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Ecosystem-based Adaptation Code of Practice Compendium for the Thai Water Sector

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Objectives of Ecosystem-based Adaptation Code of Practice Compendium for the Thai Water Sector (EbA COP)

This CoP was compiled to provide relevant operators with knowledge and understanding on ecosystem-based adaptation for aquatic ecosystem and to provide guidance on adopting measures selected for Ecosystem-based Adaptation Code of Practice Compendium for the Thai Water Sector (EbA COP). The document may also enable the operators to tailor the measures to their specific needs and circumstances.

This book was developed from literature reviews, technical dialogue and gathering of inputs from various sectors including the private sectors, state agencies, local communities, civil societies, technical institutes and international organizations. Such actions were taken to ensure identification of the most feasible and appropriate measures in adopting ecosystem-based adaptation for various local settings.

Rationale

For several decades, impacts from global warming and climate change have exacerbated in intensity, affecting not only human live but also all animals and plants on earth. Academics from various disciplines have been seeking for measures to mitigate the impacts. Ecosystem-based measures are notable ones adopted to this end.

Ecosystem-based Adaptation Code of Practice Compendium for the Thai Water Sector (EbA CoP) concerns several technical disciplines and employs multiple arrays of knowledge in a relatively complex manner, particularly in ecology.

Ecosystem-based Adaptation to climate change has been continuously developed to address human's reliance on natural resources and the environment and impacts from their exploitation and associated waste generation. Unless human activities are careful managed, they will persistently damage lives of humans, animals and plants, reservoirs and other natural components of the world. [1]

Ecosystems are of critical importance to survival of humans and natural environments. The ecological approach was reportedly first included in environmental planning and management in 1978 for Canadian and United States joint project on environmental management of the Great Lake. The project, which was carried during the 1980's, adopted the approach as the principle directive for environmental management of the five-transboundary lakes of the two countries.

[1] All humans rely on the environment and natural resources to fulfill needs and sustain health. People have the greatest impact on the environment in the ways that they exploit natural resources and dispose of waste. If these activities are not managed carefully, environmental damage can affect people, animals, plants, waterways, and other parts of the natural world.(https://www.encyclopedia.com/environment/)

Several years later, a number of technical document on ecological approach were published, offering diverse definitions of ecosystems. Such variety derived from divergence in characteristics of ecosystems including their sizes, forms, numbers of species as well as their complexity and diversity.

In 2008, the United Nations, Educational, Scientific and Cultural Organization (UNESCO) published a book entitled "Aquatic Habitats in Sustainable Urban Water Management" as an addition to Urban Water Series. The publication provides a detail description of the ecological approach and its criteria and concepts were widely adopted among members of the United Nations in later years.

UNESCO defined the ecological approach as a holistic concept with integration of ecosystem protection and rehabilitation in manner the meet human needs while enabling connection between human's social and economic interests with that of the environment [2]. Notable concepts of this description include;

- The ecological approach recognizes the extends, resiliency, alteration and limitation of ecosystems and their impacts on human activities. *Natural ecosystems therefore have a carrying capacity to accommodate human needs and activities.*

- Every components of ecosystems including physical, chemical and biological elements and human factors (economic, social. political, etc.) are interdependent and can affect each other. The ecological approach therefore requires technical and other resources to manage these multiple components to ensure sustainability.

- Balance is included as a concept for the ecological approach and is critical for sustainable maintenance of ecosystems' components.

- Natural ecosystems are dynamic, flexible and complex in nature. Such characteristics must be accommodated.

Ecological boundaries is another notable concept for management of natural environments. The boundaries are generally defined by physical characteristic in accompany with other factors such as climate conditions.

The CoP Application

Operators involved in water management in Thailand may adopt measures in the handbook by taking into accounts local water related problems and selecting the most appropriate measures in light of ecosystem and environmental settings, budgetary constrain, availability of materials, possible impacts from implementation of chosen measures and their mutually supportiveness to pre-existing measures.

[2] Definition of the ecological approach is adopted as a comprehensive regional approach that integrates ecological protection and rehabilitation with human needs to strengthen the fundamental connection between economic and social prosperity and environmental well-being (Ramsar, 1998)

Chapter 1 Introduction

1.1 State of Water Resource in Thailand: Challenges and Management

Impacts of climate change on global community and the environment have unavoidably fallen on Thailand as seen in the increase temperature and the change in rainfall pattern (i.e. heavy precipitation and absence of rain). The phenomenon has exacerbated pre-existing adverse effects of human activities on ecosystem and biodiversity further.

