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# Move from Resilience Conceptualization to Resilience Enhancement

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## Abstract

This chapter provides an analysis of various resilience definitions and depicts the differences in definition between engineering, ecological and socio-ecological resilience in an easy-to-understand graphic representation. It also articulates commons and differences between conventional flood risk management and resilience-based flood management and presents a mathematical formulation to facilitate resilience discussion. Furthermore, it highlights some studies and initiatives towards the operationalization of the resilience concept in flood disaster management practice. The most important message this chapter is intended to deliver is that resilience is not just about bouncing back. Indeed, it should be enhanced to bounce forward.

**Keywords:** engineering resilience, ecological resilience, socio-ecological resilience, flood risk, resistance, vulnerability

## 1. Introduction

Despite decades of research and engineering works on urban flood disaster prevention and reduction, flooding-caused death and economic loss continue to rise. On a global scale, flood disasters affected 2 billion people in the period between 1998 and 2017 [1]. A report by UNISDR [2] revealed that 43% of natural disasters occurred during the period of 1995–2015 were related to floods. These events affected more than half (56%) of all people who suffered from any type of natural disaster with a flood-induced death rate of about 26%. Data from the Emergency Events Database (EM-DAT) also clearly indicates that flood disaster events have increased significantly in the number over the last decade. On a regional scale, the Expected Annual Damage (EAD) from river flooding reaches €6.4 billion and the Expected Annual Population (EAP) exposure to flooding is about 195,000 people in Europe [3]. Between 2000 and 2005, Europe suffered nine major flood disasters, which caused 155 casualties and economic losses of more than €35 billion [4]. On a national scale, for example, direct flood damages for the water year 2016 totaled US \$57 billion in China [5]. In Japan, a torrential downpour in July 2018 caused 223 deaths and inundated 29,766 houses with the total economic damage as high as 1,158,000,000,000 JPY according to the Ministry of Land, Infrastructure, Transport and Tourism, Japan [6].

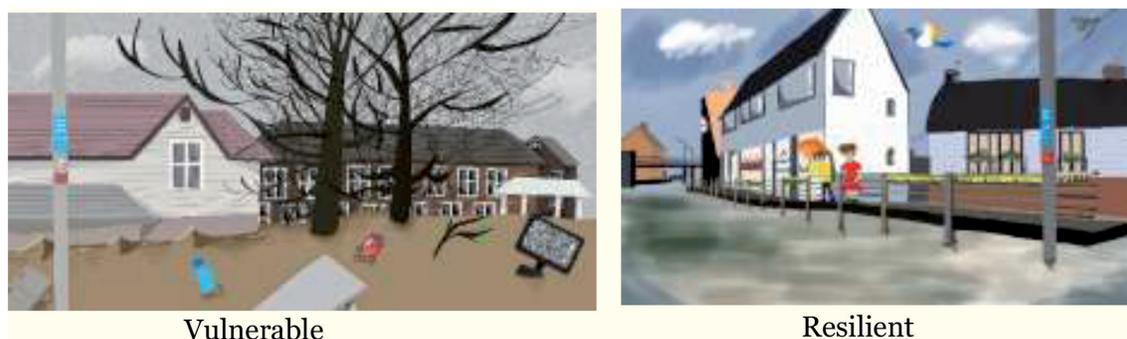
These water-related disasters were not solely caused by natural hazards. Rather, most of the major risks and disasters are triggered by vulnerable conditions of

societies. Additionally, the lack of resilience and adaptive capacity are factors that make societies or social-ecological systems unable to deal with changing environmental conditions and natural hazards effectively. Thus, there is a growing need to better understand the effectiveness of efforts and investments in resilience building that can help to minimize losses and assure a quick recovery during and after a natural hazard event.

