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Natural based Solutions(NbS) for Eco-Flood Risk Reduction

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1. Introduction

Background

Butterfly Effect in Chaos Theory :

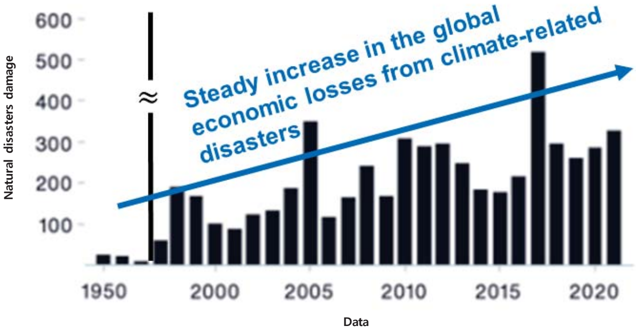
Very small change of temperature can make very huge natural disaster which can give so many impacts to nature and human society.

1. Introduction

Background

- Frequency and intensity of natural disasters such as floods and droughts are increasing trend due to climate change and urbanization. Then the damage is becoming larger and larger.
- According to the report by the Aon*, global economic loss by typhoon, heavy rainfall and flood which are climate-related disasters are increasing trend (AON, 2021).
- Flood damage: USD 1.37 billion, Death: 40 (2020); Death: 26 (2022); USD 25 billion(2002+2003)

*Aon PLC is a British-American multinational financial services firm that sells a range of risk-mitigation products, including Commercial Risk, Investment, Wealth and Reinsurance solutions, as well as boutique strategy consulting through Aon Inpoint.



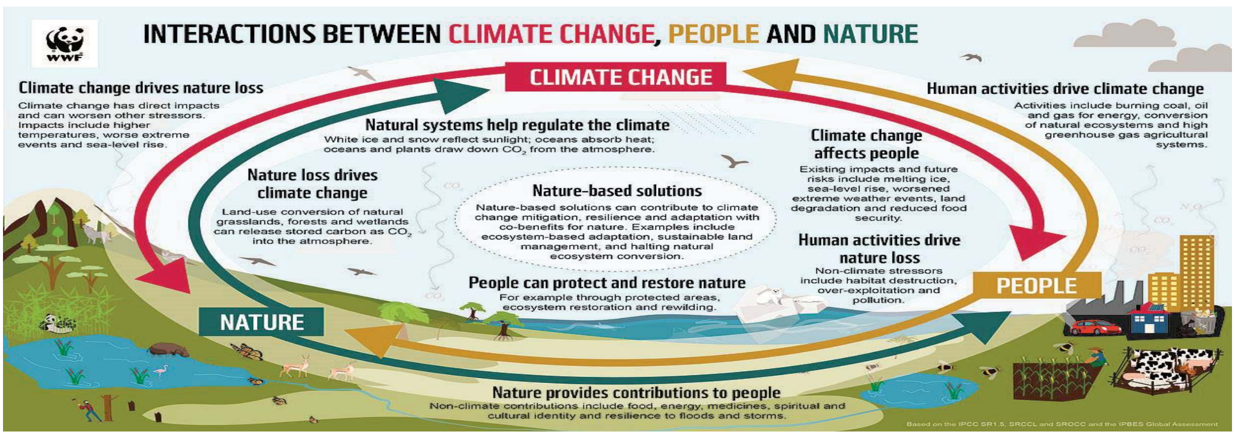
<Global economic costs from climate-related disasters (adjusted for inflation), 1950-2021. Damages in 2021 were the third-highest on record. (Image credit: Aon 2021 annual report)>

<Flooding of Seoul city in 2020, Korea>

1. Introduction

Objectives

- The objective of this study is to use NbS for protecting and restoration of natural ecosystem, that address societal challenges such as climate change, disaster risk reduction effectively and adaptively, simultaneously providing human well-being and biodiversity benefits(IUCN, 2016)
- Therefore, in order to reduce the damage caused by natural disasters due to climate change, the need for NbS (Natural based Solutions) is emerging because structural measure has its limitations in cost and in disaster prevention criteria which is becoming higher and higher due to the climate crisis.



< Interactions between climate change, people and nature. Graphic by WWF >

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2. Heavy Rain Damage Risk Assessment and Compound Natural Disasters

- Heavy Rain Damage Risk Assessment (nonstructural measure)
- Compound Natural Disasters (combination of single hazards)

2. Heavy Rain Damage Risk Assessment and Compound Disasters

1. Heavy Rain Damage Risk Assessment and Warning Technique (nonstructural measure)

[1] Procedure for warning criteria development by risk assessment using heavy rain damage data

① Grouping heavy rain damage in regions by factors of regional characteristics and rainfalls in duration

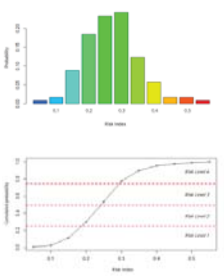
② Development of Heavy rain damage prediction function by machine learning models

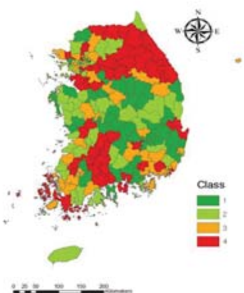
③ Heavy rain damage risk assessment and warning technique (or criteria) development by risk matrix