During the past 50 years (1951-2005), drought became more frequent in Thailand and its intensity has been more severe since the 1970's due to rise in global temperature [3]. In 2011, Thailand also suffered from the greatest flood in recorded history, causing economic loss of 140 trillion THB or one-third of the country GDP [4].

In 2021, the average national rainfall in Thailand was recorded at 1,759.3 millimetres which was greater than the 30-year average precipitation and 11% higher than that of the previous year (1,527.3 millimetres). In this very year, the country was battered by four monsoons that resulted in flooding in 41 provinces, causing major impacts on agriculture as well as on service and industrial sectors. [5]

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[3] Atsamon Limsakul et al. (2011). PDSI-based Variations of Droughts and Wet Spells in Thailand: 1951-2005. Environment Asia 4(1):12-20

[4] The World Bank. (2012). The Thai Flood 2011: Rapid Assessment for Resiliency Recovery and Reconstruction Planning. Office of the Publisher, the World Bank.

[5] Norapat Assawawallop, Kongkwan Sila, Patra Jaruwatmongkol, Prakop Suriyentarakorn, Boontarika Cholpitakwong and Karn Jaengchadjai (2021) How the 2021 Flood affects Thailand's Economy. Finance and Fiscal Journal, December 2021

Climate change clearly affects water sector and unavoidably affects human lives and ecosystems. In response, Thailand adopted a strategy on climate change adaptation for five major areas, which are (1) forests and biodiversity, (2) coastal areas, (3) agriculture, (4) water resources and (5) health [6].

Adaptation in water sector focuses on promoting integrated basin management, supporting community-based water resources management, encouraging more efficient use of water and enabling more diversity in farming. However, most undertakings for the adaptation emphasize committing fiscal resources for construction to protect against and mitigate the impact instead of taking actions to explore and employ ecosystem-based adaptation.

Agencies assigned to tackle water related crisis (i.e. flooding and drought) are integrated in providing aid to affected populations. They are also coordinated in implementation of projects on conservation, restoration and development of reservoirs, on water management, on enhancement of water distribution with funding from government budget. In addition, the agencies facilitate implementation of royal projects on community -based water resources management, monitor water management at basin level and cooperate with other countries in conducting researches and studies on water resources.

Thai-German Climate Programme - Water (TGCP-Water) supported by The German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) has been implemented by Office of the National Water Resources since 2018. The programme's Field of Action 2 (mobilizing climate change actions at provincial and local levels) aimed to support integrate water resources management in light of climate change through adoption of Ecosystem -based Adaptation (EbA).

The Ecosystem-based Adaptation employs ecosystems and biodiversity to enable populations to adapt to impacts from climate change. The concept is applicable in multiple sectors, is comparatively more cost-effective than engineering solutions, places an emphasis on community participation and enables use of local and tradition knowledge. Measures based on such concept were therefore included in plans at several levels of Thailand's administrations such as Nationally Determined Contribution (NDC) and National Adaptation Plan (NAP), and the most recent, in the 13th National Economic and Social Development Plan

[6] Aree Wattana Tummakird (2006) "Climate Change Impacts & Adaptation in Thailand", Workshop on Mainstreaming Policies and Investment in Low Carbon: Opportunities for New Approaches to Investment and Flexible Mechanisms 31 August 2006 United Nations Conference Centre – Bangkok, Thailand

1.2 Freshwater Ecosystem, Ecosystem Services and their Interconnection to Biodiversity

"Water" is a critical component of ecosystems and the extents of ecosystems are usually determined by information on water such as data on catchments and drainages which are generally composite networks of water systems and other ecosystems. Water is thus a core of environmental management and significant efforts were made to develop more knowledge on water management, yielding a wealth of concepts and factual information.

Eco-hydrology [7] was developed to focus on ecological process of hydrology. Academics took note of the importance of this technical area and have been working to widen and deepen their understanding of eco-hydrology in order to enhance its contribution to environmental sustainability.

Aquatic habitats [8] are acknowledged as a concept that define "water" as place for species inhabitation. The concept can reveal physical ranges of plant and animal species to a certain extend.

Compiling the above mentioned components may reveal local ecosystem domain/significances in a given areas and enable identification of ecosystem potential, a concept in which biodiversity can be used as an indicator.