In the 20th century, the main approach to deal with flood risk has often been the adoption of control-centered strategies, attempting to prevent flood disasters from happening. This approach is evidenced by the worldwide development of water infrastructure such as dam, levee, and diversion channel. Although this approach can provide substantial protection against floods, including reducing flood fatality significantly, it does not cope with changing environments. With climate change, the magnitude of a 100-year flood in the future may become much higher than a 100-year flood today. Consequently, a levee designed to resist a 100-year flood today could fail to function in the near future. More importantly, levee creates dilemmas because building stronger levee to reduce flood risk in turn may encourage more development in flood-prone areas, resulting in high flood risk. As more people and assets are concentrated in flood-prone areas, a higher levee to resist a large flood may cause higher damage should the levee breach. A study by Ferdous et al. shows that flood death rates associated with the 2017 flooding in Bangladesh were lower in the areas with lower protection level. Indeed, various studies so far have led to a general notion that a sole focus on resistance to flooding can be costly in terms of human life, property, and infrastructure. In places where the infrastructure or regulatory controls fail to provide adequate protection against unexpected events, flood risk management should rely more on the combination of hard and soft countermeasures.

Thus, the development of new approaches to deal with flood risk or the pursuit of paradigm shift in flood risk management is an urgent demand. In recent years, the concept of resilience has been gaining more recognition and momentum and is evolving to become a cornerstone for new approaches in flood risk management [7–11]. Building a flood-resilient city is a strategy for building a future in which we can live with floods and has become a widely known catch phrase. Streetscapes for vulnerable and resilient cities are illustrated in **Figure 1**. A vulnerable city may suffer from flood disaster, but a resilient city may allow residents to enjoy flood watching. As a matter of fact, resilience is explicitly incorporated in the United Nations (2015) Agenda for Sustainable Development: Goal 11 encompasses making cities and human settlements inclusive, safe, resilient, and sustainable.

The resilience is a relatively new notion referring to the ability of a system, community, society to defend, react and recover quickly and easily from the damaging effect of realized hazards. The large amount of research works has contributed



**Figure 1.**  
*Vulnerable and resilient cities (drawn by Alice Wang based on [12]).*

to the development of better understanding of the concept and its applications is currently being discussed in various fields from flood management, transportation, drinking water supply to power supply with the recognition of the difficulty of defining resilience precisely. Restemeyer et al. [13] attempted to develop a strategy-based framework to allow scientists and governmental bodies to evaluate the flood resilience of cities, whereas van der Vaart et al. [14] tried to crystallize suggestions for some of the core bottlenecks of the implementation of flood resilience strategies via an expert group workshop.

Although the concept of resilience has obtained a foothold in international academia and practice, playing increasingly important roles in the fields of ecology, spatial planning, social science, structural engineering and flood risk management as demonstrated by an ever increasing number of entries in scientific books and articles, its implementation in practice remains not always to be a matter of course. For example, a review work of resilience practice in New Taipei City showed that although New Taipei City government actively promotes resiliency in various sectors, particular townships are facing different challenging such as rapid urbanization and the lack of emergent facilities [15].

A technical issue, which could be considered a barrier to the development of resilience-based risk management approach, is that the definition of resilience varies from engineering, ecology to sociology. It may not necessary or even not possible to have an unanimous definition of resilience for all fields, an assessment of major definitions of resilience and its relationship with other concepts such as vulnerability and coping capacity will promote cross-sector communication and contribute to refinement of the concept and establishment of resilience-based or resilience-centered risk management discipline.

Therefore, the general aim of this chapter is to provide a concise analysis of different definitions of resilience in relation to flood risk management and to explain the commons and differences between conventional flood risk management and resilience-based flood management. Besides, it is intended to present a mathematical formulation of resilience for better understanding and assisting in-depth discussion. Moreover, it gives an account of the current application of resilience-based flood risk management concept. Nevertheless, it should be mentioned here that the analysis of definitions and discussion of current applications is not aimed to be comprehensive but selective.

## **2. Definitions**

While it appears intuitive to most people, the notion of resilience proved to be extremely difficult, if not impossible to define in a general and comprehensive way. Numerous qualitative and quantitative definitions have been proposed in different fields from ecology, engineering, social sciences to psychology. Some of them were explained as follows.

In ecology, the concept of resilience was first introduced by Holling [16], which states that the resilience is defined as “the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior.” Another definition is “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks” [17]. The focus of this definition is on the dynamics of the system when it is disturbed far from its modal state. As explained by Holling [17], the first definition concentrates on stability near an equilibrium steady state, where resistance to disturbance and speed of return to the equilibrium are used to measure the property, and such a notion may

be termed engineering resilience. The second definition emphasizes conditions far from any equilibrium steady state, where instabilities can flip a system into another regime of behavior, which can be termed ecological resilience. Wording differently, ecological resilience is not just about being persistent in a certain state but also allowing the evolution of the system to new equilibrium states.

