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Assessing national flood management using a sustainable flood management framework

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Abstract

This paper presents a prototype framework for sustainable flood management at the national level which features stakeholder participation, and is modified and applied to a case study. Through literature reviews and an interview survey of South Korea (the case study country), the causes of recent flood damage are found to be heavy rainfall due to climate change, urbanization, insufficient channel capacities and the application of inadequate measures. The interview survey also shows that, to reduce flood damage, along with consistent implementation of systematic long-term plans, minimizing injudicious artificial development is critical and necessary. Using the framework developed for South Korea on the basis of the findings and the prototype framework, national flood management is assessed and discussed. In particular, an implementation process based on flood risk management and integrated strategies is proposed to practically achieve the objectives of management practices with the cooperation of governmental organizations and stakeholders under circumstances of high uncertainty. Consequently, it is concluded that the effective conduct of sustainable flood management at the national level in South Korea requires a recognition of the context of flood management, cooperation and information sharing about flooding, and social learning and change, all of which can be achieved through the active participation of stakeholders.

Keywords: Assessment; Framework; Participatory governance; South Korea; Sustainable flood management

1. Introduction

Recently, extreme hydro-meteorological events have occurred more frequently in many parts of the globe due to climate change and have resulted in huge natural disasters (WWC, 2000; UN ISDR, 2005; Webster *et al*., 2005). In particular, the growing magnitudes of floods are closely related to climate

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change, given that climate change is considered to be one of the main causes of higher rainfall intensity. Urbanization has also caused higher levels of peak flood discharge and total runoff, as it typically increases the size of impervious areas and decreases the infiltration portion of total rainfall. In addition, in many countries, due to population pressure, developments in upper watershed areas and floodplains have constrained channels from controlling floods (Kundzewicz, 2002; APFM, 2004b; Werritty, 2006). For example, the flood damage of New Orleans in the USA from Hurricane Katrina in 2005 reached an estimated $28,000 million in property losses, with a death toll of 714 persons. It was reported that the major factors of the natural disaster were attributable to climate change, the rise in sea level, the increase in the number of buildings and residents in the flood-prone areas, and insufficient measures taken for flood management (US ACE, 2006).

As such, the apparent changes in socio-economic and natural systems due to both anthropogenic and natural factors have increased the potential for more severe flooding globally. To cope with these circumstances and their consequences, in many countries current flood management systems are expected to be changed from traditional hydrologic design-based systems to more proactive, holistic and sustainable ones. Recently, there has also been a paradigm shift toward sustainable flood management that has been recognized by several nations and international organizations to be momentous (Kundzewicz, 2002; APFM, 2004b; Scottish Executive, 2005; Werritty, 2006). In general, sustainable flood management can be defined as minimizing flood damage and building resilience against flooding in an economically efficient and socially equitable manner, while taking the environment, ecosystems and future generations into account. In addition, maximizing the benefits from flood management requires measures to be integrated with one another and consistently implemented, and their results should be fed back to the processes. Also, in recent years, it has been important to share lessons from past floods and information related to flood management with all stakeholders in order to carry out management practices within the same context at the national, regional and community levels. Particularly, it has been reported that public involvement in the governance of resources and environmental management may facilitate a more sustainable society (Keen *et al*., 2005; Marschke & Sinclair, 2009). Therefore, to effectively and consistently reduce flood damage at the national level, it is necessary to change old flood management systems, incorporating sustainability into flood management, employing state-of-the-art measures and integrating them, and accommodating stakeholders' participation and encouraging their changes.

Recently, to adequately identify system problems, to efficiently introduce new methodologies into processes, and to effectively adjust systems to changes, definite frameworks have been established in many fields and have been applied to real situations (Turner II *et al*., 2003; Freedman *et al*., 2004; Achet & Fleming, 2006). In the flood management sector, the Scottish Executive developed a framework with well-defined flood management concepts to conduct sustainable flood management using an overall sequential procedure. It recommended identifying goals, objectives and principles of flood management, plugging them into the framework, and developing an indicator system to evaluate the achievement of the goals and objectives and measure the degree of adherence to the principles (Scottish Executive, 2005). The United Nations International Strategy for Disaster Reduction (UN ISDR) proposed the Hyogo Framework to build nations' and communities' resilience against disasters by sharing information and cooperatively carrying out natural hazard management internationally (UN ISDR, 2007). However, because these frameworks include neither participatory decision-making processes nor the feedback of evaluation results to the processes and do not provide specific methodologies for national flood management, it is difficult to apply the frameworks to adaptively

carry out sustainable flood management at the national level. Meanwhile, in the resources management field, the sharing amongst stakeholders of an overall framework which includes a participatory decision-making process has been considered necessary for reaching social agreement about plans and measures, while avoiding unproductive debates. In this context, as a tool for investigating people's opinions about policies and reflecting their preferences in establishing strategies and measures, several decision-making methods have been proposed, such as multi-objective decision making, multi-attribute decision making and interview surveys (Kang & Lee, 2011). In particular, interview surveys are useful for investigating respondents' perceptions about the physical environment under circumstances of high uncertainty (which can result from changes in climate and in socio-economic systems) and for analyzing variations in their perceptions by periodically comparing interview results (Kusenbach *et al*., 2010). Therefore, for each country, a specifically appropriate framework needs to be developed, reflecting the state of flood management, incorporating methodologies for ameliorating any inadequacies and taking stakeholder involvement into account. During the process, strategies and measures need to be adaptively modified according to changes in the related circumstances and in stakeholder perceptions.

In this study, we develop a prototype framework for sustainable flood management at the national level in various countries on the basis of the concept and principles of sustainability, which is modified and applied to a case study country to prove its transferability into other specific countries. To identify the problems of the case study country (South Korea), we investigate the status quo of flood management and methodologies for flood management practices through literature reviews and an interview survey. Then, based on the research results, a framework is developed for sustainable flood management within South Korea. Using the framework, the national flood management of South Korea is assessed, and the results are discussed.

2. Development of a prototype framework

2.1. Principles of sustainable flood management

Natural and socio-economic systems adapt to changes in climates, paradigms and ecosystems. Figure 1 shows the processes of water resources development and management projects that evolve, with feedback on the processes and adaptation of systems. In the processes, the natural and socio-economic systems are evaluated periodically from multiple perspectives. If the states are not satisfactory in terms of the criteria (such as water shortage, flood damage and ecological degradation), measures are taken to tackle the problems and implemented to improve the states through the integration of related projects. In general, the measures are modified and adjusted to changes, varying with the related systems, through periodic evaluation and review of the results. Thus, the system changes to become more satisfactory for people.