Water ecosystem services heavy focus on supplying water to humans and other organisms, environments and other ecosystems. The services can be classified as follow [9] :

1. Provisioning services concerning provision of foods and water for consumption, agriculture, industry and etc..

2. Regulating services including groundwater replenishment, hydrological cycle maintenance and micro climate control.

3. Cultural services relating to contribution to prevision of recreation sites and development of water-related local beliefs, tradition and culture (boat race, offering, etc.)

4. Supporting services consist of providing spawning and feeding sites for aquatic animals, contributing to local food security and accommodating natural maintenance of biodiversity.

Biological Diversity [10] implies the variety of every organism of all species as well as all breeds and varieties in a given ecosystems. The concept also address diversity among ecosystems.

[7] Eco-hydrology is a sub-discipline of hydrology that focuses on ecological processes occurring within the hydrological cycle and strives to utilize such process for enhancing environmental sustainability (Wagner and et al, 2008).

[8] Aquatic habitat may be defined as the living place of an organism, a population, a species or a species group in an aquatic ecosystem characterised by its physical and biological properties (Wagner and et al, 2008).

[9] UN-Water. Water and Ecosystems. https://www.unwater.org/water-facts/ecosystems/

[10] Biodiversity may be defined as the variability among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are parts; this includes diversity within species, between species and of ecosystems (Wagner et al, 2008).

Professor András Szöllősi-Nagy, UNESCO Deputy Assistant Director General for Sciences and Chairman of the UNESCO International Hydrological Programme (UNESCO-IHP), took note of several impacts of climate change on freshwater habitats including rivers, lakes, wetlands and other reservoirs. He pointed out that change in water table, water flow (both in direction and quantity), water temperature and other features of freshwater ecosystems can result in significant loss of biodiversity.

Applying ecosystem approach to climate change adaptation is a process with multiple context of significant importance. Study and assessment of ecosystems' characteristics and their biodiversity are the primary undertaking for adopting such approach and would require gathering of topographical, hydrological, climate and other physical environment information in addition to systematic collection of data on populations and species richness of plants and animals. This inventory is crucial in revealing actual circumstance and more time as well as more human, material, and financial resources are likely needed for larger, more complex and more diverse ecosystems.

Basically, ecosystems can be physically divided into terrestrial ecosystems [11] and aquatic ecosystems. Shorelines are generally a transition of these two types. Such site is known as Ecotone [12] which was defined as a strip of more than one ecosystem and as an area with explicit ecosystem diversity.

On March 21 to April 1, 2022, the 56th session of the Intergovernmental Panel on Climate Change (IPCC) was held in Geneva, Switzerland. At the meeting, a forum on ecosystems and biodiversity identified targets to be pursued by Contracting Parties to the United Nations Framework Convention on Climate Change (UNFCCC) as follow;

- Primary target: Halting or minimizing extinction rates in ecosystems
- Secondary target: Building awareness on biodiversity value and supporting and promoting conservation, restoration and sustainable use of biodiversity.
- Other targets concerting general practices for climate change adaptation in light of practical aspects of resiliency and sustainable development. these include reducing pollution, phasing out pesticide and other chemicals with serious impacts on ecosystems, amending laws and regulations to facilitate campaigns to mitigate climate change and securing financial supports.

This and other guidance from the global community of relevance are noteworthy and should be adopted and integrated in manner that consistent with circumstance and the environment in Thailand.

To this end, characteristics of ecosystems require articulate assessment in order to enable harmonization and mutually supportiveness of actions.

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[11] The type of ecosystems which are predominantly found on land are called the terrestrial ecosystem (https://byjus.com/biology/terrestrial-ecosystem/)

[12] Ecotone may be defined as narrow and fairly sharply defined transition zone between two or more ecosystems, which is typically species rich (Wagner and et al, 2008).

1.3 Ecosystem Services and Climate Change

Climate change was known to derive from accumulation of greenhouse gases emitted mostly from human activities and is the cause of the increase in temperature in the atmosphere, the water body and on the ground. AR5 Report of the Intergovernmental Panel on Climate Change found that average global temperature increased by 0.85 Celsius over the past 100 years. The report noted that the rise in temperature contributed to melting of polar ice, rise in sea level, increase in severity of natural disasters including rapid flooding and prolong droughts and alteration in water quality and quality in natural reservoirs due to change in precipitation [13].