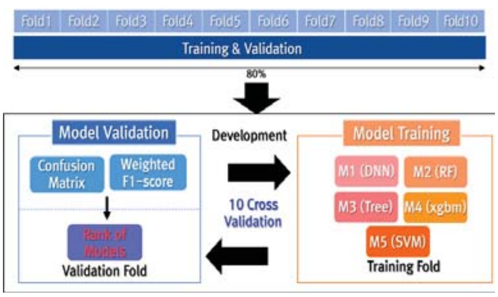
1 Grouping heavy rain damage in the regions

2 Machine learning-based heavy rain damage prediction

3 Heavy rain damage risk assessment and warning technique development by risk matrix

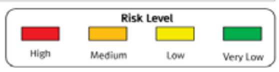






Heavy rain Damage Risk – Prediction Warning Technique

		Severity			
		Negligible (Scale ①)	Minor (Scale ②)	Major (Scale ③)	Catastrophic (Scale ④)
Probability	100%	VL	L	M	H
	75%	VL	L	M	M
	50%	VL	VL	L	M
	25%	VL	VL	L	L
Eliminated		Eliminated			



< Procedure for heavy rain damage risk assessment and warning technique development by risk matrix >

2. Heavy Rain Damage Risk Assessment and Compound Disasters

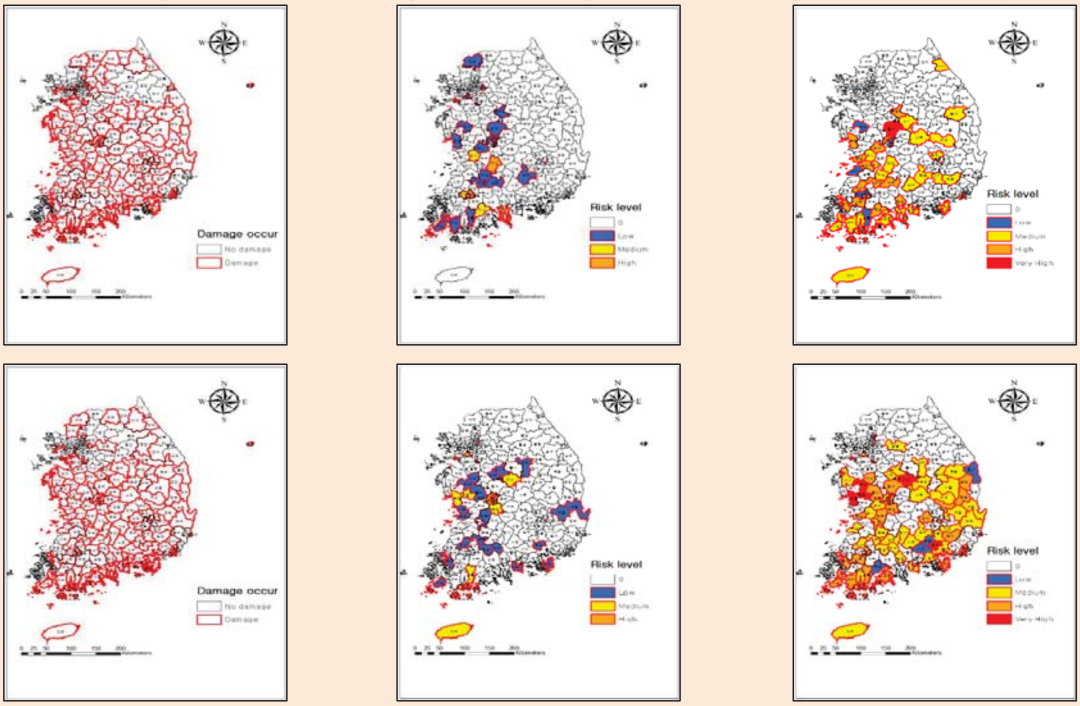
1. Heavy Rain Damage Risk Assessment and Warning Technique (nonstructural measure)

[2] Use of Developed Warning Criteria by heavy rain damage risk assessment and risk level

Actual damaged area | *By Current warning criteria* | *By Developed warning criteria*

For an event of July 29, 2020

For an event of July 30, 2020



2. Heavy Rain Damage Risk Assessment and Compound Disasters

2. Compound Natural Disasters (bigger impact than single disaster)

- Compound natural disasters was presented in IPCC's special report on climate extremes (SREX) in 2012
- Definitions of Compound natural disaster

Year	Definition	Source
2011	Devastating multiple occurrences as Catastrophic disasters	KAWATA
2012	A combination of multiple drivers and/or hazards that constributes to societal or environmental risk	IPCC
2012	A combination of events that are not themselves extreme but which collectively lead to an extreme aggregation of impact	Seneviratne
2018	A combination of two or more climate drivers or hazards that have implications on natural and/or human systems	Zscheischler
2022	Two or more extreme disaster events occurring simultaneously or successively	Gissing
2022	A combination of extreme events with underlying condition that amplify their impact	Gissing

1. Two or more disaster drivers or hazards
2. Occuring simultaneously or successively
3. Combination or interaction between drivers or hazards

