Towards Resilient, Floodable Cities:
Floodability as an Alternative Flood Safety Standard to Promote River Health

Kuei-Hsien Liao
School of Architecture
Chinese University of Hong Kong
Hong Kong SAR, China

ABSTRACT

Around the world many cities are challenged simultaneously by heightened flood risk and degraded river health. Flood control, the prevailing approach to urban flood hazard mitigation, has been recognized to be unable to guarantee long-term flood safety and has been criticized for causing ecological destruction because it not only affects riverine habitats, but also eliminates periodic flooding that is a critical mechanism to maintain river health. Based on a theory of urban flood resilience, this paper calls for a paradigm shift from flood control to flood adaptation in urban flood hazard mitigation to simultaneously address flood safety and river health in the long term. Urban flood resilience is nurtured through adapting to, not resisting, flooding. Flood hazard mitigation needs to address the “floodability” of the city, as opposed to the engineering protection standard of flood control infrastructure, to reconcile the seemingly conflicting goals of flood safety and river health. The mitigation approach based on the flood adaptation paradigm would focus on making the city “floodable” to prevent flood damage during flooding. Floodability is defined as the degree to which a place can be flooded without incurring physical damage and socioeconomic disruption. Urban design as a profession plays an indispensable role to move towards floodable cities through retrofitting the existing built environment, including buildings, open spaces, and infrastructure, to make it adapted to floods. Floodable cities would be capable of accommodating floodwater and flood-associated processes, such that flood safety could co-exist with a more biologically diverse riverine environment. In the flood adaptation paradigm, the ideology of flood safety standard is defined by floodability and is fundamentally different from that of the flood control paradigm defined by the engineering design standard of flood control infrastructure (i.e., protection against X-year flood). This paper presents some preliminary thoughts on how to measure the floodability of an urban area, as an alternative flood safety standard.

1. INTRODUCTION

Flooding is one of the most widespread and costly natural hazards in the world [1]. Because of the concentration of population and wealth, cities around the world are particularly vulnerable to flood hazards. Many cities are located in lowland, deltaic, and costal areas that are naturally flood-prone; moreover, climate change is expected to increase the frequency of extreme storm events to heighten flood risks [2]. Despite the extensive implementation of flood control infrastructure, costly flood disasters continue to occur in cities in both developed and developing nations. Flood control infrastructure refers to engineering structures that aim to change the hydrology and geomorphology of the river to prevent flooding to occur. A city’s flood control infrastructure may include levees, channelization, pump stations, drainage network that are geographically within the city; as well as dams and diversion channels that are located outside and upstream of the city. The limitations of flood control infrastructure are well recognized. On one hand, although it works effectively to prevent most floods, it cannot prevent an extreme event that exceeds the design capacity; it can also fail unexpectedly in a smaller event due to complex, unpredictable reasons [3]. On the other hand, by dramatically modifying the hydrology and geomorphology of the river, flood control infrastructure contributes to the degradation of aquatic and riparian ecosystems. The ecological degradation associated with the dramatic change of the natural river into a concretized channel is obvious; however, the more detrimental impact of the very function of flood control infrastructure to prevent flooding is little known to the general public. The impact is profound, since periodic flooding is the very mechanism that maintains river health.

With additional flood risk arising from climate change and the growing importance of urban sustainability, cities today are facing a much greater challenge of flood hazard mitigation. The realization that flooding cannot be entirely prevented has given rise to the concept of 'integrated flood risk management' that emphasizes the importance of non-structural measures and basin-scale management [4-6]. Non-structural measures are not to prevent flooding but to reduce flood impacts, and it includes flood forecasting, flood warning systems, evacuation programs, flood insurance, flood proofing, landuse control, etc. However, in the urban areas non-structural measures often play a supplementary role to flood control infrastructure. The basin-scale management emphasizes upstream storage and/or retention in the rural area to reduce flood risk downstream. Some of the basin-scale management practices also aim for ecological enhancement and include floodplain restoration, such as the 'Room for the River' project in the Netherlands and the 'Making Space for Water' policy in UK. Nevertheless, the basin-scale management addresses neither the eventuality of extreme fluvial and costal flooding nor pluvial flooding in downstream cities.