In light of adaptive water resources management, as shown in Figure 1, there has been a paradigm shift in the flood management sector toward sustainable flood management. As such, a part of flood management has been modified toward non-structural measures, rather than only taking those measures oriented to engineering structures and simply increasing the sizes and capacities of structures in proportion to the increased magnitudes of floods. In addition, the criteria of flood management have been intensified and management practices have been carried out adaptively. In reality, some nations have changed their paradigms for flood management and tried to incorporate best mixes of structural

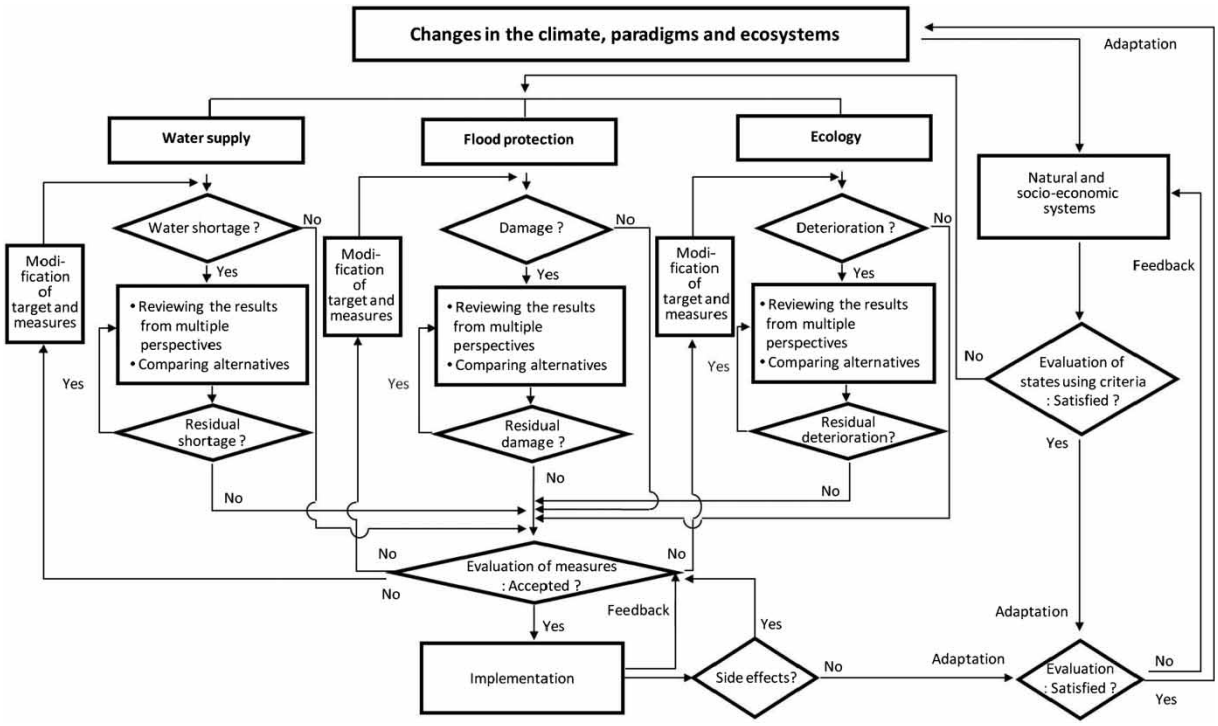

Fig. 1. Flowchart for carrying out water resources development and management projects, with adaptation to changes in related circumstances and feedback.

and non-structural measures into their flood management processes, including early warning systems and dissemination of flood information (APFM, 2004b; Werritty, 2006). In particular, the UN ISDR proposed that activities related to flood management should be sustainable and be conducted adaptively and consistently, adjusting plans and measures to changes in related circumstances (UN ISDR, 2005).

Recently, it has been reported that sustainable flood management provides more reversible, commonly acceptable and environmentally friendly options (Kundzewicz, 2002; APFM, 2004a, b; Scottish Executive, 2005; UN ISDR, 2005; Werritty, 2006; Blackmore & Plant, 2008), and it is believed that, since floods closely interact with related systems, measures and related resources should be integrated, employing inter-sectoral and holistic approaches within the context of sustainability.

In this study, based on the results of the above-mentioned literature surveys and the concept of sustainable flood management, we establish principles to develop a successful sustainable flood management system:

1. taking into account more reversible and flexible measures for the conservation of ecosystems;
2. making decisions about flood management through transparent and democratic processes;
3. integrating resources and using them multi-functionally to maximize benefits;
4. adapting to changes in related circumstances with integrated strategies;
5. optimally combining site-specific structural and non-structural measures; and

6. accommodating the participation of stakeholders in the activities and sharing responsibility for the achievement of goals and objectives.

2.2. Prototype framework for sustainable flood management

To incorporate the concept of sustainability into flood management and resolve complex problems related to flood management in various countries, a systematic prototype framework of components, methodologies and processes is necessary. Figure 2 shows a prototype framework that is developed to adaptively carry out sustainable flood management at the national level on the basis of the principles described above, in which a holistic approach is employed to take into account the interaction of systems. The prototype framework is composed of four components: 'governance', 'context', 'indicator system' and 'implementation methodology', which are connected by processes with other components. As shown in Figure 2, in the 'governance' component, various stakeholders who affect flood management or can be affected by it are encouraged to form a coalition. After identifying problems with flood management, they establish the definite goals of flood management to consistently carry out sustainable flood management. In addition, as part of governance, the authorities inspect the processes through