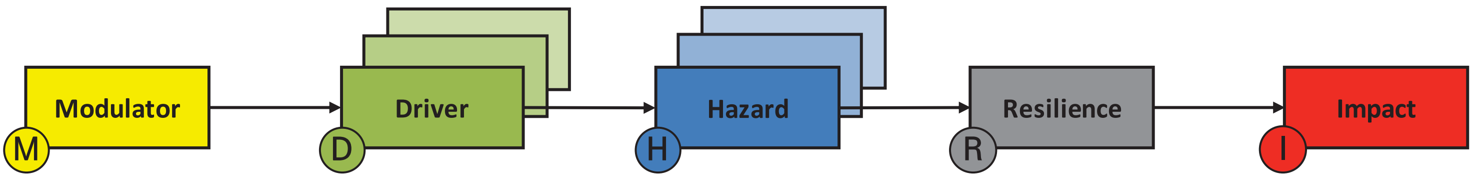
Compound natural disaster is occurring more and more frequently

2. Heavy Rain Damage Risk Assessment and Compound Disasters

2. Compound Natural Disasters (bigger impact than single disaster)

- Five elements of compound natural disaster (Zscheischler et al., 2020)
  : Modulator, Driver, Hazard, Resilience, and Impact

Indicator	Definition	Example
Modulator (M)	Influencing the Driver's impact and frequency	El Nino-Southern Oscillation
Driver (D)	Direct factor in causing disaster	Heavy rainfall, Storm surge
Hazard (H)	A disaster caused by Driver	Drought, Flood, Heatwave
Resilience (R)	Capability of a system, community, or society exposed to Hazard	Emergency resuce and relief
Impact (I)	Ripple effect caused by Hazard	Flood damage, Wildfire



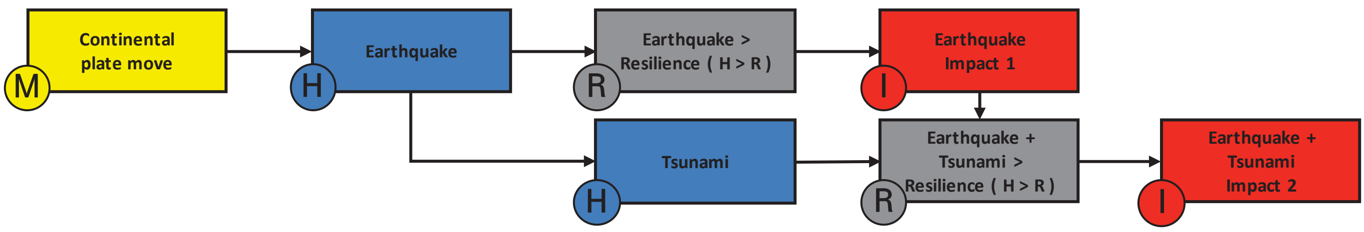
< Components of Compound Natural Disaster >

2. Heavy Rain Damage Risk Assessment and Compound Disasters

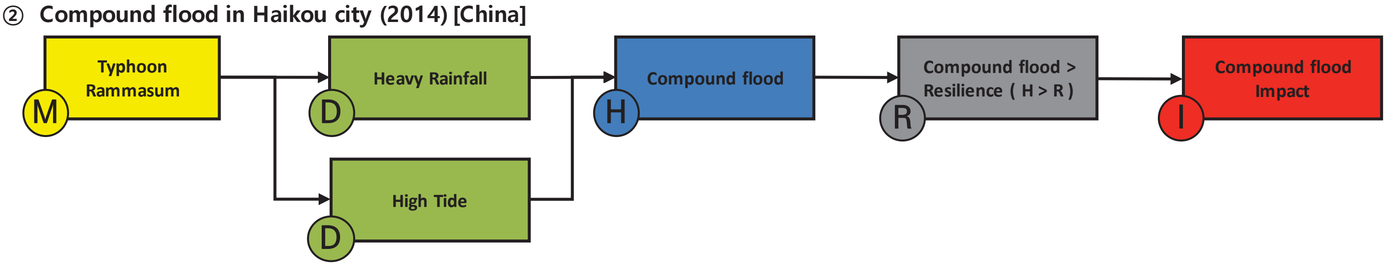
2. Compound Natural Disasters (bigger impact than single disaster)

- Cases of compound natural disaster in East Asia

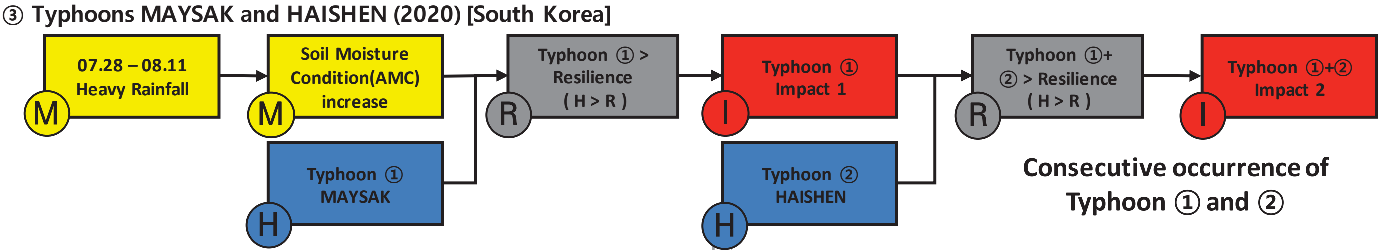
① Great East Japan Earthquake (2011) [Japan]



② Compound flood in Haikou city (2014) [China]