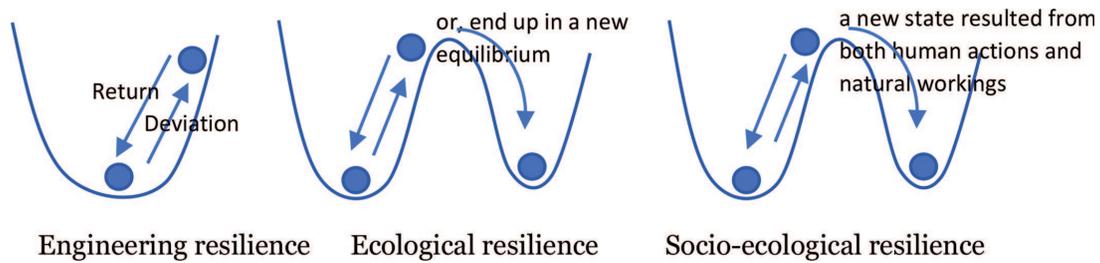
Meanwhile, Youn et al. [18] defined engineering resilience as “the sum of the passive survival rate (reliability) and proactive survival rate (restoration) of a system.” Similarly, the American Society of Mechanical Engineers (ASME) defined resilience as “a system’s ability to rapidly recover to the full function after disruption.” Haimes [19, 20] defined resilience as “the ability of system to withstand a major disruption within acceptable degradation parameters and to recover with a suitable time and reasonable costs and risks,” which highlights the recovery time and associated cost. He stressed that the resilience of a system is threat-dependent, and some particular states of a system are inherently more resilient than others. This notion requires the characterization and assessment of resilience to be specific to the threat under consideration. A system may be resilient to certain types of hazard but may not be so to another type of hazard. For example, flood-tolerant evergreen tree species of the Amazonian floodplain forests may suffer from seedling mortality due to draught. A poor coastal community in the Mekong Delta area may be resilient to damage from storm surge but could be very vulnerable to water pollution. A population might have resilience (immunity) to flu A but could be easily infected by Covid-19.

In addition to the type of threat, the present work suggests the explicit consideration of the maximum magnitude of the threat or the upper limit of disturbance that a system can withstand before it loses all functions. For instance, the IPCC story of “1.5 degrees Celsius limit” [21] tells greatly increased risks if global warming exceeds 1.5°C above pre-industrial levels and even “catastrophic” impacts to our world if we warm more than the target.

An underlying assumption in resilience study is that all systems have a certain degree of resilience. A system loses its resilience or loses its structure and functions only when the disturbance is too large to be coped with by system’s capacity. However, how the largeness of disturbance should be defined remains little explored. In other words, the critical point is not easy to determine. Up to now, resilience study has been largely disconnected to threshold assessment. So, a dilemma is how we could quantify resilience without knowing the conditions under that a system would collapse and lose it all functions. Besides, the upper limit or elasticity of a system depends on the type of threat because the system responds to different type of threat differently. Furthermore, system capacity is time-dependent and may be affected by surrounding conditions. Therefore, there could be a spatial–temporal variation in the upper limit of a system to withstand disturbance. As a result, the determination of the upper limit or quantification of system capacity considering its spatial–temporal variation in relation to the type of threat is an important step to operationalize the concept of resilience.

Allenby and Fink [22] defined resilience as “the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must.” A new and important point in this definition is its inclusion of exit strategy. However, this important aspect has received little attention in the field of flood risk management so far. The idea of degrading gracefully when it must also serve as a call for more in-depth study on the upper limit of a system to different types of hazards.

In social sciences, Adger [23] defined social resilience as “ability of groups or communities to cope with external stresses and disturbances as a result of social,



**Figure 2.**  
*Graphic illustration of different concepts of resilience.*

political, and environmental change.” The Community and Regional Resilience Institute [24] defined the resilience as “the capability to predict risk, restrict adverse consequences, and return rapidly through survival, adaptability, and growth in the face of turbulent changes.” Keck and Sakdapolrak [25] defined social resilience as “comprised of three dimensions: coping capacities, adaptive capacities, and transformative capacities.” What is important is that people are included in socio-ecological resilience discourse and such a coupling added new values to classical ecology in which humans are treated as external.

