

3.3. Other representative cases

3.3.1. United Kingdom

The government of the UK attached great importance to the flood risk management and flood control planning, from making space for water (Department for Environment, Food and Rural Affairs, 2004) to natural flood management – working with natural processes (Ngai et al., 2017) in delivering sustainable flood defense in the UK, which is part of the nation's flood resilience (Warner et al., 2012; Barlow et al., 2014). These plans aim to protect, restore, and regulate functioning natural processes on different scales and reduce flood risks, mitigate flood damages, and enhance flood benefits finally. It takes many different forms of minimal intervention and changes the heavily modified river or coastline into a natural or semi-natural form which can be applied both in urban and rural areas, from headwaters to estuaries, from inlands to coasts. Many successful cases are present in the UK, especially on small to medium catchment scales. For example, a 400 m reach of a river was restored at Hunworth Meadows. The project's objectives are to improve the river corridor habitat by restoring river processes as well as reconnecting the river and its floodplain and develop the basis of experience focusing on multi-porosity space optimization. Measures that improved the form of the river and connectivity to the floodplain were considered. Method of hydrologic risk analysis with a coupled hydrological- hydraulic model, which has been used as references for decision-making, was employed to assess the impact of floodplain reconnection. Several adaptation strategies, including river restoration, embankment removal, remeandering and riffle creation have been adapted to permit widespread

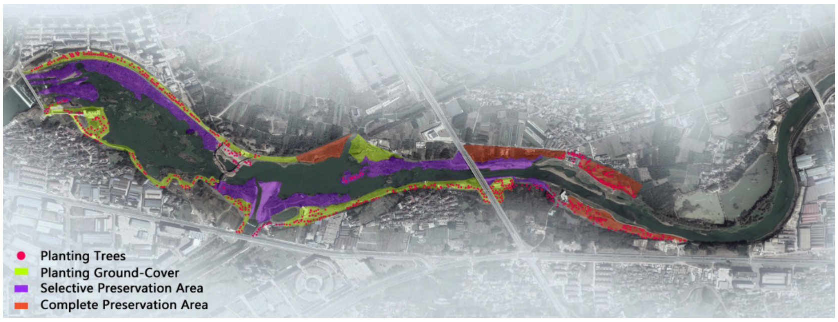

Figure 2. Vegetation preservation and planting planning

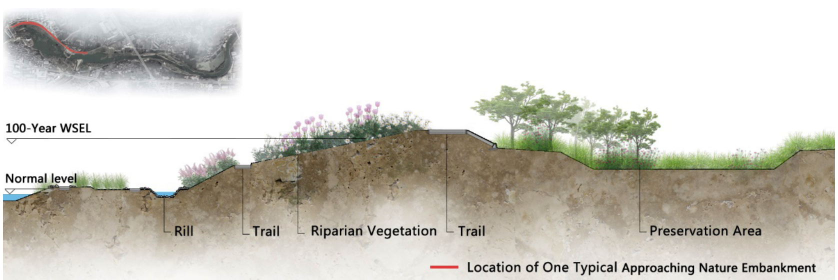

Figure 3. Cross-section of one typical approaching nature embankment

inundation of the floodplain at high flows (>1.7 m^3s^{-1}) as well as enhancing flooding of the immediate riparian area during lower magnitude events. This involved embankment removal including a 40–80 m wide (3 ha) floodplain area (2009) and remeandering (2010).

3.3.2. Japan

Japan is a country with frequent flood hazards. Thus, Japan has given great importance to flood disaster management throughout its history (Osugi et al., 2007). Through more than 100 years of exploration and practice, the small and medium-sized floods have been tried to control. In a period of rapid urbanization, it is challenging to control floods by constructing flood prevention schemes. Through the River Act, the Japanese government restricts land usage of retarding basins that belongs to the state appropriated land and does not permit residential construction (Takahasi, 2004). And an integrated river management system for flood management, water utilization and environmental conservation have been established. Methods of river hydrologic analysis have been used to aid practices of flood control in design practices. Comprehensive Flood Control Measures have been adapted for different types of areas. For water retaining areas, flood control ponds, rainwater storage, permeable pavements and rainwater infiltration inlets have been constructed. For Water retarding area, restrictions on constructing mounds had been set and several regulations were formulated to improve farm management. For lowland areas, facilities that can drain water into rivers have been developed, as well as flood-resistant buildings. In addition to flood retarding, basin areas usually serve as paddies, parks, or nature reserves. In Japan, with comprehensive regulation on rivers with frequent flood problems, wetlands are often set up on both sides of the river as areas for flood storage and retention, while sometimes the land obtained by straightening the river channel is used as retarding basins (Takeuchi, 2002). Restorations of waterways focus on both continuous space and diversified space. However, as the land in the city centre is particularly expensive, some parts of the flood storage and retention areas are often been used for multi-functional development. They can be used as a golf course, tennis court, parking lot, water feature and driver training school. In addition, it also decreases the construction costs of flood control projects.