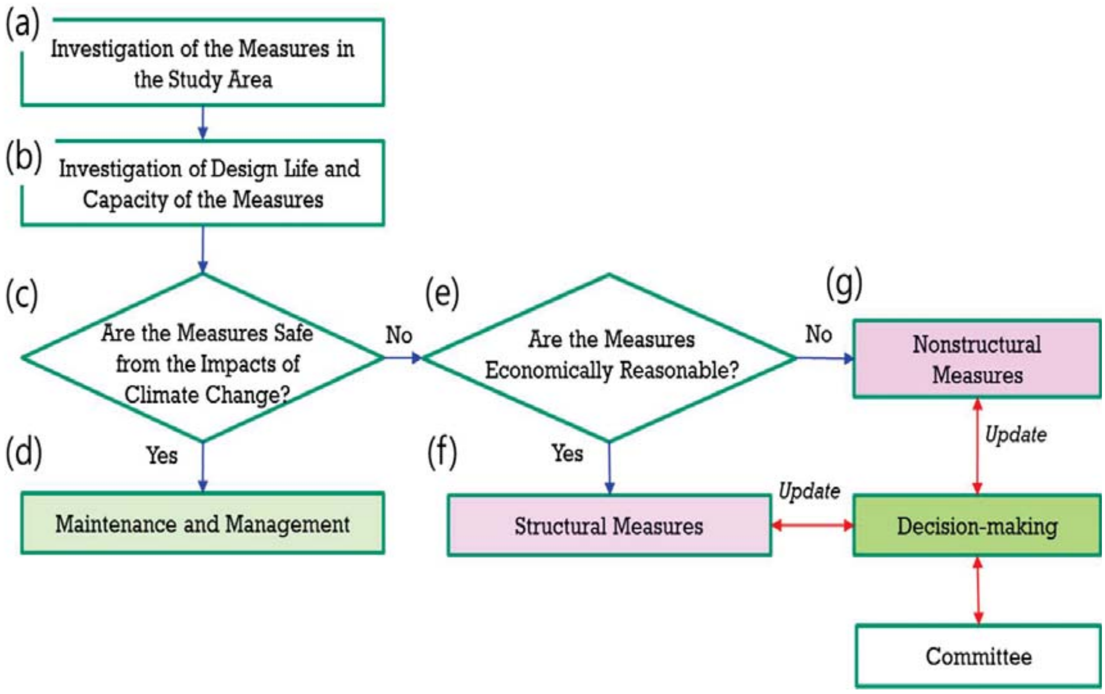


③ Typhoons MAYSAK and HAISHEN (2020) [South Korea]



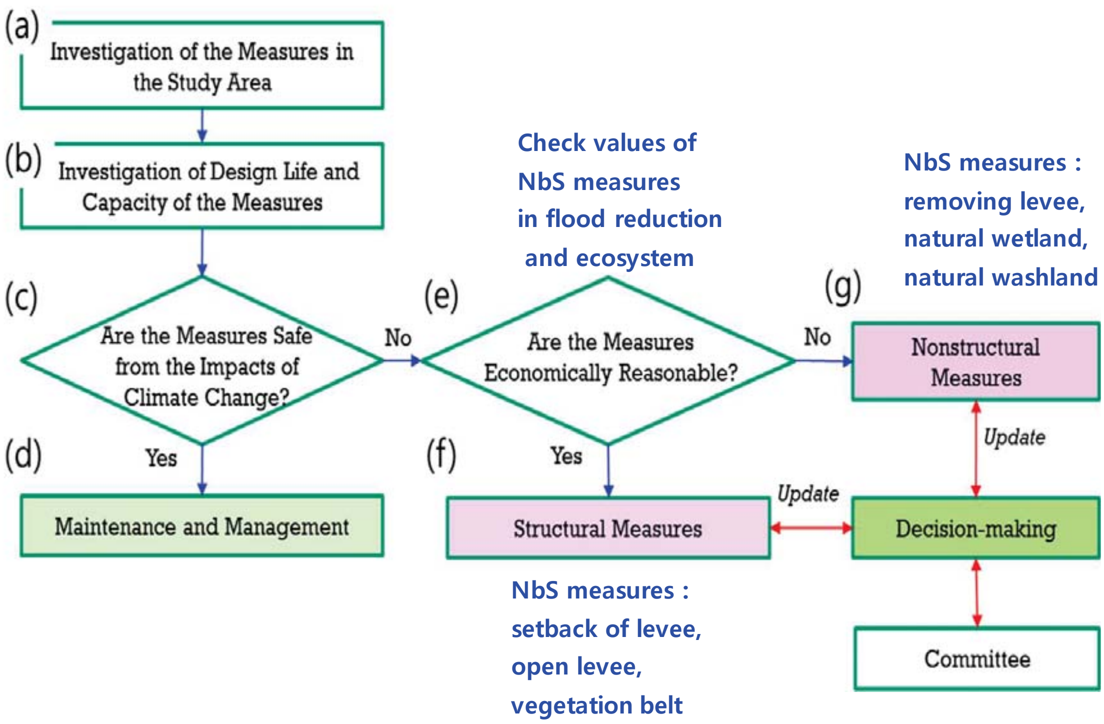
How can we reduce heavy rain damage risk and compound disasters?

- Decision-making procedure for applying a new design criteria for climate change adaptation (Kang et. al., Water, 2016)



How can we reduce heavy rain damage risk and compound disasters?