Climate change has impacts on ecosystem services, particularly regulating services. Higher temperature in reservoirs adversely affects spawning of aquatic animals and induces excessive growth of aquatic flora, effectively depleting dissolved oxygen to critical level. Change in rainfall pattern including irregular precipitation reduce ground water replenishment while higher temperature brought about hordes of locusts and other pest insects that can do serious damage to crops and put food security as risk as seen in Africa.

Climate change does adversely affect ecosystem services and cause ripple effects to utilization of natural resources and quality of life.

[13] Sirirat Sangkharat, Patchapan Rattanapan, Artith Petchrak, Suthirat Kittipongwiset (2020) Effects of Climate Change on Changes in Water Resource and Management. Journal of Environment, (4-1)

Chapter 2

Definition of Ecosystem-based Adaptation and Guidance for Selection Measures

2.1 Definition and Characteristics of Ecosystem-based Approach

Ecosystem-based approach enables inclusion of biodiversity and ecosystem services as components of an adaptation strategy with the view to enhance adaptation to impacts of climate change (CBD, 2009 & 2010). Ecosystem-based adaptation is one of nature-based solutions (image 1) to protect nature with sustainable management as well as ecosystem restoration and improvement in response to any challenges while yielding benefits to human wellbeing and biodiversity as dictated by the principle of sustainability (IUCN Global Standard for NbS, 2020). As shown in image 1, nature-based solutions consist of ecosystem-based adaptation, ecosystem services and green Infrastructure.

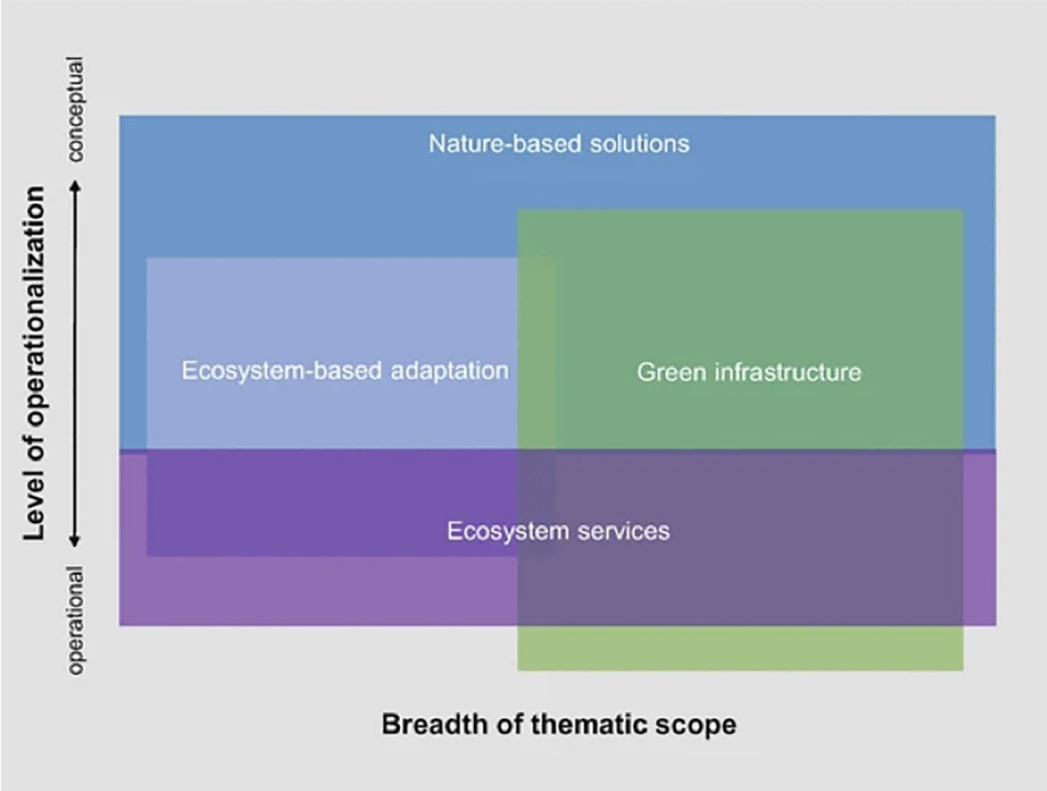

Figure 1 *Ecosystem-based adaptation as a part of nature-based solutions*
Source: Nature-Based Solutions and Climate Change – Four Shades of Green (2017)

Integration of sustainability concept and operation, cost-effectiveness, inclusion of local knowledge and flexibility in resizing activities are features that make nature-based solutions the best possible tool in mitigating impacts from climate change.