3.3.3. Netherlands

The Netherlands built the amazing levee system for flood control, which worked effectively for centuries. Effective flood mitigation is a national priority in the Netherlands, as flooding is a regular occurrence requiring significant attention. In 1993 and 1995, Netherland had suffered two disastrous floods, which made the Dutch rethink the ideas on flood control, and thus putting forward the Ruimte voor DE Rivier (2001–2015), i.e. the Room for the River. Focusing on water channel morphology and process, this project aims at giving back the space occupied from the river corridors to the rivers, to make the river flow or being diverted as in the past and improve the capacity of flood discharge. Making "room for the river" allows landscapes along rivers to be restored to act as "natural water sponges" facing the event of a flood (Rijke et al., 2012). Rotterdam, which is located in the Rhine-Meuse-Scheldt delta, west of the North Sea, is in parts several meters below the sea level. The city already has a remarkable levee system, as well as the magnificent Hartelkering (Hartel barrier) which prevent storm surge from the North Sea. The key of the "Room for the River" in Rotterdam is to restore rivers detention and ecological functions, including a series of specific measures, such as protection of important wetlands and planting more trees and plants. The project created "room for the river" by increasing the depth of rivers, storing water, relocating dikes, creating high water channels, lowering floodplains, lowering groynes and removing polders surrounded by dikes (Stadsregio Rotterdam, 2005). Another type of measure that turns the city into a sponge includes a series of innovative designs such as floating communities, water storage facilities, water-absorbing roofs and walls. For instance, Water Square Benthemplein can store 1.800 cubic meters of rainwater, which can temporarily collect rainwater runoff from nearby. By constructing the storm barriers outside, and sufficient areas for flood storage and detention inside, the Dutch are believed to have a better symbiosis with the flood. These measures appear as an integrated measure to reduce flood risk and make spaces more attractive by stepping back from the river and allowing water to flow through the river system without hindrance, as well as improving environmental quality.

3.3.4. United States

Learning lessons from Hurricane Sandy and coping with climate change, New York City plans an ambitious project, the BIG U, which is part of Mayor Bill de Blasio's OneNYC sustainability plan, designed to build infrastructure projects that protect the city from environmental damage (Graham et al., 2016; Fainstein, 2018). The BIG U is composed of a series of hydraulic engineering elements and landscape elements, including levee, floodwall, and park, and preserve or transform low-lying land into a series of semi-natural green belts extending over the inland to the coast, which would help protect the city from inundation. The BIG U would act as a 10-mile-long "protective ribbon" that wraps around Manhattan's most flood-prone neighborhood, including plant-topped berms, public parkland, artist-decorated flood walls and other elements to avert catastrophic flooding. The BIG U Plan includes two main projects: One is the East Side Coastal Resiliency Project (ESCR), which stretches along the East River from East 25th Street to Montgomery Street; the other is the Lower Manhattan Resiliency Project (LMCR), which expands from Montgomery Street to Battery Park City. A proposed restoration area will both protect the area from storm surges and rising sea levels, and offer coast access for relaxation, socializing, and enjoying river vistas by providing pleasant, accessible routes over the highway through the park. Additionally, salt-tolerant trees and plants will provide a resilient urban habitat. Deployable walls will be constructed to flip down to mitigate flooding. The Battery Berm weaves an elevated path with a series of upland knolls to form unique landscapes. The plan envisions transforming the existing Coast Guard building into environmental education facility featuring a "Reverse Aquarium" where visitors can observe tidal variations and sea-level rise. The plan now is moving forward on the stage of the final design, and construction is expected to begin in spring 2020. The whole plan focuses on the core themes of past plans- growth, sustainability, and resiliency and is guided by an additional focus on equity and a regional perspective, which encourages applying a strategy of physical, social, and economic resiliency to the planning and design processes for creating an integrated flood protection system and to meet recreational, ecological, and community needs simultaneously, and most of all, prerequisite to reduce flood risk. New York City hopes that the project could create flood resiliency spaces throughout the city not only to recover quickly from storms, but also offer high-quality coastal public spaces during normal weather conditions.