- We can use NbS as structural and nonstructural measures



3. Applications of NbS

1. Nature-based Solutions

- **Nature-based Solutions** are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits. (IUCN, 2016)

Major societal challenges to which NbS can be applied
Climate change mitigation and adaptation
Disaster risk reduction
Economic and social development
Human health
Food security
Water security
Environmetal degradation and biodiversity loss

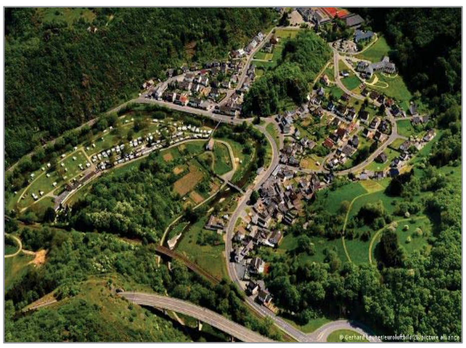
< 7 Societal challenges of NbS(IUCN, 2020) >

< Conceptual diagram of NbS(IUCN, 2020) >

3. Applications of NbS

1. Nature-based Solutions

- The natural-based solution is the most suitable technology for Carbon neutrality and sustainable integrated water management at the government level.
- As uncertainties increase due to localized heavy rains and abnormal flooding, the flood mitigation facility design methods based on past observation records have limitations in defending extreme events.
- Existing flood defense by levees effectively protects the lives and assets of local and residents from medium-sized floods that occur frequently, but it is insufficient for extreme-scale flood with low frequency.
- By applying NbS technology to the surrounding space of the river, it can be used as a carbon sink zone in normal seasons and as a flood buffer zone in flood seasons.



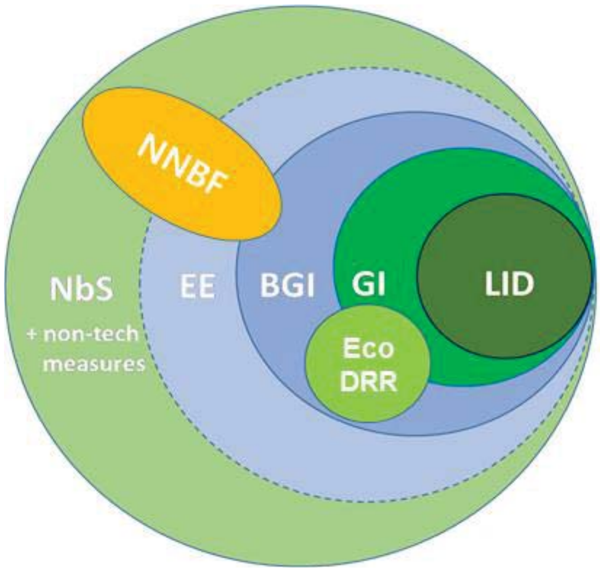
< Before and after for Altenahr Flood, Germany(WMO, 2021) >
Limitation of levees for extreme-scale flood prevention (Death : 110)

3. Applications of NbS

1. Nature-based Solutions

- **Nature-based solutions have been used in various fields from the past to the present, and their sub-concepts and similar concepts exist depending on the characteristics of the field.**

Type	Concept
NbS (Nature-based Solution)	Resolving Social Environmental Issues through Natural Ecosystem services
EE (Ecological engineering)	Integrated Design of Human Society and Natural Environment
BwN (Building with Nature)	Infrastructure Design Utilizing Natural Dynamics
GI (Green Infrastructure)	Maintaining the role of infrastructure through networks such as open spaces, rivers, and green areas within the construction environment
LID (Low Impact Development)	Maintain hydrologic status before development (≒ < GI)
NW (Naturnaher Wasserbau)	Design materials and shapes in natural form when designing infrastructure
NNBF (Natural, Nature-based Features)	Flood Risk Reduction Based on Nature of Landscape Scale



< Types and Concepts of similar concepts of nature-based solutions>

3. Applications of NbS

1. Nature-based Solutions

- **Nature-based solutions element technics : strategy through the expansion of river space**
  - **Increasing the ecosystem value by improving the connectivity of flood areas divided by the levees.**

Nature-based solutions element technics			
	Floodplain excavation		Water storage
	Depoldering		High water channel
	Strengthening dykes		Lowering breakwater spurs
	Relocation of dykes		Removal of obstacles
	Riverbed excavation		