In general, flood hazard management has indeed become more holistic and integrated. The overall theory of flood hazard mitigation has significantly de-emphasized structural measures. However, in the urban areas flood control continues to be the centerpiece of flood hazard mitigation in both theory and practice [7]. The importance of flood control is reflected in the conventional wisdom that cities need to be protected from flooding. The continuing suppression of flooding of urban rivers leaves little room for more progressive and effective restoration projects. This status quo needs to be critically examined. The current mitigation paradigm, where flood control is considered necessary for flood safety, can be understood as the 'flood control paradigm'. Under this paradigm, flood safety comes into conflict with river health that requires periodic flooding. As an alternative, this paper argues for the 'flood adaptation paradigm' to reconcile flood safety and river health, based on a theory of urban flood resilience [8].

To move towards flood resilience, urban flood hazard mitigation needs to focus on increasing the city's tolerance of flooding, or "floodability", through urban design, as opposed to continuing to enhance flood resistance through river engineering, i.e., to increase the engineering design capacity or protection standard of flood control infrastructure. The remainder of this paper is organized as follows: First, I introduce the concept of floodability and the theory of urban flood resilience from which the concept is derived. It is followed by a discussion of the perceived conflict between flood safety and river health. Then I explore the flood adaptation paradigm—how it is different from the flood control paradigm and the role of urban design. Finally I present the preliminary thoughts on how to measure the floodability of an urban area, as a flood safety standard, alternative to the engineering design standard of flood control infrastructure

2. THE CONCEPT OF FLOODABILITY

2.1. Urban Flood Resilience and Floodability

As it has become evident the floods cannot be fully controlled, the concept of resilience has received increasing attention in flood management [9,10]. However, the term resilience is subject to various interpretations. Two different interpretations that have been applied in environmental management have been identified, namely engineering resilience and ecological resilience [11]. Engineering resilience originates in engineering sciences, focusing on the engineering system's ability to resist a disturbance and to recover to the previous, fully functional state if perturbed. Ecological resilience originates in ecological science, focusing on the ecosystem's ability to absorb the impact generated by a disturbance and to reorganize if perturbed. In natural hazard management, in many cases resilience is interpreted more akin to engineering resilience, often associated with post-disaster recovery and seen as the capacity to quickly "bounce back" from a disaster [8]. Other authors define hazard resilience more akin to ecological resilience as the capacity of a system to absorb recurrent hazard impacts and to reorganize while undergoing change so as to maintain fundamental structures, processes, identity, and feedbacks [9,12]. This definition recognizes the inevitability of natural hazards, and the focus is on how the system could survive through a hazard by making necessarily internal adjustment. Resilience in this case is not only about post-disaster recovery but also about the ability to adapt to changing conditions so as to survive.

Following the aforementioned interpretation of hazard resilience akin to ecological resilience, urban flood resilience is interpreted as the capacity of the city to tolerate flooding and to reorganize if physical damage and socioeconomic disruption occur [8]. In short, urban flood resilience is characterized by flood tolerance; and if disrupted, quick reorganization. Flood tolerance relates to hazard mitigation and quick reorganization relates to post-disaster recovery. With a focus on flood hazard mitigation, this paper addresses the aspect of flood tolerance of urban flood resilience. Flood tolerance is defined as the capacity to avoid physical damage and socioeconomic disruption during a flood; it is essentially the capacity to prevent a flood disaster, not preventing a flood altogether [13]. It should be noted that a flood, as a natural phenomena, does not necessary lead to a flood disaster.

How the built environment is designed plays a particularly important role in flood tolerance because socioeconomic disruption would not occur if the built environment remains intact and functional during a flood. Therefore, whether the built environment can be "floodable"—being flooded without physical damage and socioeconomic disruption—reflects a city's flood tolerance. The floodability of a city thus can be an indicator of flood tolerance and a surrogate for urban flood resilience to turn theory into operation [8]. Existing literature on the quantification of flood resilience is scant. De Bruijn (2004) develops a set of resilience indicators for flood risk management [14]; however, flood resilience in this case is about post-disaster recovery, not about hazard mitigation. The systematic and quantitative assessment of the mitigation aspect of flood resilience—flood tolerance—is still largely unexplored. But the concept of floodability is instrumental for cities to address the dual challenge of flood safety and river health. On one hand, it addresses the eventuality of flooding; on the other hand, it indicates that flood control is not the only way to achieve flood safety. Cities could possibly achieve flood safety through increasing floodability.