3.4. Lessons on landscape resilience and flooding

From the cases mentioned above, several lessons on landscape resilience to flooding can be drawn.

Firstly, the strategy for landscape resilience to flooding should be emphasized on adaptation and integration. Flooding is a natural process, people cannot eliminate it and have to live with it. A multi-scale approach needs to be considered from regional to local by management and construction means. Secondly, making the river flow or divert resembling natural flow in the past could be beneficial for stormwater management with SUD-oriented strategies. Ecological infrastructure for river ecosystem restoration should be constructed, including zonal vegetation and ecological embankment. In addition, high-quality waterfront public spaces designed with NBS concepts should be integrated into riparian areas to meet recreational, ecological and community needs. The core diagram of landscape resilience to flooding generalized from cases can be seen in Figure 4.

Proper management and control of the floods need to introduce multi-dimension theories and measures according to different flood types and spatial or temporal scales. However, resilience-based flood risk management requires further research efforts to gain a more systematic and relatively complete understanding of flooding mechanisms. Related knowledge and practical experiences are crucial in contributing to a more comprehensive and effective flood risk management.

For landscape architecture, the risk in flood control is the uncertainty of flood scope and magnitude under the influence of multiple factors in the future, such as rising sea levels, extreme weather, urban ground subsidence, etc. And further attention could be paid to the following tasks:

(1) The study on the connectivity and the density of water networks by GIS technology, combined with green infrastructure and agricultural systems should be studied more thoroughly and systematically. In addition, evaluation of flood resilience and regulation strategies of green infrastructure and a mutual correlation among these systems need to be examined.

(2) The integration of specific engineering technology with landscape architecture should be given greater attention. These are just as important concerns as issues from comprehensive views at the macro scale and deserves further discussion and practical tests that need to be carried out.

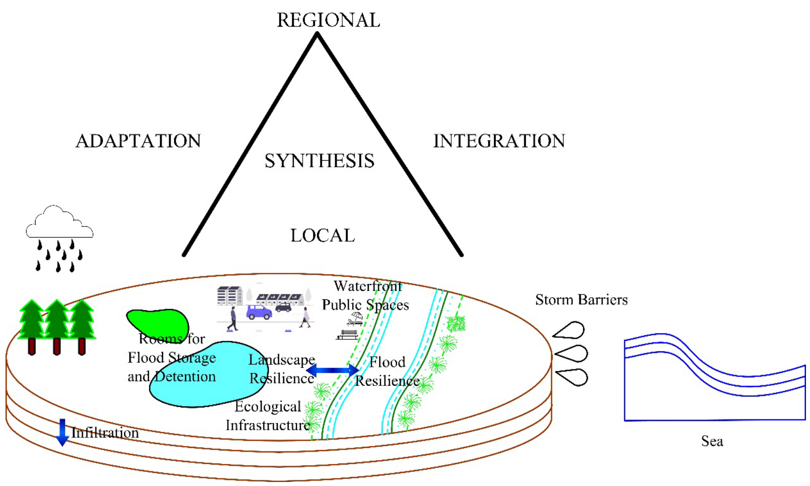

Figure 4. Core diagram of landscape resilience to flooding from cases

Conclusions

Delta areas are threatened by the impacts of worsening floods. To ease the risks and damages of floods, the concept of "landscape resilience" has been presented in this paper. The main conclusions can be summarized as follows:

For the complexity of the flood problems, the strategy of landscape resilience could effectively respond to different flooding events. The core concepts of the strategy are synthesis, adaptation and integration. The main technical means of landscape resilience to flooding in delta plains include water channel morphology and processes adjustment, riparian corridor and riparian buffer, and flood-specific landscape structural measures.

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