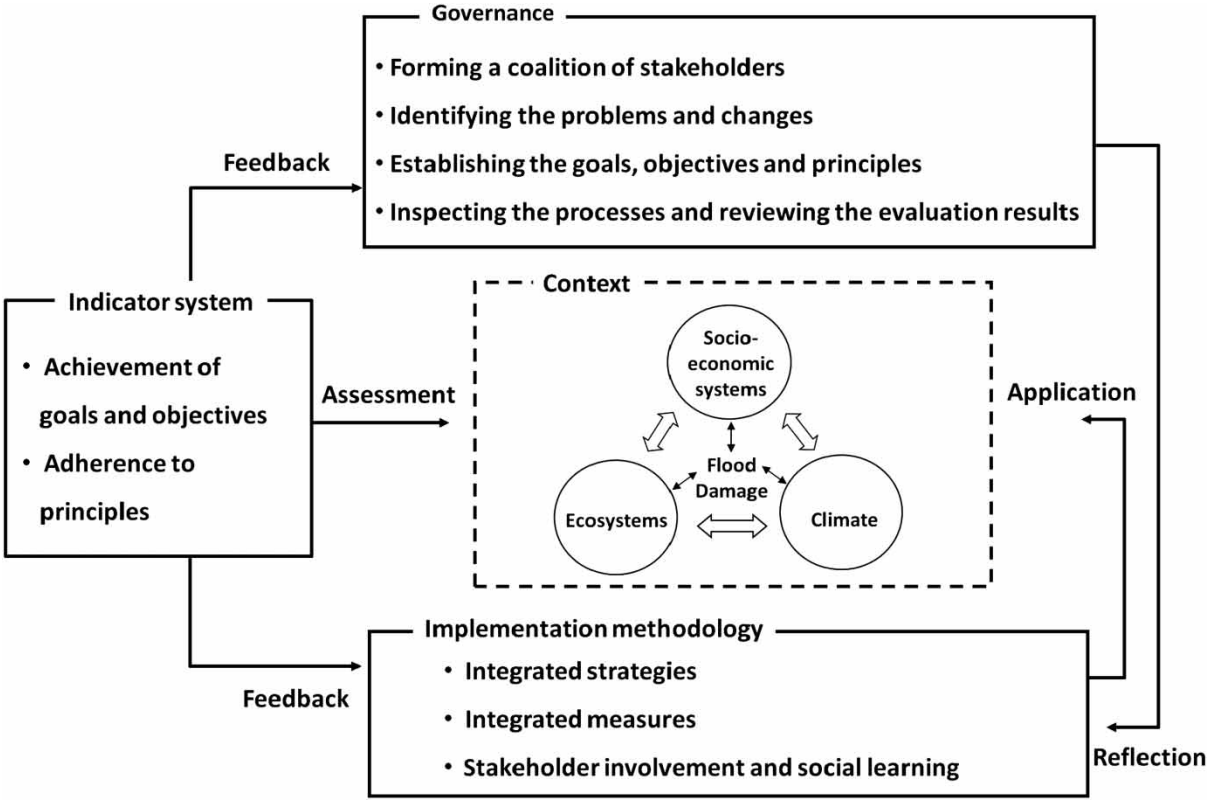

Fig. 2. Schematic diagram of a prototype framework for sustainable flood management at the national level.

monitoring and reviewing the results of the measures. Since flooding affects related systems, each of which interacts with one another, and the systems have an influence on flood management pertaining to society, the problems related to flood management are exposed and measures take effect at the 'context' component. Additionally, changes in related circumstances are brought to the surface by flooding. Therefore, to accurately identify the state of flood management, the context should be investigated and analyzed thoroughly. The 'indicator system' component provides a methodology for evaluating the state of flood management from multiple perspectives. Since the effects of flood management are not immediately apparent, periodic evaluations concerning the achievement of goals and objectives, and the adherence to principles, are necessary. Therefore, the evaluation methodology should be embedded in the framework in order to consistently carry out flood management with adaptation to changes and to make society more sustainable. In the 'implementation methodology' component, measures and strategies are developed and implemented to obtain goals in real situations. In particular, the participation of stakeholders in implementing measures is considered to maximize the benefits of flood management activities through their cooperation, and social learning then occurs.

As shown in Figure 2, the components are connected with processes, such as 'feedback', 'assessment', 'application' and 'reflection'. The 'governance', 'context' and 'indicator system' components are connected by 'assessment' and 'feedback'. In this framework, to identify problems of flood management and changes of the context at national level, the state of flood management are evaluated using an integrated indicator system. The evaluation results are fed back to the 'governance' component, and then the goals and objectives are then established. In addition, in the long term, the goals and objectives are modified and adjusted to changed circumstances, varying with the related systems, through periodic evaluation and review of the results. The 'governance' and 'implementation methodology' components are connected by 'reflection' and, simultaneously, the 'context', 'indicator system' and 'implementation methodology' components are connected by 'assessment' and 'feedback'. In this framework, measures and strategies are developed by the process of the two components, 'governance' and 'implementation methodologies', reflecting the goals and objectives of flood management. The developed measures and strategies are each integrated and applied to national flood management through the 'application' process, which connects the two components, 'implementation methodology' and 'context'. Appropriate measures are taken, taking into account the results found by evaluating the state of flood management in detail. The results of measures are monitored, evaluated and fed back to the 'implementation methodology' component, and changed with a view to achieving the goals and objectives. Through participation in flood management activities during the process, stakeholders share information about flooding and change their objectives through social learning.

3. Application to assessing national flood management

In South Korea, several river projects have been undertaken since 2009, including enlargement of channel capacities through dredging, construction of reservoirs and weirs, and creating retarding basins in the vicinity of rivers, to provide more room for ecological wetlands and water-friendly facilities along the four major rivers (the Han, Nakdong, Keum and Youngsan) (Jun & Kim, 2011). However, as a late starter in conducting advanced sustainable flood management at the national and river basin levels, South Korea needs to develop a new flood management system, reflecting the changes in these circumstances, as well as climate change, urbanization and paradigm shifts. Therefore, in this

study, South Korea has been used as a case study country and the prototype framework is appropriately modified and applied to assess the national flood management of South Korea.

3.1. Flood management in South Korea

3.1.1. Flood damage. On average, two to three typhoons pass through the Korean Peninsula every year. Most of the floods in South Korea are caused by these typhoons and their accompanying heavy rainfall during the summer rainy seasons. To prevent flooding and to secure water resources, the mouths of several rivers were closed by estuary dams, which have been operated, taking the differences between river stages and sea levels into account. Also, several multi-purpose and flood control dams have been put into place in the upper river basins. Streamflow and rain gauging stations were installed along the river basins and have been used to measure hydro-meteorological states. Since the early 2000s, high-tech flood forecasting and control systems have been developed and upgraded, and applied to the major rivers in South Korea to provide advance warnings and to control flooding. These systems, as described above, have been integrated and utilized to reduce damage from floods (Kang, 2011a).

Nevertheless, South Korea has seen a high increase of flood damage from floods resulting from extraordinary weather conditions and typhoons. Table 1 shows the casualties and property damage caused by the ten most devastating typhoons from 1925 to 2006. In 2002, Typhoon Rusa resulted in the deaths of 246 persons and an estimated $5,590 million worth of property damage. From this typhoon, Gangneung incurred an extraordinarily heavy rainfall recorded as 870.5 mm/day. In 2003, Typhoon Maemi caused an estimated $4,590 million worth of property damage. Then, in 2006, property damage due to Typhoon Ewiniar reached an estimated $380 million. During the 2006 rainy season, including Typhoon Ewiniar, the total rainfall amounted to 717.3 mm, which was the highest rainy season total rainfall recorded in the Han River basin since 1973 (Kang, 2011b). Recently, these floods have been used as the baseline for establishing plans and taking measures in South Korea.