2.2. The Engineering Design Standard and Flood Resilience

According to aforementioned definition of urban flood resilience, the degree of flood control—represented by the engineering design standard or the protection standard—is irrelevant to resilience [8]. Because flood control is to prevent flooding altogether, it does not make a city floodable. In fact, a flood arising from levee or dam failure is more catastrophic than the naturally slow rising flood. As long as flooding would cause damage, a city is not resilient to floods, no matter how high the engineering protection standard of is. Flood control can even compromise flood resilience in the long term [8]. Resilience to a disturbance is nurtured through learning from and adapting to that very same disturbance over time [15,16]. It implies that resilience to larger floods requires episodic learning from numerous smaller floods [8]. Therefore, periodic floods are not only ecologically critical but are also agents of flood resilience, the elimination of which results in the erosion of flood resilience in the long term [8]. This theory is supported by the false sense of security associated with flood control infrastructure: People falsely assume that flooding will never occur when the levee or dam is in place [17]. The urban built environment is accordingly designed based on the assumption that the naturally flood-prone area will never be flooded again. The increasing uncertainty and unpredictability of future floods will continue to falsify this assumption.

3. FLOOD SAFETY VS. RIVER HEALTH

The recent decade has seen growing attention to urban river health and interest in the restoration of urban river's ecosystem goods and services, such as clean water, fish, and water purification [18]. However, flood safety and river health conflict with each other when flood hazard mitigation relies on flood control [19]. Flood control infrastructure drastically modifies the river, resulting in the degradation and homogenization of aquatic and riparian habitats; as a result, river fisheries are damaged and biodiversity compromised around the world [20,21]. Most destructive is the physical and hydrologic disconnection between the channel and the floodplain. It severely affects the native aquatic and riparian species that have adapted their life cycles to periodic flooding. The elimination of periodic flooding thus means the loss of the very mechanism sustaining the functionality of the river over the long term [22,23]. There have been numerous restoration projects that were implemented to reconstruct habitat complexity; however, it is widely agreed that without restoring the process of flooding, the ecological effects would be limited [24,25].

The basin-scale flood management allows for the possibility to reintroduce ecologically critical flooding, since the importance of the role floodplains play in flood hazard mitigation is recognized [26]. Floodplain restoration has emerged as a solution to reducing downstream flooding [27,28]. For example, the flood hazard mitigation projects of 'Room for the River', 'Making Space for Water', and 'Building with Nature' involve levee removal and setback to allow flooding on previously protected agricultural lands. Similar practices that simultaneously address flood safety and river restoration were also carried out in the urban areas, such as the restoration project of River Isar in Munich and the re-naturalization of Kallang River in Bishan-Ang Mo Kio Park in Singapore. In the two cases, the river is free to flood within a limited floodplain area along the river, which is a rather an unconventional practice in urban flood hazard mitigation.

Nevertheless, such a practice is still uncommon. For many, it would be unthinkable to permit much larger-scale flooding in cities. Since cities are densely populated with high land values and intense socioeconomic activities, it is widely believed that flood control is imperative and that the associated ecological degradation is a necessary trade-off for flood safety. It should be pointed out that such a perceived trade-off is a fallacy, for on one hand, the sacrifice of river health does not led to long-term flood safety; on the other hand, flood safety may be achieved through increasing floodability as theorized in the previous section.

4. THE FLOOD ADAPTATION PARADIGM

4.1. The Flood Control Paradigm vs. the Flood Adaptation Paradigm

There has been a prevailing perception that flooding is harmful and must be eliminated; hence the flood control paradigm that is about prevent flooding in the first place. However, as mentioned earlier, a flood does not necessarily lead to flood damage. Flooding is not always harmful; it also brings benefits [10]. Before the widespread implementation of flood control infrastructure, many settlements around the world evolved to live with floods. Today the living-with-floods lifestyle is still practiced in some rural communities in developing nations [29,30]. For example, in the Mekong Delta, people in the villages located near the boarder between Vietnam and Cambodia have lived with floods for generations. They in stilt houses and use boats and bridges to maintain mobility, such that the villages remain undamaged and functional during a prolonged flood of 3-4 months, which would likely to physically and economically devastate most modern cities around the world. Seasonal flooding in the Mekong Delta is not only mostly harmless and also important development resource that benefits wild fisheries, agriculture, and aquaculture [31]. The villages that still practice the living-with-flood lifestyle exemplify floodability through physical and livelihood adaptation to floods. They demonstrate that a flood is not necessarily disastrous. Arguably, theses villages are more flood-resilient than many modern cities, even if they are not protected by flood control infrastructure.