In economics, resilience is defined as “the inherent ability and adaptive response that enables firms and regions to avoid maximum potential losses” [26]. It can be further classified into static and dynamics resilience. Static economic resilience is referred as the capability of an entity or system to continue its functionality like producing under a severe shock, while dynamic economic resilience is defined as the speed at which a system recovers from a severe shock to achieve a steady state [27].

Vugrin et al. [28] defined system resilience as “given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is the ability to reduce efficiently both the magnitude and duration of the deviation from targeted system performance levels.” There are three key factors in this definition: (1) the disruptive event, (2) the efficiency of recovery of the system, and (3) the system performance.

It can be noted that a common feature among ecological, economic, and social resilience is that they do not demand the return to its original state but allow for regime change.

Based on these above-mentioned explanations, a graphic all-inclusive representation of resilience is provided in **Figure 2**. It is important to note that the social-ecological resilience may lead to a new equilibrium state depending on the combined effects of human restoration efforts and the workings of nature.

### **3. Commons and differences between conventional flood risk management and resilience-based flood management**

Conventional flood risk management focuses on the reduction of both flood probability and flood-caused damage. Flood probability reduction is pursued by technical measures such as dam and levee construction to keep flood waters in river channels. Resistance is a keyword to describe this practice. On the other hand, flood damage reduction is pursued by vulnerability reduction. Vulnerability is a concept that originated from social sciences and evolved to be a major framework in risk science and management and related academic fields, although a general and unanimous definition of vulnerability remains non-existent. One of the widely known definitions is given by the United Nations Development Program (UNDP),

which describes vulnerability as “a human condition or process resulting from physical, social, economic and environmental factors, which determines the likelihood and scale of damage from the impact of a given hazard” [29]. A mathematical expression of vulnerability may be given as below

$$\text{Vulnerability} = \frac{\text{Exposure} \times \text{Susceptibility}}{\text{Coping Capacity}} \quad (1)$$

where exposure is defined as the degree, duration, and extent to which a system is subject to perturbation. Susceptibility refers to the factors and attributes that make a community or society more or less likely to be negatively affected by perturbation. Coping capacity is defined as the ability to cope with, or absorb and adapt to, hazard impacts [30].

As resilience is the capacity to absorb, to recover and to adapt, the coping capacity of vulnerability bears some similarity with resilience. Wording differently, there is a resilience thinking to a certain extent in conventional flood risk management. Nevertheless, the prevailing notion in conventional flood risk management is stability and persistence while the socio-ecological resilience does not only stress absorption and recovery but also emphasize the adaptation and transformation to a new equilibrium state. Such an evolutionary perspective can be considered as one of the most important difference between conventional flood risk management and resilience-based approach. As pointed out by Chaffin et al. [31] that social-ecological systems should be managed holistically for either increased resistance to undesirable change or the ability to transform a system to a more desirable state.

The difference between resistance and the ability to absorb in resilience concept deserves some more discussions. The ability to absorb can be considered having two parts: ability to resist and ability to tolerate. Therefore, the ability to absorb in the concept of resilience may be interpreted as the ability to resist to external force first and then to bend if the force is too strong to resist but not to break. Because of the existence of various flood defense infrastructure, this interpretation is crucial for development and application of resilience-based management approaches at the top of conventional measures.

Resistance-centered flood control approach does not consider maximum possible resistance and assume the level of resistance is limitless with technology development and economic growth. To be specific, levees are traditionally designed based on a quantity named probable maximum flood at the location, which is the level of protection levees are supposed to provide. Up until recently, many river managers believed that the level of protection can be raised high enough as long as the societal capacity to commit resources to levee construction becomes available. With or without consideration of resistance limit is one of the separation points between resistance-centered and resilience-based approaches.