Based on the comparative results in Table 1, it appears that the death toll has decreased over the years, while the amount of property damage has increased. This pattern is thought to be formed by climate

Table 1. Summary of damage from top 10 typhoons in South Korea from 1925 to 2006, ranked by loss of lives and by property damage.

	Ranking according to loss of lives			Ranking according to property damage		
Rank	Typhoon	Period	Death toll (Persons)	Typhoon	Period	Property damage* ($1,000 million)
1	3693	28 Aug. 1936	1,232	Rusa	31 Aug.–1 Sep. 2002	5.59
2	2353	11–14 Aug. 1923	1,157	Maemi	12–13 Sep. 2003	4.59
3	Sara	15–18 Sep. 1959	846	Olga	23 Jul.–4 Aug. 1999	1.08
4	Bete	18–20 Aug. 1972	550	Selma	15–16 Jul. 1987	0.60
5	2560	15–17 Jul. 1925	516	Jenis	19–30 Aug. 1995	0.55
6	1427	7–13 Sep. 1914	432	Ewiniar	9–10 Jul. 2006	0.38
7	3383	3–5 Aug. 1933	415	Gladis	22–26 Aug. 1991	0.32
8	Selma	15–16 Jul. 1987	345	Yani	26 Sep.–1 Oct. 1998	0.28
9	3486	20–24 Jul. 1934	265	Prapiroon	23 Aug.–1 Sep. 2000	0.25
10	Rusa	31 Aug.–1 Sep. 2002	246	Jun	31 Aug.–4 Sep. 1984	0.25

*Property damage converted to the monetary value of 2006.

change and urbanization which, as in other countries, are considered to be the causes of the changes in the magnitudes of flooding and property damage, and by policies which have been carried out to reduce the death toll (MOCT, 2006). In particular, the results from analyzing the causes of recent flood damage generated by typhoons and meteorological conditions from 2004 to 2007 reveal that the primary causes were increases in flood discharges due to heavy rainfall and urbanization, insufficient channel capacities, inadequate river management, flawed measures for preventing disasters and the failure of disaster prevention facilities (Kang, 2011b). Therefore, to improve the state of flood management in South Korea, the paradigm of flood management, related systems and measures should be changed to be more effective and sustainable.

3.1.2. Perceptions of flood management. An interview survey was conducted to identify the current state of flood management and to create methodologies for a sustainable flood management system in South Korea. The interview results were intended to be incorporated into the framework for sustainable flood management in South Korea. The survey included an investigation of experts' thoughts on flood management and the identification of their opinions on how to approach sustainable flood management when factors that change (such as climate, socio-economic systems, ecosystems and social preferences) are considered in the decision-making process. The survey had eleven questions in total, and was conducted by sending questionnaires to members of the Korea Water Resources Association by email. The respondents were broadly divided into three groups, namely: researchers, engineers and policy-makers groups, of which the numbers of respondents were 67, 75 and three, respectively. The survey questionnaire included multiple choice answers for each question, and the respondents were required to select the best answer for the question based on their experience, knowledge and judgment. Respondents who could not find the appropriate answer choice were allowed to freely write their opinions for each question.

Table 2 shows percentage results for the preferred responses to eight questions regarding the state of flood management in South Korea and appropriate measures to improve the flood management system. On a question about the causes of flooding, most respondents recognized climate change and extraordinary events as the primary causes of flooding, and that development projects in the vicinity of rivers also triggered flooding. The survey participants recommended the following measures to reduce flood damage due to climate change, extraordinary events and urbanization: enlarging channel capacity by managing floodplains and dredging; carrying out embankment work and constructing dams, taking into account the increase of the amount of officially registered flood discharge; restricting land use in the vicinity of rivers and implementing structural measures; and reducing flood discharge by managing land use and crop patterns upstream of watersheds. As shown in Table 2, the results of a question regarding what is necessary to enhance the efficiency of flood management indicate that appropriate structural and non-structural measures should be integrated. There should also be a positive investment in integrated flood management, as well as consistent implementation and adjustment, taking into account changes in related circumstances. Additionally, the interview results about restrictions on land use upstream of watersheds show that respondents believe the influence of urbanization would be mitigated with a combination of appropriate measures, since only strong regulation and restriction on land use upstream of watersheds would be insufficient. Table 2 also shows that the most appropriate measures for frequently inundated areas were identified to be moving residents away from the areas prone to flooding and then using those areas for river or storm water storage (40.7%), and taking structural measures such as constructing dams, reservoirs and retarding basins (40.7%). Accordingly, it is concluded that a good mix of structural and non-structural measures is necessary to prepare for the

Table 2. Results of responses to questions about the state of flood management and progress direction in South Korea.

Question	Choices	Response (%)
What is the cause of the increase in recent flooding?	Climate change and extreme rainfall	44.1
	Deficiencies of flood control structures	16.6
	Highly valuable land use in the vicinity of rivers	14.5
What is necessary to reduce the effects of land use change?	Taking the best mix of measures	42.8
	Severely restricting land use upstream of rivers	37.2
	Taking other measures, except for strong restrictions	17.9
What is an appropriate measure for frequently inundated areas?	Moving residents away from the areas prone to flooding and using those areas as parts of river	40.7
	Taking structural measures such as constructing dams and retarding basins	40.7
	Building embankments and improving drainage facilities	15.2
What is preferentially necessary to prevent flooding?	Taking the best mix of structural and non-structural measures	26.9
	Establishing long-term plans and consistent implementation	22.1
	Integrating flood control systems	15.2
What must be recommended to reduce flood damage due to climate change and urbanization?	Enlarging channel capacities by managing floodplains and dredging	26.2
	Constructing dams, taking into account the increase in design flood discharge	25.5
	Restricting land use in the vicinity of streams and implementing structural measures	20.7
What are your thoughts on related people participating in establishing plans and risk levels?	Positive participation	76.7
	Participation only of the people in charge	8.3
What is necessary to enhance the efficiency of flood management?	Incorporation of Integrated Flood Management	36.6
	Making systematic flood management plans and implementation	29.0
	Selective increase of design flood discharge	13.8
What are your thoughts on the use of farm lands in vicinity of rivers?	Providing subsidies and using the land as temporary retarding basins	53.8
	Rehabilitation of farmlands to rivers	24.8
	Taking other measures, except for retarding basins	11.7

increase of flooding due to climate change, considering that these responses can be high priorities for establishing flood management plans. Subsequently, measures should be integrated and consistently implemented for sustainable flood management in South Korea and adjusted to any changes in related circumstances.