3. Applications of NbS

1. Nature-based Solutions

- Nature-based solutions cases

< Levee planting for flood prevention>

< Mangrove coastal forest >

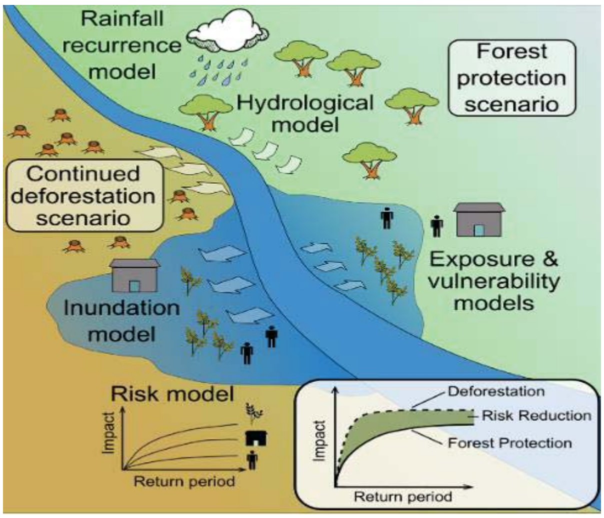
< Riverine wetlands >

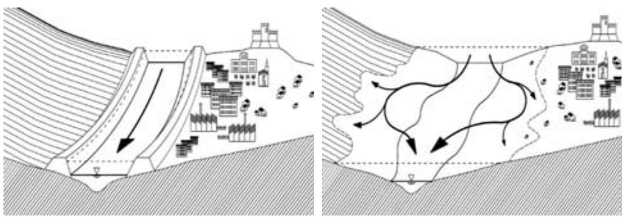
< Retention ponds >

3. Applications of NbS

1. Nature-based Solutions

- Lallemant et al.(2021) present probabilistic risk modeling framework to assess the value of nature-based solutions.
- The probabilistic risk analysis conduct to quantify the benefits of nature-based solutions in economic and human terms.
- Measuring risk reduction in economic terms can help mainstream nature-based solutions in infrastructure planning and insurance practice.





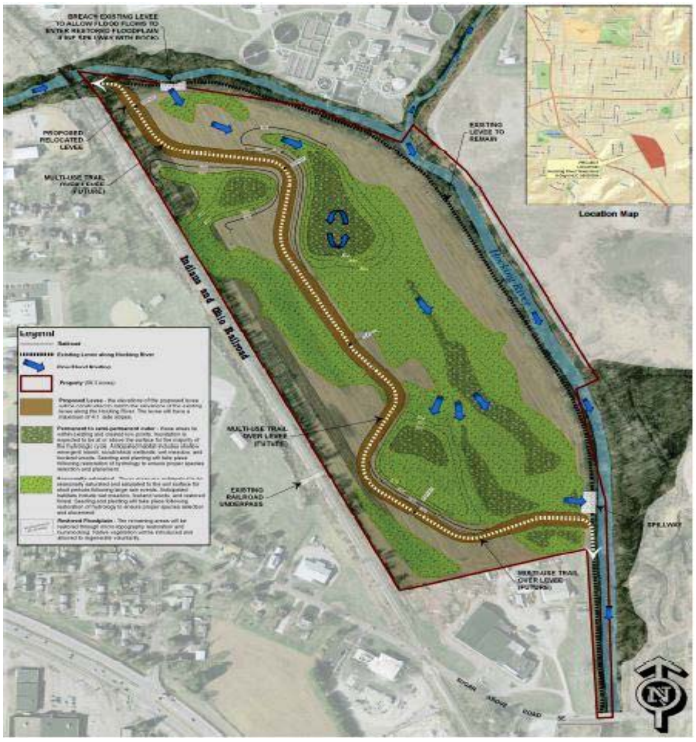
3. Applications of NbS

2. Examples of Nature-based Solutions

Example 1 : Expansion of Inundation Area by Modified Levee

- **Flooding wetland restoration by gate construction in existing levee**

- Deed Wetland (Lancaster city, Ohio, USA) : Flooding wetland restoration by the constructions of gate in existing levee and of vegetation belt.
- Lancaster city bought restoration area by Clean Ohio Grant and buffer zone land by the city's fund for the protection of the wetland from development



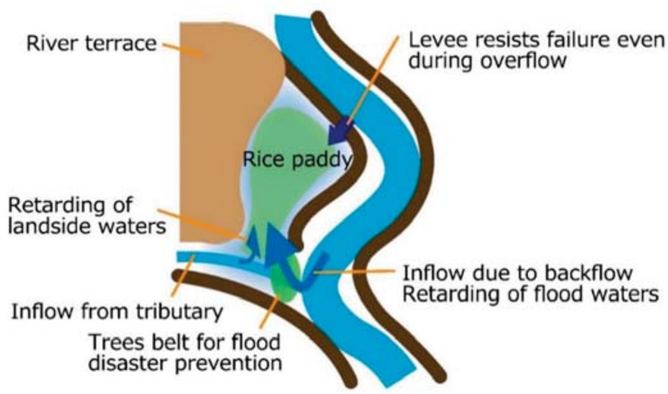
3. Applications of NbS

2. Examples of Nature-based Solutions

Example 2 : Expansion of Inundation Area by Modified Levee

- **Flooding wetland restoration by open levee of existing levee**

- Floodplain restoration by open levee of existing levee (Okawano, Japan)



Open levee system

Concept of Open levee system

3. Applications of NbS

2. Examples of Nature-based Solutions

Example 3 : Expansion of Inundation Area by Modified Levee

Flooding wetland restoration by removing levee

- ➢ Removing levee for flood control and fish restoration (Gree/Duwamish River, Kong county, Washington state, USA)
- ➢ Removing or relocation of levee for floodplain construction for flood damage reduction and ecosystem restoration (for 57acre(about 230,000m^2))