Research and adoption of ecosystem-based adaptation for water sector in Thailand were carried out by multiple sectors including the academics, civil society and relevant state agencies. The most common form of the adoption is the construction of "living dikes" which combines the concept of forest ecosystem rehabilitation with that for community-based water management. The dikes were proven useful for water retention and flood mitigation in rainy seasons and in maintaining water table during drought seasons, contributing to local supply of water and replenishment of groundwater as shown in Figure 2.

Figure 2 *Living dam as a measure of ecosystem-based adaptation*
Source: the 2018 Living Dike Project, Nikhom Nam Un Sub-district Administration (2018)

In addition to the living dikes, a number of |ecosystem-based adaptation measures can be adopted for Thailand. Several others measures have been implemented without being labeled as ecosystem-based adaptation. These include reforestation and forest restoration, nature-based protection against shoreline erosion, construction of temporary retention ponds and restoration of coastal wetlands. As mentioned earlier that Ecosystem -based Adaptation is a new concept in Thailand, however, when compared with research and relevant documents, it is found that those practices are Ecosystem-based Adaptation as well. [14]

To widen knowledge, understanding and adoption of Ecosystem-based Adaptation Code of Practice Compendium for Thai Water Sector (EbA COP), taking into account diversity of topography and other environmental setting in Thailand, Thai-German Climate Programme - Water (TGCP -Water) which is supported by The German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) and implemented by Office of the National Water Resources appointed Thailand Environmental Institute as a consultant for gathering information and selecting measures for EbA COP so that they can be collectively made available as a handbook for operator in the sector.

[14] FEBA (Friends of Ecosystem-based Adaptation). (2022). Ecosystembased Adaptation and the successful implementation and achievement of the Sustainable Development Goals. IUCN, Gland, Switzerland. 40 pp. https://doi.org/10.5281/zenodo.6789086

2.2 Process and Criteria for Selection of EbA Measures

The consultant conducted a literature review on local and oversea researches and studies related to ecosystem-based adaptation and identified stakeholders in water resources management in Thailand. Interviews were carried out with stakeholders on ecosystem-based adaptation for water sector.

Measures for ecosystem-based adaptation for water sector were complied into a draft CoP with description and criteria for their selection. The draft was submitted to stakeholders for review. Through participatory approach, the stakeholders consist of experts from relevant organizations from various sector. The government sector including Office of the National Water Resources, Office of Natural Resources and Environmental Policy and Planning, Department of Public Works and Town & Country Planning, Royal Irrigation Department, Department of Water Resource, Hydro-informatics Institute, Department of Fisheries, Department of Marine and Coastal Resources, Department of National Parks, Wildlife and Plant Conservation and the Engineering Institute of Thailand. The representatives from local organizations for Yom and Sakae Krang River Basins, academic institutes, civil societies and international organizations were as well included.

Upon review and approval by the stakeholders and Office of the National Water Resources, the draft CoP was revised based on recommendations and inputs before being subjected to final editing by experts from specialize agencies on ecosystem -based adaptation. The process is as shown in image 3 below.

Details of measures for ecosystem-based adaptation for water sector, criteria for their selection and scoring for the measures are include in Annex A, B and C.