The survey also investigated a cycle for evaluating the state of flood management. Respondents were asked how often flood management measures should be evaluated. The first-ranked choice amongst the respondents was every 3 years (45.5%), followed by every 5 years (27.6%). On a question about the level of stakeholder involvement, the majority of respondents (76.7%) reported that their active participation would be necessary when establishing flood management plans and assessing flood risks. On a question about the appropriate cycle for establishing the criteria for evaluation and instruction for new projects, 40.7% of respondents answered that 5 years would be appropriate, 35.2% 3 years, and 11.7% 2

years. In addition, 53.8% of respondents answered that 5 years would be adequate, 29.7% 3 years, and 6.2% 2 years as the cycle for establishing the goals, objectives and principles of flood management. These results indicate that stakeholders should actively participate in establishing flood management plans, in evaluating the results of projects, and in establishing criteria for evaluation. They also reveal that establishing flood management criteria and evaluating the results of the measures implemented in a 3- or 5-year cycle are considered appropriate.

3.2. Tool for assessing national flood management

Taking into account the foregoing results, we modified the prototype framework to a process-based framework for carrying out sustainable flood management in South Korea, as shown in Figure 3, and practically assessed the national flood management of South Korea from the perspective of sustainable

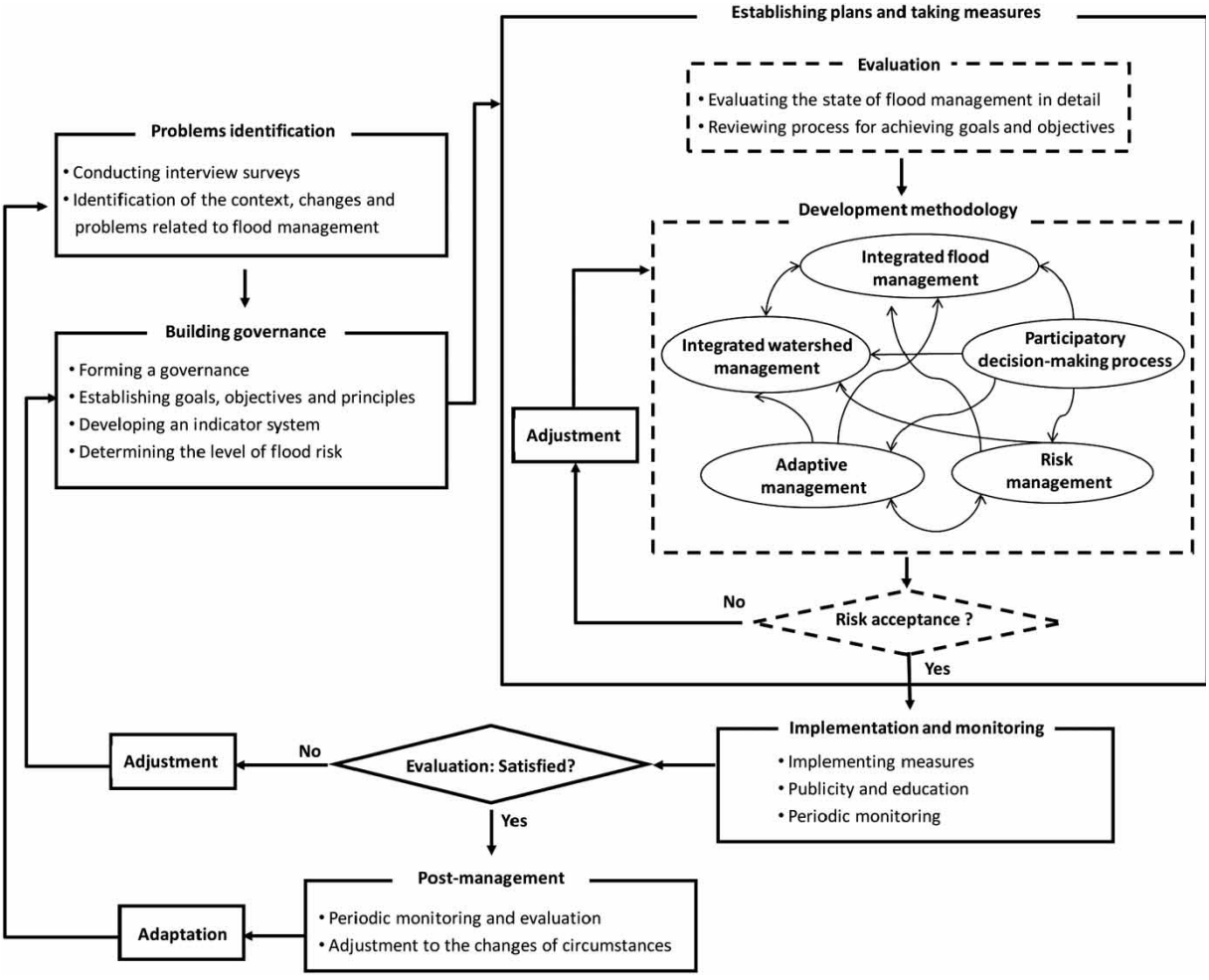

Fig. 3. Typology of the framework for Sustainable Flood Management in South Korea based on a prototype framework with participatory processes.

flood management using the framework. The framework developed consists of six steps, and the participation of stakeholders is incorporated into the framework to effectively and cooperatively obtain flood management goals and objectives. During the 'problems identification' step, the context of the society, changes in related circumstances and problems related to flood management are indentified through literature reviews, field investigations and interview surveys. Then, during the 'building governance' step, to ameliorate the state of flood management, governance is built in, taking into account people, groups and organizations related to flood management. In addition, the goals and objectives are established, the evaluation system developed, and a reasonable flood risk determined by governance through consideration of the states of the socio-economic systems and the value system.