Before removing levee

After removing levee

3. Applications of NbS

3. Open levee and flooding buffer zone

- Open levee in an experimental area to see flood risk reduction

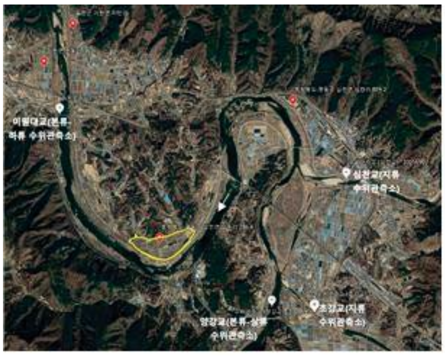
Flooding buffer zone

Open levee

3. Applications of NbS

3. Vegetation belt

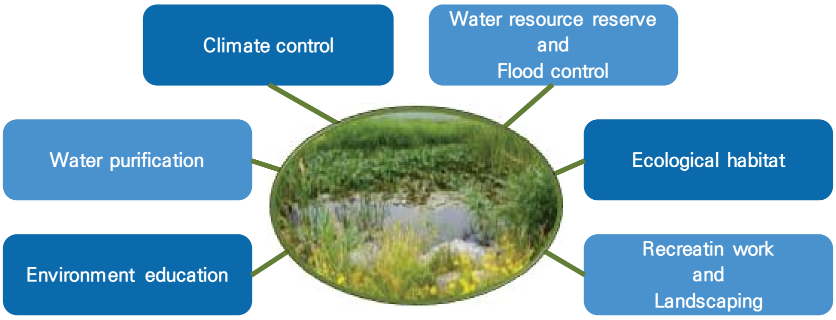
- Vegetation belt in an experimental area to see flood risk reduction and CO2 sink



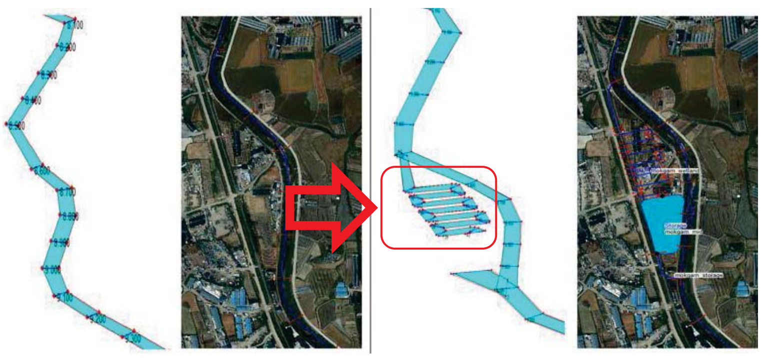
3. Applications of NbS

4. Design and construction of artificial wetland As an example of NbS

- **Functions :**
  - Flood control, Ecological habitat, Climate control, Water quality control, Recreation work, Environment education
- **Objectives :**
  - Water quality control
  - Flood control
  - Use of wetland as Waterfront area
- **Study area :**
  - Kyeongan cheon stream, a tributary of NamHan river
  - Designed as a riverine wetland



< Function of artificial wetland >

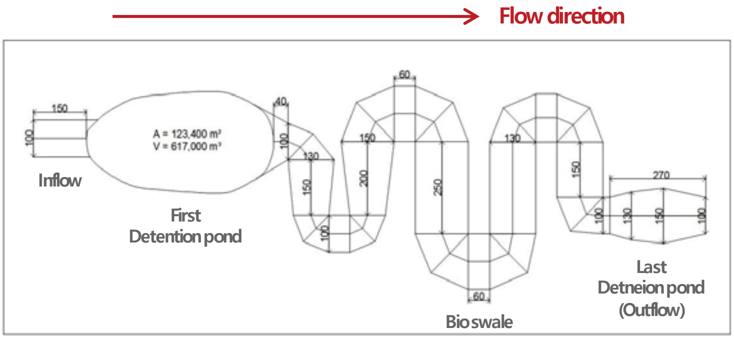


< Artificial wetland in riverine >

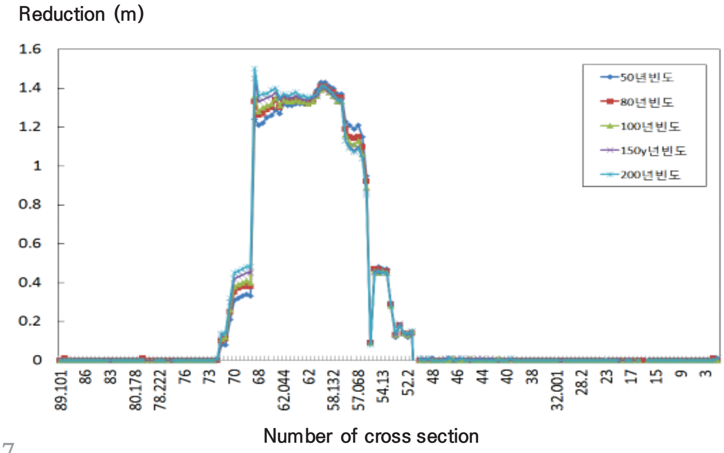
3. Applications of NbS

4. Design and construction of artificial wetland As an example of NbS

- Design of an artificial wetland for flood control and water quality control
- First Detention pond : 5m length, 617,000m^3
- – Bio swale : 1,460m length
- Use of HEC-HMS and HEC-RAS for analyzing the flood control function of artificial wetland
- – Use of 50 to 200 years frequency for flood control effect estimation
- – Flood water level reduction: Average 0.25 ~ 0.26m and the maximum 1.4 ~ 1.5m



Design of artificial wetland (Unit: m)