From a viewpoint of flood hazard mitigation, the communities that have evolved to live with floods can be said to practice the flood adaptation paradigm, in which flood damage and socioeconomic disruption are avoided not through preventing flooding to occur but through adjusting the built environment and livelihoods to minimize flood impact. The flood adaptation paradigm focuses on how to tolerant flooding, while the flood control paradigm on how to resist flooding. It should be noted that here the term 'adaptation' is different from that used in the climate change literature, which often all-inclusively means adjustments to actual or expected climatic conditions and their effects [32]. In the climate change literature, the adaptation measures to climate-change-induced higher flood risks often include more flood control [33]. However, flood adaptation here is used to contrast flood control (an attempt to change the flood regime) and is narrowly defined as measures to fit for actual and expected flood regime without attempting to change it.

4.2. Urban Design and Flood Adaptation

The flood adaptation paradigm implies a change of the subject of of flood hazard mitigation from the river to the design of the built environment. The river has often been blamed as the culprit of flood disaster in the flood control paradigm. In the flood adaptation paradigm, they key issue is how to make cities floodable. Floodable cities would allow floodwater to enter the city, therefore also allow for the re-introduction of ecologically critical periodic flooding. Urban design plays an indispensible role to adapt buildings, open spaces, and infrastructure to floods. Urban design involves professions that are responsible for shaping the urban built environment, such as architecture, landscape architecture, civil engineering, and planning. Relevant design solutions and finished projects have existed and/or are emerging. For example, buildings can be elevated, made floatable, or wet-proofed; open spaces can become multifunctional to convey and store floodwater during wet seasons; the transportation system can employ amphibious vehicles and temporary elevated walkways can be installed to maintain mobility during flooding. While a floodable modern city has not emerged, many existing design cases in different cities together point to the technical possibility of and professional capacity for the realization of floodable cities. Therefore, it is time to explore how to quantify floodability as an alterative flood safety standard and a policy tool to facilitate a paradigm shift from flood control to flood adaptation.

5. MEASUREING FLOODABILITY

An indicator for flood tolerance, the floodability of a place is defined as the degree to which it can be flooded without physical damage and socioeconomic disruption. The overall floodability of a city may be represented by the portion of its floodable lands to its flood-prone area. This measure is referred as the ‘Urban Floodability Index’ (UFI), where the value 1 means that the city is fully floodable (i.e., no damage and disruption would occur during a flood), and the value 0 means the city is entirely non-floodable (i.e., a flood would cause a catastrophe with severe damage and disruption). UFI could apply to any defined urban area of any spatial extent, from an entire municipality to a neighbourhood. The concept of UFI can be used for assessing the existing condition as a benchmark for the improvement of flood tolerance; a higher UFI can also be set as a goal. It can potentially be a policy tool to help the city to move towards flood resilience in the long term. Determining the UFI for an urban area involves (1) delineating the naturally flood-prone area, and (2) identifying its floodable lands. Below I discuss how UFI for lowland, riverine cities can be determined.

For a riverine city the naturally flood-prone area is the floodplain of the river. In contemporary flood hazard management, a floodplain is often defined by a predetermined recurrence interval through hydraulic simulation. For example, the floodplains in the US is defined by FEMA (the Federal Emergency Management Agency) by the 100-year flood for insurance purpose. However, nature does not follow artificially defined lines, and such floodplain delineation is based on an assumption of stationarity, which has been proclaimed dead [34]. Since the assessment of flood resilience should be forward-looking [35], floodability should not be limited to a flood of a specific and often arbitrarily chosen return period based on historic records. Therefore, for the purpose of determining UFI here, floodplain refers to the entire valley floor between valley walls [36]. The floodplain within the city may be delineated by a specific contour line that includes the river valley to best capture the geographic extent subject to extreme, basin-scale flooding. However, a floodplain is like other geomorphic systems and does not have a clear-cut boundary. Some floodplains may be relatively easy to identify because of the sharp topographic change between the valley floor and the valley wall, but it may not be the case for others. More studies are needed to understand different types of floodplain to develop a floodplain delineation method that can be widely applicable.