During the next step, 'establishing plans and taking measures', first, using the evaluation system, the state of flood management is evaluated in more detail, and the process reviewed. Second, plans are established, reflecting the evaluation results, and appropriate measures taken through comparisons with alternatives. In particular, in the framework for South Korea, a methodology for taking measures was embedded and was made in a way to reflect the results of the interview survey described above. This methodology has five elements, specifically: integrated flood management within the Integrated Water Resources Management (IWRM) context; flood risk management; integrated watershed management; a participatory decision-making process; and adaptive management (GWP, 2000; Plate, 2002; APFM, 2004a; Braden & Johnston, 2004; UN ISDR, 2005; Knight & Shamseldin, 2006; Blackmore & Plant, 2008; Kang, 2011a). During the 'development methodology' process shown in Figure 3, each element is combined with the other elements based on the goals of flood management and then, based on the integration of the elements, measures are optimally developed. To choose appropriate measures and combine them for specific sites, alternatives are assessed using the determined level of flood risk. This process requires identifying risks, analyzing the frequency of occurrence of events, and estimating the magnitude of the flood damage. Furthermore, estimating the probability of extreme events and their influences on society, the economy and the environment is indispensable. Then, the risks of all feasible alternatives developed in response to specific extreme events are predicted, and appropriate measures taken from amongst the alternatives. During the 'implementation and monitoring' step, the measures are implemented, and their results monitored. In particular, governance authorities can keep up with the latest information about the circumstances related to flood management. During the 'evaluation' step, the results of the implemented measures are evaluated periodically, and if the evaluation results are unsatisfactory, the measures can be adjusted by reflecting the evaluation results reviewed by the authorities. If the evaluation results satisfy the criteria (such as the determined flood risk), the accepted policies, systems, or measures are consistently carried out during the 'post-management' step, and then their results are periodically monitored and evaluated. In the long term, plans and measures are adapted to changes in the natural system, socio-economic systems and social preferences. Following this procedure, flood management proceeds with appropriate measures which are developed and modified to achieve the goals required.

4. Assessment results and discussion

4.1. Problem identification

Since flood management and socio-economic systems are closely linked and affect each other, it is difficult to precisely identify the state of national flood management without taking into consideration

the public's preferences. In particular, due to several anthropogenic factors that influence flood damage, the perceptions of people need to be investigated from multiple perspectives, and variations within them should be analyzed to effectively find solutions at the national level to the problems caused by human activities. In addition, during the process, any misunderstandings can be discovered and corrected through social learning. Especially when flood management is considered at the national level, various stakeholders must first form a governing authority and work together to establish management goals and objectives.

However, in South Korea, some people and groups are reluctant to participate in activities conducted to identify the various problems of flood management. In light of previous research results, it is thought that policy-makers may have a tendency to distance themselves from the problems and are not well informed about the state of flood management (Kang & Lee, 2011). The percentages of groups of researchers, engineers and policy-makers who participated in the interview survey conducted in this study were 47, 51 and 2%, respectively. Comparing the percentage of each group's respondents, the policy-maker group had a significantly smaller number of respondents than those of other groups. Therefore, to adequately identify problems and people's perceptions, and to reflect them within the flood management process, it is necessary to induce the participation of representatives of various sectors and groups.

4.2. Building governance

In developed countries, stakeholders participate in flood management and related committees have been established. For example, in the USA in the middle of the 1950s, non-structural measures aroused interest, and, in 1969, the National Flood Insurance Program (NFIP) was developed and has induced community participation in the regulations pertaining to land use in floodplains. Through these activities, about 13,000 homes were removed from the floodplains of the upper Mississippi and Missouri rivers, and the residents relocated to safer areas (APFM, 2004b).

In South Korea, key stakeholders including non-governmental organizations, experts, campaigners and affected people have actively participated in the processes of water resources planning and development projects since the late 1990s, creating a new form of governance in the water resources sector (Park, 2004). The active participation of these stakeholders was confirmed to be very crucial in successfully conducting sustainable flood management in the responses to the interview survey conducted in this study. Therefore, to effectively reduce flood damage and to quickly recover from flooding, the flood management of South Korea should be changed using the framework developed, moving toward taking measures and adaptively implementing them spatially and temporarily within the same context, and sharing goals and information with various stakeholders. Moreover, in South Korea, flood management should be shifted toward making society more sustainable and democratic on the basis of the principles of sustainable flood management established in this study.

4.3. Establishing plans and taking measures

To effectively reduce flood damage, appropriate structural and non-structural measures need to be developed and implemented. Structural measures are those that modify the flow of water and control flooding using multi-purpose dams, flood control dams, retarding basins, channel maintenance, watershed management and afforestation. Some of the non-structural measures decrease susceptibility to

flooding using early flood warning systems, zoning of flood-prone areas, relocation of residents and buildings away from floodplains, and flood insurance. These structural and non-structural measures are linked to human activities and actualized in real situations to minimize flood damage. For example, recently, in Scotland, as alternatives to engineered structures, the following non-structural strategies have been linked together: awareness, avoidance, alleviation and assistance (Werritty, 2006).

Various activities related to flood management have been carried out in South Korea. Flood control centers were established in the four major river basins and have controlled floods by operating water resources facilities, including multi-purpose dams and estuary dams. In addition, many investments have led to various river works to reduce flood damage in the vicinity of the main rivers, and inundations near large rivers have decreased. In contrast, a great deal of flood damage has been generated due to insufficient channel capacity, poor river management and injudicious upper watershed development in small rivers that are managed by local governments – especially at the confluences of main rivers and their tributaries (Kang, 2011b). In South Korea, some primary structural measures, including river works to refurbish the four major rivers, have been undertaken. Amongst feasible measures, the sizes and capacities of all structures have been carefully engineered, taking into consideration possible flood magnitudes and frequencies. However, because climate change embraces high uncertainty, it is not efficient to modify existing structures or construct new and larger structures in proportion to the increased flood discharges. Therefore, measures are required to be reversible and flexible, and coincide with the concept of sustainable flood management. The balancing of structural and non-structural measures within the context of watershed and river basin management is to be taken into account in order to overcome these limitations and to respond to extreme events. In addition, site-specific measures should be selected, taking into account the best mix of these measures that would obtain synergistic gains and minimize vulnerability to flooding. Moreover, in the framework developed for South Korea in this study, the methodology for developing measures needs to be reviewed and updated, reflecting the state of flood management and any changes in related circumstances.

4.4. Implementation

Since flooding affects all the sub-systems of a society and, specifically, damage to any sector affects all the others, disaster prevention activities are implemented from all social perspectives. And, due to the characteristics of complex systems, it is difficult to gauge and obtain the desired effect of a measure if the interactions among the sectors are not clearly known. Therefore, it is necessary to accept inter-sectoral and holistic approaches within the context of IWRM in order to collectively estimate the effects of flood damage, to accurately predict the effects of measures and to achieve the objectives of the measures from multiple perspectives. In this context, by evaluating activities implemented at the national level during flooding periods, it has been shown that the operation of the flood management systems in related organizations in South Korea, such as flood control centers, local governments, corporations for operating flood control facilities, and central government, have not been effectively connected (Kang, 2011b). At each stage, an ineffective environment for achieving the goals and objectives of flood management cooperatively has been created. In particular, measures have been taken independently, lacking any coordination amongst the organizations. Therefore, to effectively prevent floods in South Korea, measures taken by each organization need to be integrated through the designed flood management process.