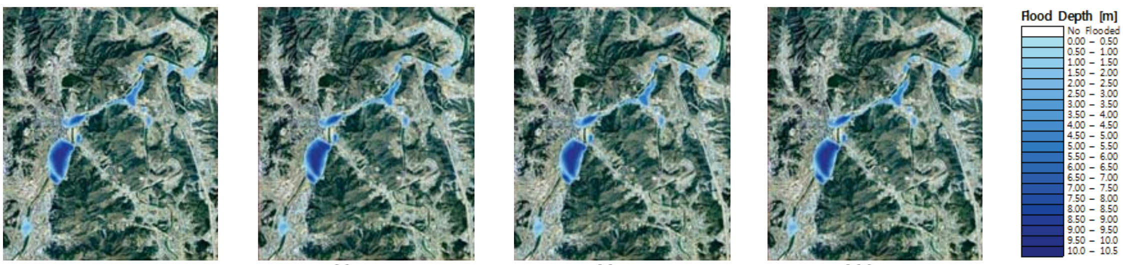
Frequency	50year	80year	100year	150year	200year
Average	0.25m	0.26m	0.26m	0.26m	0.26m
Maximum	1.43m	1.41m	1.40m	1.45m	1.50m

3. Applications of NbS

4. Design and construction of artificial wetland As an example of NbS

- Calculated the reduction of inundation area before and after construction of artificial wetland

1. Before construction



50 years	80 years	100 years	200 years
3,642,000m^3	3,928,000m^3	4,083,000m^3	4,461,000m^3

2. After construction

50 years	80 years	100 years	200 years
3,440,000m^3	3,703,000m^3	3,864,000m^3	4,293,000m^3

3. Reduction ratio of inundation area

▼ 5.5%	▼ 5.7%	▼ 5.4%	▼ 3.8%

3. Applications of NbS

5. Functional Assessment and Value of Wetland as NbS

Functional Assessment of Upo Wetland Considering Climate Change (for 2100)

Use of HGM(HydroGeoMorphic) method

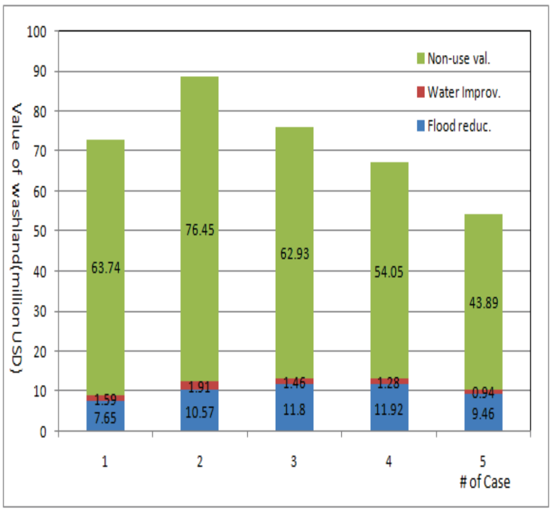
- ✓ Present functions of Upo wetland for all the items are 1.
- ✓ Future function of Upo wetland will be reduced in each item due to climate change (22.5%)

Functions		Index
Hydrological	Dynamic surface water storage	0.775
	Long term surface water storage	1.000
	Energy dissipation	0.791
	Subsurface storage of water	1.000
Biogeochemical	Nutrient cycling	1.000
	Removal of imported elements and compounds	0.833
	Retention of particulates	0.816
	Organic carbon export	1.000
Plant Habitat	Maintain characteristic plant communities	0.833
	Maintain characteristic detrital biomass	1.000
Animal Habitat	Maintain the spatial structure of the habitat	0.833
	Maintain interspersion and connectivity	1.000
	Maintain the distribution and abundance of invertebrates	1.000
	Maintain the distribution and abundance of vertebrates	1.000

3. Applications of NbS

Value for expansion of Upo wetland

- ✓ Value of Upo wetland is increasing as the area is increasing



(unit : USD in Million)

Cases In Area	Wetland Area (ha)	Non-Use value		Ecological value	Total value
		Flood reduction value	Water quality improvement value (annual mean)		
case 1	314.04	7.65	1.59	63.74	**72.98**
case 2	376.86	10.57	1.91	76.45	**88.93**
case 3	287.60	11.80	1.46	62.93	**76.19**
case 4	251.23	11.92	1.28	54.05	**67.25**
case 5	185.12	9.46	0.94	43.89	**54.29**

Contents

4. Summary

4. Summary

- [Heavy Rain Damage Risk Assessment] : use of flood warning technique as nonstructural measure
  Machine learning is more predictable than regression model for damage prediction.
  Disaster risk assessment and risk level can give us more reasonable and accurate warning information
- [Compound Natural Disaster] : combination of single hazards make damage more and more bigger
  We should more focus on compound natural disaster having big damage than single hazard and we have to consider the influence on society and economy by compound natural disaster
- [What is the solution for flood risk reduction and for protection and conservation of ecosystem?] :
  ☞ We can not use typical structural measures for flood risk reduction because the cost and flood prevention criteria are becoming higher and higher due to climate crisis.
  ☞ Alternative measure should be more focused on Natural and Nature-Based Features(NNbF) or NbS for both natural ecosystem and human society.
- [Nature-based Solutions] : will do Nature restoration, conservation, and contribution to net zero of carbon with flood risk and damage reduction
- [Combination of modified typical measures and NbS measures can be solution for flood risk reduction]

Thank You

Thank You