Thus, in developing resilience-based flood management approaches, the concept of engineering resilience or resistance can be applied to design and assessment for structures such as dam and levee while the concept of social-ecological resilience is useful in formulating flood adaptation strategy and determining acceptable level of risk and designing ways to deal with residual risk. Such an understanding can obviously help decision-makers do better flood management. The old mindset of confining flood waters in river channels and belief that levees can be constructed high enough to prevent overflow and strong enough to prevent any breach are wishful thinking. River overflow and levee breach have been occurring across the world even without climate change, and climate change is increasing its frequency and

intensifying the magnitude. In light of the inevitable, the confinement or resistance approach appears not sustainable and a shift from confinement to living with water is indispensable.

#### 4. A mathematical formulation of resilience

Based on the afore-mentioned definitions and analysis, a mathematic formulation was proposed here to facilitate in-depth discussion of resilience, which follows a logistic equation as below

$$\frac{dR}{dt} = rR \left( 1 - \frac{R}{K} \right) \quad (2)$$

Where  $R$  is the state of recovery (mathematically  $R = N/N_{in}$ :  $N$ : current state,  $N_{in}$ : original state),  $r$  is recovery rate,  $K$  is the carrying capacity of a system.

Integration of Eq. (2) yields

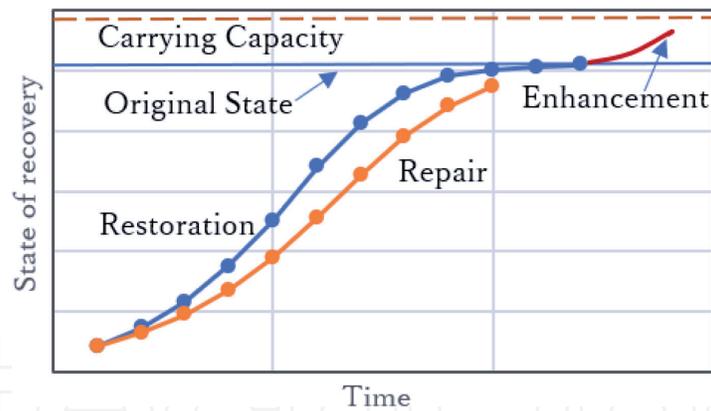
$$R = \frac{R_0 K}{R_0 + (K - R_0) e^{-rt}} \quad (3)$$

where  $R_0 = N_0/N_{in}$  is the deviated state of the system due to disturbance. Since  $R$  asymptotically approaches the carrying capacity  $K$  as time approaches infinity, it means a full recovery to the original state when  $K=N_{in}$ . It indicates partial recovery if  $K < N_{in}$ , and a new and better equilibrium if  $K > N_{in}$ . This can be interpreted as that a large carrying capacity is a premise for a system to have ecological resilience. If the capacity is not large enough, the achievable state of recovery is back to the normal at the best or even worse as being repaired. On the other hand, the speed of recovery may be expressed as

$$r = \frac{1}{T + Res / Resin} \quad (4)$$

where  $T$  is the intrinsic time of recovery, which is a function of local attributes including local natural landscape and local community structure.  $Res$  is the external resources used for restoration, which is a function of the magnitude of disturbance and local attributes as well.  $Resin$  is the internal resources available for restoration. This indicates that the less time the system uses for recovery, and the less the amount of external resources needed for recovery, the more resilient the system is. The availability of  $Resin$  is carrying capacity-related, and it depends to a large extent on governmental polies and decisions of how to mobilize internal sources. It also implies that the recovery rate may largely depend on external help if disturbance is too large for the internal mechanism to function. An illustration of resilience-dependent recovery based on Eq. (3) is given in **Figure 3**.

Compared to previous studies, such a mathematical expression of resilience can be used for both qualitative and quantitative discussions and to analyze the effects of more factors, especially the time of recovery and the amount of potentially used resources. For example, the recovery processes of vulnerable developing countries



**Figure 3.** Visual representation of resilience-dependent recovery process (low resilience: Repair; good resilience: Restoration; high resilience: Enhancement).

tend to rely largely on international aids, which reflects low resilience according to Eq. (4). Moreover, the outcomes are often superficial reconstruction without resilience building due to its limited capacity as can be explained by Eq. (2). As a result, recipients of relief aid lose their initiative to fend for themselves and repeat the cycle of disaster-aid-reconstruction-disaster. Quantitative or semi-quantitative assessment of the dependency of recovery rate on external source using mathematical formulas can certainly facilitate better decision-making regarding the long-term resilience building.