To upgrade the current poor situation described above, a systematic implementation process has been proposed, considering that flood management is dynamically implemented in a procedural format, taking appropriate measures during the pre-flooding, flooding and post-flooding periods. As shown in Figure 4, the process of flood management has been divided into six stages, namely: prevention, mitigation, preparedness, response, recovery, and reconstruction. The developed implementation process is based on flood risk management to quantitatively reduce flood damage by decreasing flood risks from multiple perspectives. Flood risk management can be incorporated into the existing operation system, into new planning, and into new structure design and modification (Plate, 2002; Knight & Shamseldin, 2006; Kang, 2011a). To carry out flood risk management, the risk of each alternative is estimated and compared at each stage, taking into account each alternative's damage magnitude and recovery time, which varies with the states of the socio-economic systems. A scenario analysis is employed to select the most appropriate alternative, comparing the risk of each one. Therefore, in this implementation process, determining appropriate risks involves factors which are uncertain, such as the occurrence of extreme hydrological events due to climate change, the increase of flood discharges due to urbanization, and changes in socio-economic systems. Various sectors are related to flood management and are mutually affected, and damage that occurs in any of the sub-systems (such as culture, economy and

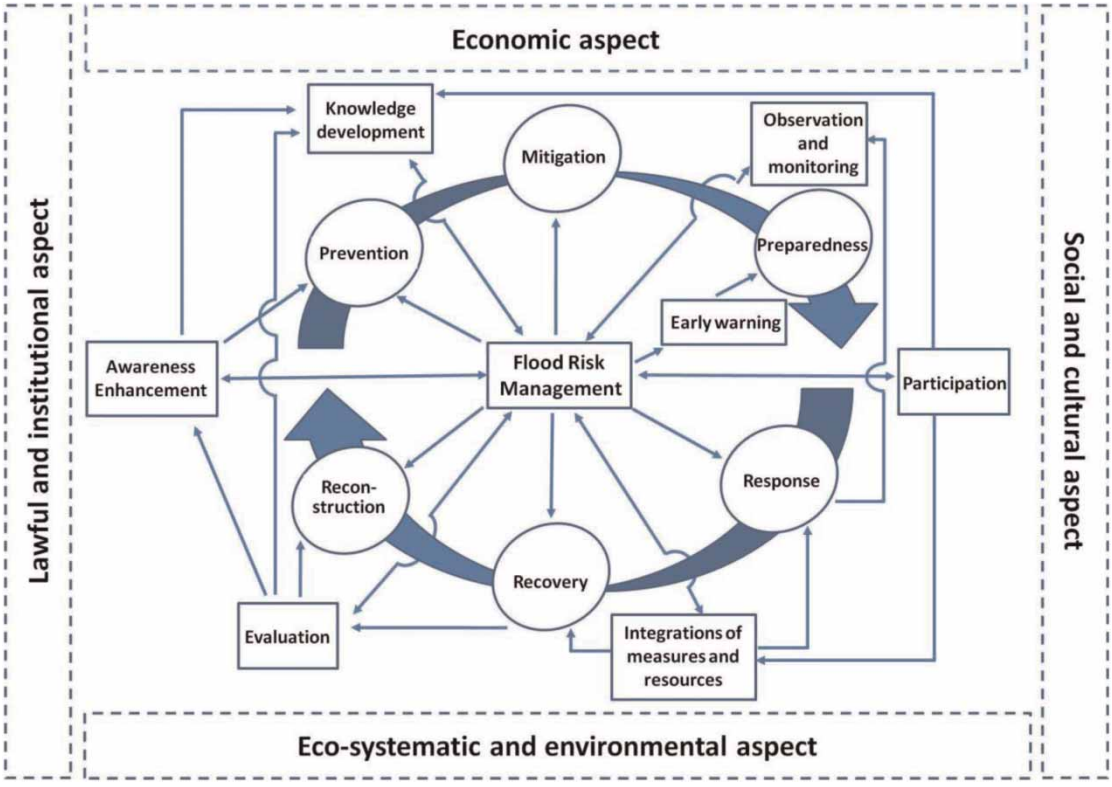

Fig. 4. Configuration of the process to dynamically implement flood management based on flood risk management in terms of different aspects (economic, social and cultural, eco-systematic and environmental, and lawful and institutional) at different flooding stages.

health) affects the others. Thus, appropriate measures are considered from the economic, social and cultural, eco-systematic and environmental, and lawful and institutional aspects, and are then implemented. A balance amongst these aspects is considered to achieve the goals and the objectives of flood management. And, at each stage, awareness enhancement, knowledge development, observation and monitoring, early warning, stakeholders' participation, integrations of measures and resources, and evaluation are considered to be the objectives of the measures.

Since flood management is carried out under a degree of high uncertainty due to rapid changes in circumstances, related activities need to be scheduled, integrated and strategically implemented, taking into account the multi-dimensional perspectives of society as a whole, and any flood management system should be incorporated into the general social disaster management system. Particularly, structural and non-structural measures should be incorporated into the activities of prevention, mitigation, preparedness, response, recovery and reconstruction throughout the pre-flood, flooding and post-flooding periods, as shown in Figure 4. The measures at all stages need to be implemented consistently, considering the effects of potential measures planned for the following stages. In addition, lessons from the flooding and flood-fighting activities should be extracted during the post-flooding stage, well documented, and fed back into the entire flood management process. Therefore, to effectively implement the measures in real situations, strategies (such as adapting to changes of climate and related circumstances, site-specific measures and optimal combinations, positive participation of stakeholders in flood management, integration of measures and maintenance of their consistency through all flooding stages, and inter-sectoral and holistic approaches) are integrated and applied to the implementation process proposed in this study.

4.5. Evaluation and post-management

In order to satisfy stakeholders, the goals and objectives of flood management should be adaptively evolved, reflecting the changes in related systems. Thus, the state of flood management and the effects of measures taken should be evaluated periodically, and the evaluation results reflected when modifying the measures and revising flood management plans. In South Korea, most recently, the states of flood management for the four major rivers have been evaluated from the perspectives of flood defence infrastructures and flood control operation systems (Kang *et al.*, 2010), however there has been a scarcity of cases that evaluated the results of systems, policies and measures, and reported them. Subsequently, post-management of the measures has been conducted incorrectly and similar problems have occurred frequently. Moreover, since the effectiveness of the measures are often not immediately apparent, and it typically takes a long time to attain the objectives, post-management of the measurements is necessary in South Korea. Therefore, evaluation results should be reviewed by the authorities in governance from multiple perspectives. Furthermore, systems and committees should be established to promote the activities related to post-management so that measures can be adapted legally and institutionally.