The identification of the floodable lands can be more complicated. It requires developing the criteria against which the floodability of lands of different uses is judged. A floodable land in general is defined as an area that conveys or stores floodwater, sediments, and debris during a flood without incurring physical damage locally or elsewhere and without interrupting socioeconomic activities. But since a flood would have different impacts on different lands of different uses, the floodability of different land uses need to be assessed differently. For example, a shopping center may suffer from severe damage of the building contents and interior decoration by a flood of 1 meter high; but the same flood may do little damage to a park. The land uses here mainly refer to different built components of the city, i.e., buildings, open space, transportation network, and other infrastructural systems. It is hypothesized that the floodability of a built component is controlled not only by its physical design but also by the flood attributes (e.g., depth, duration, and velocity). Therefore, the floodability criteria of each built component need to take both factors (the design and the flood itself) into account.

The floodability of a land also needs to be assessed by two aspects: (a) whether a flood would cause any physical damage, and (b) whether a flood would cause any socioeconomic disruption. The former aspect can be assessed by the elevation of the damageable valuable (e.g., furniture) and whether the material of the built element subject to flooding is resistant to flood damage. The later aspect is related to whether a flood would result in a discontinuation of the function and to the access to and from the land in question. For example, If a hospital is flooded but continues to function, and there is still a safe way for people to go to the hospital, then the hospital can be considered floodable. How this can be possible is a different question, pertaining to the design of hospital and related transportation network. A lot more investigation into the floodability of the built environment needs to be done before UFI can become a sophisticated policy tool.

5. CONCLUSION

This paper introduces the concept of floodability to raise the awareness of the adaptability of the built environment to floods. How the urban built environment can be flooded without physical damage and socioeconomic disruption is still a mitigation approach that is under-explored. This approach needs greater attention, as the focus in mitigation has been on the controllability of the river because of the prevailing assumption that flooding is disastrous. Flood control infrastructure has received tremendous investment, despite that it has been clear that it cannot be the answer to the greater challenges of flood risk and river health. This paper proposes the flood adaptation paradigm as the answer. UFI, a measure for the overall floodability of a city, can be a new policy tool for resilience-based flood hazard mitigation for existing flood-prone urban areas to respond to the uncertainty and unpredictability of future floods. By focusing on the ability to avoid physical damage and socioeconomic disruption when flooded, the concept of floodability attends to the limitation of ecologically destructive flood control that cannot cope with extreme event, and tackles the deficiency of basin-scale management that ignores the eventuality of fluvial and pluvial flooding in the downstream urban areas.

UFI is proposed as a different form of flood safety standard, alternative to the engineering design standard of flood control infrastructure that is based on flood probability, i.e., the probability of the occurrence of a flood of a certain magnitude in any given year. With flood probability as the flood safety standard (protection against the X-year flood), cities have focused on whether a place would be flooded or not, and the government has been considered to be solely responsible for flood protection to deliver flood safety to the citizens. With floodability as a flood safety standard, the focus would shift to whether a place is floodable when a flood occurs, and not only the government but also the citizens would own the problem of flood safety. The engineering design standard of flood control infrastructure is a concept often difficult for the general public to comprehend. Few understand the representation of flood probability, and misunderstanding is common; for example, it is often thought that the 100-year flood occurs every 100 years; that is, if it occurs this year, it won’t occur again until 100 years later. Floodability may be a concept that is easier to understand, as it is more straightforward.

The paradigm shift from flood control to flood adaptation and the implementation of floodability as an alternative flood safety standard require the urban design profession to take greater responsibility in flood hazard mitigation. It also requires the government to redirect the resources from constructing and/or strengthening flood control infrastructure to flood adaptation measures. It is foreseeable that in the short term, flood adaptation measures will still be secondary to flood control infrastructure. Nevertheless, climate change and urban sustainability are both issues of long term. Society cannot wait too long for the paradigm shift.

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