The earthquake and tsunami that hit Japan in 2011 cost \$235 billion economic damage according to the World Bank. Six years later, Japan's Reconstruction agency announced that out of the 150,000 evacuees who lost their homes, 50,000 of them were still living in temporary housing. The reason behind the delay is the lack of construction workers and rising cost of building materials. This case proved that large dependence on external resources could delay the recovery process greatly and resilience building should be promoted to reduce a system's dependency on external sources.

## 5. Current move towards the application of resilience-based flood risk management concept

The importance of resilience building in flood risk management has been well recognized as evidenced by large amounts of academic articles on resilience. In practice, however, resilience concept tends to be only marginally applied as a supplement to flood risk management. There are several well-known initiatives such as Rockefeller Foundation's 100 Resilient Cities programme (100RC) [32], the UNISDR Making Cities Resilient campaign, and the OECD Resilient Cities project [33]. These programs are mainly intended to promote resilience as a source of policy inspiration, and the development of policy instruments for cities to address immediate shocks and long-term stresses that undermine the functions of cities.

In the paper by Gralépois et al. [34], the flood defense strategies in six European countries (Belgium, England, France, the Netherlands, Poland, and Sweden) are analyzed. Although they do not find radical changes in either of the countries, they do find that the defense strategy in all countries has created more room for local, private, and individual responsibilities. In all countries except Sweden, defense remains the primary method of protection, leading the authors to conclude that flood defense has remained a cornerstone of European flood risk management.

The paper by Gersonius et al. [35] addresses the debate as to how transformations from resistance-based to resilience-based approaches can be achieved by studying the implementation of various measures that aim to enhance the flood resilience of the Dutch “Island of Dordrecht.” The case illustrates that a multilayered, i.e., diversified, approach is more effective and efficient than its resistant, i.e., flood defense dominated, counterpart and provides substantial co-benefits. However, it is incompatible with the existing institutional framework. Such an incompatibility may be considered a challenge that will also be present in other countries with an established institutional framework for resistance-based approaches. Then, the authors recommend searching for ways to reinterpret existing frameworks and applying them differently by setting up pilots and experiments to foster social learning.

The paper by Hegger et al. [36] assesses the now prominent assumption that a diversification of flood risk management strategies leads to resilience. They propose that the resilience concept should be operationalized into three capacities: capacity to resist, capacity to absorb and recover, and capacity to adapt and transform, and they compared six countries’ achievements in terms of these capacities. The work found that having a diverse portfolio of strategies in place contributes to resilience, especially in terms of the capacity to absorb/recover and the capacity to adapt and transform. However, the authors also stated in this work that they see different ways to be resilient. The importance of explicating the normative starting points of flood risk governance in a country, considering the unavoidable trade-offs between the three capacities, and assessing strategies’ fit with existing physical circumstances and institutional frameworks was further elucidated in the work.

Despite various efforts to adopt resilience-based approach to flood risk management, the actual application or the operationalization of the resilience concept remains to be explored, planned, tested, and evaluated. At present, many flood-prone regions have good pre-disaster preparation such as flood hazard map, evacuation plan and early warning system. However, few municipalities have resilience-based post-disaster recovery plan or guideline prepared before disaster. Instead, what was often seen is ad hoc recovery plans after disasters.

The Cedar Falls is a residential community located in Eastern Iowa. A good practice of the city is that it has a hazard mitigation plan, which includes a series of future hazard mitigation activities involving a wide range of hazards including floods [37]. Although one of the goals of the plan is to return to pre-disaster or improved conditions as soon as possible after a disaster occurs, the emphasis is placed on prevention than rebuilding. Technical advices on recovery process are limited and general. Suggestions such as “Continue membership with the National Flood Insurance Program (NFIP)” or “Establish and/or maintain Continuity of Government plans to handle post disaster operations (i.e. animal disposal, clean-up, demolition) are important but insufficient.

EPA developed a Flood Resilience Checklist [38] to help communities identify ways to improve their resilience to future floods. It includes five areas: (1) Overall strategies to improve flood resilience; (2) Conserve land and discourage development in flood-prone river corridors; (3) Protect people, businesses, and facilities in vulnerable settlements; (4) Plan for and encourage new development in safer areas; (5) Implement and coordinate stormwater management techniques throughout the whole watershed. The five areas can be regrouped as overall strategies (area 1) as well as specific strategies (areas 2–5).