5. Summary and conclusions

This study has presented a prototype framework for sustainable flood management in various countries, and the framework was modified for the national flood management of South Korea, taking into account the concept and principles of sustainability and employing results from literature

reviews and an interview survey about the improvement of the state of flood management. The national flood management of South Korea was assessed, inadequate aspects discussed and new methodologies proposed. Through this study, it has been found that flood damage in South Korea is mainly the result of heavy rainfall, increased urbanization, deficiencies in channel capacity, inadequate river management and the failure of disaster prevention measures. The study has shown the need to create systematic long-term plans and to consistently implement them, cutting injudicious artificial developments upstream of watersheds, and combining site-specific structural and non-structural measures, all of which are indispensable for sustainable flood management. It has also been shown that the utilization of the framework, the participation of stakeholders and social learning about flood management are all necessary to efficiently deal with problems related to flood management, and measures should be considered from multiple perspectives and implemented consistently and strategically.

Currently, it is recognized that, to efficiently manage water resources within the context of IWRM, there should be a balance between water use and flood seasons, and the hydrologic cycle should not be separated into two periods. Plans and measures for flood management should be established, employing an inter-sectoral approach. In addition, in the near future, it is predicted that flood risk management will be accepted and implemented during flood management processes so as to virtually overcome the high uncertainty due to climate change, and allowable risks could be determined through participatory decision-making processes and social consensus. Therefore, the framework, implementation process and integrated strategies which are developed and discussed in this study could be utilized to generate a sustainable flood management system within South Korea and provide a benchmark for sustainable flood management planning in other countries.

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References

Achet, S. H. & Fleming, B. (2006). A watershed management framework for mountain area: lessons from 25 years of watershed conservation in Nepal. *Journal of Environmental Planning and Management 49*(5), 675–694.

Associated Programme on Flood Management (APFM) (2004a). *Integrated Flood Management: Concept Paper*. APFM, Geneva, Switzerland.

Associated Programme on Flood Management (APFM) (2004b). *Integrated Flood Management Case Study USA: Flood Management – Mississippi River*. APFM, Geneva, Switzerland.

Blackmore, J. M. & Plant, R. A. (2008). Risk and resilience to enhance sustainability with application to urban water systems. *Journal of Water Resources Planning and Management 134*(3), 224–233.

Braden, J. B. & Johnston, D. M. (2004). Downstream economic benefits from storm-water management. *Journal of Water Resources Planning and Management 130*(6), 498–505.

Freedman, P. L., Nemura, A. D. & Dilks, D. W. (2004). Viewing total maximum daily loads as a process, not a singular value: adaptive watershed management. *Journal of Environmental Engineering 130*(6), 695–702.

Global Water Partnership (GWP) (2000). *Integrated Water Resources Management*. GWP, Stockholm, Sweden.

Jun, K. S. & Kim, J. S. (2011). The four major rivers restoration project: impacts on river flows. *Korean Society of Civil Engineers (KSCE) Journal of Civil Engineers 15*(2), 217–224.

Kang, M. G. (2011a). Incorporating risk management into sustainable flood management in river basins' context. *Magazine of the Korean Society of Civil Engineers 59*(4), 23–31 (In Korean).

Kang, M. G. (2011b). Identifying the damages and causes of floods and the outlook for future floods in South Korea. *Magazine of the Korean Society of Civil Engineers 59*(1), 98–105 (In Korean).
Kang, M. G. & Lee, G. M. (2011). Multi-criteria evaluation of water resources sustainability in the context of watershed management. *Journal of American Water Resources Association 47*(4), 813–826.
Kang, B. S., Lee, J. H., Hong, I. P., Oh, K. R. & Jeong, S. M. (2010). Web-based assessment for flood forecasting and warning systems. *Desalination and Water Treatment 19*, 129–137.
Keen, M., Brown, V. & Dyball, R. (2005). *Social Learning in Environmental Management: Towards a Sustainable Future*. Earthscan, London, UK.
Knight, D. W. & Shamseldin, A. Y. (2006). *River Basin Modelling for Flood Risk Mitigation*. Taylor & Francis Group plc, London, UK.
Kundzewicz, Z. W. (2002). Non-structural flood protection and sustainability. *Water International 27*(1), 3–13.
Kusenbach, M., Simms, J. L. & Tobin, G. A. (2010). Disaster vulnerability and evacuation readiness: coastal mobile home residents in Florida. *Natural Hazards 52*, 79–95.
Marschke, M. & Sinclair, A. J. (2009). Learning for sustainability: participatory resources management in Cambodian fishing villages. *Journal of Environmental Management 90*, 206–216.
Ministry of Construction & Transportation (MOCT) (2006). *Updated Long-Term Comprehensive Water Resources Planning (Water Vision 2020)*. MOCT, Seoul, South Korea (In Korean).
Park, S. J. (2004). *Water Policy in South Korea: Towards a New Paradigm*. *Dissertation of Department of Civil Engineering*, Colorado State University, CO, USA.
Plate, E. J. (2002). Flood risk and flood management. *Journal of Hydrology 267*, 2–11.
Scottish Executive (2005). *Sustainable Flood Management Pilot Study (Final Report)*. MWH–Jacobs Babtie, Edinburgh, UK.
Turner II, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., Kasperson, J. X., Luers, A., Martello, M. L., Polsky, C., Pulsipher, A. & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America 100*(14), 8074–8079.
United Nations International Strategy for Disaster Reduction (UN ISDR) (2005). *Guideline for Reducing Flood Losses*. ISDR, Geneva, Switzerland.
United Nations International Strategy for Disaster Reduction (UN ISDR) (2007). *Words into Action: A Guide for Implementing the Hyogo Framework*. ISDR, Geneva, Switzerland.
United States Army Corps of Engineers (US ACE) (2006). *Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System*. ACE, MS, USA.
Webster, P. J., Holland, G. J., Curry, J. A. & Chang, H. R. (2005). Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science 309*(5742), 1844–1846.
Werritty, A. (2006). Sustainable flood management: oxymoron or new paradigm? *Area 38*(1), 6–23.
World Water Council (WWC) (2000). *World Water Vision: Making Water Everybody's Business*. 2nd World Water Forum. WWC, The Hague, The Netherlands.

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