The area of Overall Strategies to Enhance Flood Resilience is designed to promote the integration of the community’s comprehensive plan and other community’s plans such as open space or park plans with a flood management plan

including both structural and non-structural measures. It also promotes community participate in the National Flood Insurance Program Community Rating System. For specific strategies such as Incentives for restoring riparian and wetland vegetation in areas subject to erosion and flooding and Acquisition of land (or conservation easements on land) to allow for stormwater absorption, their importance are well recognized and have been pursued in various ways. A representative case is the Room for the Rivers program along the Rhine and Meuse Rivers, which started from 2006 with a \$3.3 billion budget from the Dutch government. Flood risk management strategies in the Netherlands have traditionally focused on reducing the probability of flooding [39] by means of dikes, pumps, and canals. After experiencing severe flooding in the 1990s, the Dutch government decided to safeguard flood-prone areas by stepping back from the river to enable the rivers to safely discharge far greater volumes of water. The program resulted in a reduction of water levels by 10–19 cm during high water in target river reaches. Although the primary goal of the Room for the River program is flood attenuation, it also recognizes the importance of esthetics and cultural and ecological elements and has increased biodiversity as the project transformed 4576 acres of land back to natural conditions. Therefore, such an initiative functions as an opportunity rather than a solely means to fix a problem because it is designed not only for river management, but also for social and economic advances.

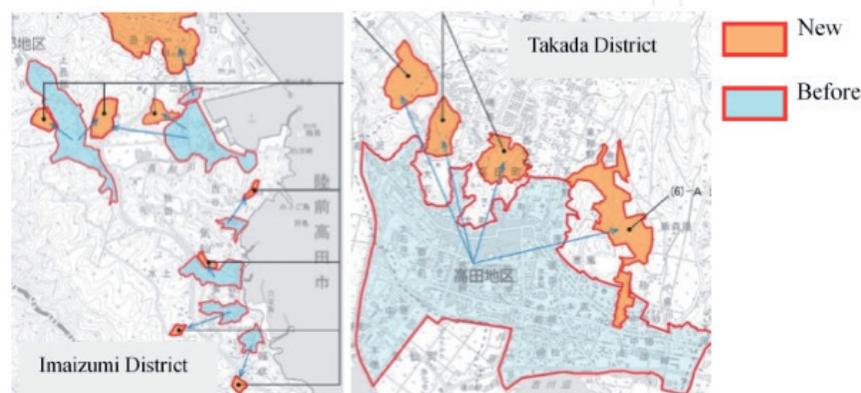
In the meantime, some U.S. communities have also implemented their own Room for the River strategies to deal with flooding. The Iowa River Corridor Project [40], begun after a severe flood in 1993, compensates farmers who permanently stop farming fields in floodplains. Much of the 50,000 acres involved have reverted into natural wetlands, grassland, and bottomland forest, and provide habitat for wildlife. The Napa River in California often floods between November and April. The \$400 million Napa River/Napa Creek Flood Control Project is lowering dikes, creating floodplains and a bypass, relocating bridges, and restoring 900 acres of wetlands according to “living river” principles. Floodplain and wetlands restoration projects are also ongoing in other parts of the U.S. such as Illinois, Massachusetts, Missouri, North Dakota, Minnesota, Oklahoma, and Wisconsin.

On the other hand, studies focusing solely on disaster recovery have also progressed greatly in parallel to resilience research. Smith and Wenger [41] defined the disaster recovery process as “the differential process of restoring, rebuilding, and reshaping the physical, social, economic, and natural environment through pre-event planning and post-event actions,” while Schwab et al. [42] defined recovery as “Recovery includes restoring housing, transportation, and public services; restarting economic activity; and fostering long-term community redevelopment and improvements. The definition adopted by the UN Office of Disaster Risk Reduction is “decisions and actions aimed at restoring or improving livelihoods, health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development, including build back better to avoid or reduce future disaster risk.” This definition emphasizes both returning the community to normality, which is a short-term objective and sustainable development to be less vulnerable and more capable of dealing with future disaster risk, which is a long-term goal and this long-term goal implies building back a better state, similar to the multi-equilibrium state concept in socio-ecological resilience. Therefore, the dialog between flood resilience researchers and disaster recovery planners should be promoted because it can deepen the understanding of resilience by resilience researchers and contribute to better recover planning for long-term resilience. In other words, the integration of conventional disaster recovery planning with resilience concept is a pathway for resilience building.

## 6. Concluding remarks

Science has revealed that the human immune system has 2 broad functions: (1) defending our body's health and (2) maintaining our body's health. Similarly, resilience can be viewed as urban's or community's immune system to natural disasters, possessing two functions: (1) resisting to disturbance and (2) maintain its viability. To date, resilience has been mainly understood as the system's capacity to restore its structure and functions. However, we chose to use the word of viability to emphasize our understanding that resilience is not limited to bouncing back but can bounce forward. In general, there are three options for a damaged system: (1) full restoration, (2) repair, which means the restoration with replacement, and (3) restoration with enhancement. For example, if the life of a city once flooded is now fully back to pre-disaster conditions, then such a situation is full restoration. If the disaster's impacts can never be fully erased from the city, it is a case of repair. For example, the city of New Orleans was severely damaged by Hurricane Katrina in 2005. Fifteen years after the disaster, the population of New Orleans has shrunk from 10 to 15 per cent, especially it lost many African Americans residents, who were either killed in the hurricane or could not afford to come back. This situation led some researchers to declare the housing recovery in New Orleans a secondary disaster [43, 44]. The Great East Japan Earthquake of 2011 and the vicious tsunami that followed it caused widespread destruction in the Tohoku region. Rikuzentakata City in Iwate Prefecture is one of the most badly hit cities in the disaster. The recovery plan focuses equally on reconstructing and improving damaged transport networks along the coastline, re-establishing affected local businesses and empowering the disaster-struck agricultural and fishing industries which used to thrive in the area. For the restoration of urban districts, it promoted the introduction of universal design, aiming to create more opportunities for people with disabilities and the elderly to work and do sports as well. Furthermore, residential houses and hospitals have been moved to much less disaster-prone locations. As shown in **Figure 4**, it is a large-scale project. In total, 298 ha of residential areas were relocated to relatively higher grounds. Such a scale of disaster-mitigation-driven relocation is unprecedented in Japanese history. Furthermore, the coastal protection system has been resigned innovatively. As illustrated in **Figure 5**, it consists of a double-dike structure with a vegetation zone in-between and submerged breakwater at the front. In light of these developments, Rikuzentakata City can be considered a successful case of restoration with enhancement.

A critical issue in choosing recovery path is the financial cost. The cost of each option may vary greatly, so that resilience building could be constrained by local



**Figure 4.** Relocation from low-lying lands (light blue) to high grounds (brown) in the city of Rikuzentakata after the Great East Japan earthquake (source: the city office).



**Figure 5.**  
*New protection system along the coast of the city (source: the city office).*

economic condition. In general, sustainable, resilient water management can be considered costly since it involves engineering and land use challenges and often a long-term process. The financial sustainability of resilience building and enhancement has been largely neglected up to now and deserves serious in-depth study. It is our belief that resilience building should be pursued in relation to economic growth in developing countries. In developed countries, solutions harnessing flood risk while unlocking further development potential should be explored, which require innovation. However, as we may face multiple pathways for building a resilient tomorrow, further studies should be conducted to develop optimal design approaches for resilience building with more than one objective.

Finally, it should be mentioned that conventional flood risk management is probability-based. It deals with the magnitude of potential consequences due to an event or disturbance with a chosen probability of occurrence. It provides little insights into the nature's or society's self-restoring or anti-disturbance function and is unable to cope with events with magnitudes of impact exceeding the chosen level. By contrast, resilience-based management is not constrained by likelihood of occurrence and can accept extremely large shocks by allowing adaption to new regimes. Therefore, it is more capable of and more flexible in restoring or reestablishing an affected system. Furthermore, resilience enhancement strategy can lead to better knowledge fusion than conventional flood risk management approach.

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## **Conflict of interest**

The authors declare no conflict of interest.

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