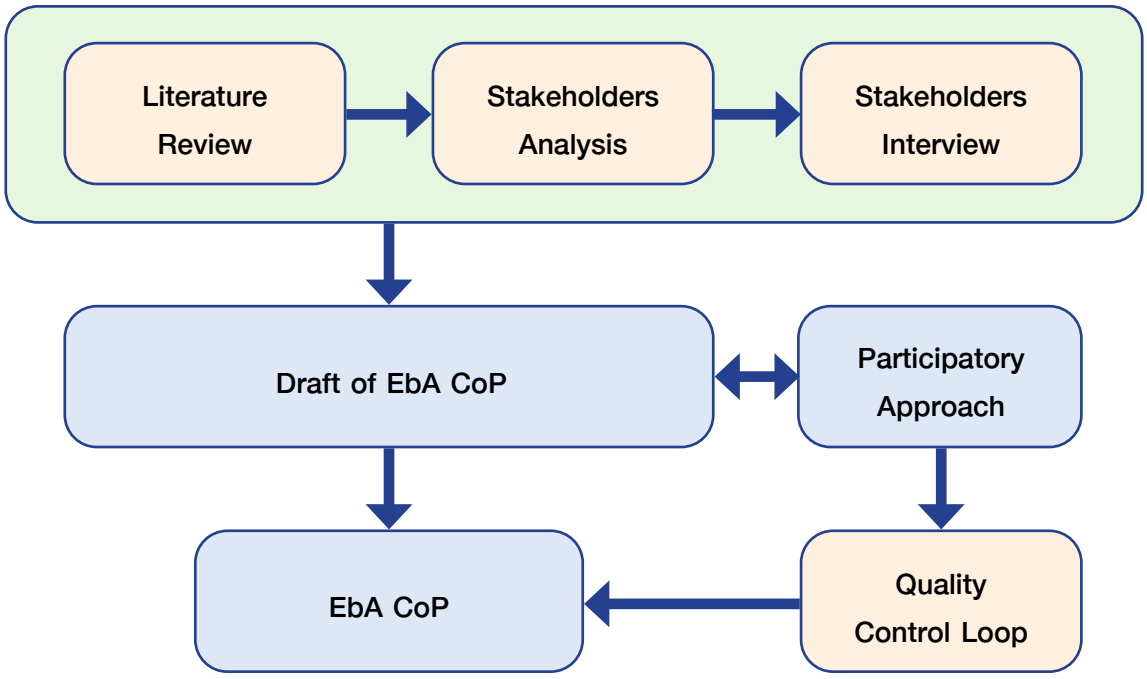

Figure 3 *Process in developing the Ecosystem-based CoP*

2.3 Selected Measures

Through participatory approach, the stakeholders and the ONWR endorsed the following 6 measures for their inclusion in the handbook in light of their capacity to address issue in upstream, midstream and downstream areas.

1. Reforestation and forest restoration
2. Establishing shoreline greenbelts
3. Construction of temporary retention ponds and restoration of oxbow lakes
4. Nature-based protection against shoreline erosion
5. Mangrove reforestation and restoration
6. Coastal wetland restoration and management

Details of these measures are elaborated in chapter 3.

Chapter 3

Details of the Selected Measures

Ecosystem-approach and climate change adaptation have been adopted by several countries for decades. They, however, remain a novel concepts in Thailand. Certain state agencies took note for the concepts and initiated pilot projects for their adoption in aspects that are consistent with their legal-binding obligations and policies. The adoption was thus constrained by the lack of basic understanding on ecosystems and natural systems among their staff and the absence of specialized personnel to set common targets and support joint implementation. For example, eco-landscape planning for soil and water conservation was carried out without substantive inclusion of ecosystem approach.

The handbook on Ecosystem-based Adaptation Code of Practice Compendium for the Thai Water Sector (EbA CoP) focuses on importance of ecosystems in water sector and pursues adoption of adaptation measures for diverse circumstances with the view to mitigate impacts from global warming and climate change. The document was aimed to provide knowledge and advice, promote and support adoption of ecosystem-approach and climate change adaptation by every concerned sectors. All measures provided are technically sound and accommodating application in manner that yields the best possible outcomes in each of local setting.

Developing measures for ecosystem-based adaptation for water sector in Thailand should take into consideration factors and components in every aspect as well as avoid and mitigate adverse impacts as far as possible. Guidance for such undertaking can be listed as follow;

1. Measures should take into account carrying capacity of natural ecosystem to accommodate human activities and limit or regulate the activities with rules or laws.

2. Principle measures should reduce risk to extinction, population decline and biodiversity loss in ecosystems.

3. Adaptation measures should integrate roles and functions of ecosystems with human activities in order to enable harmonization and avoid conflict.

4. Every adaptation measure must be sustainable, environmentally sound, cost effective and easy to maintain in longer term.

When adaptation requires construction of physical structures such as building dikes, process and method of the construction should be consistent with the above mention guidance in every detail. In addition to having basic knowledge and understanding on ecosystems, the contraction should use locally available materials, ensure that modified landscape resembles natural setting as far as possible, limit the size of working areas as necessary, avoid following-up works that may alter natural environments and facilitate securing financial resources for maintenance.

3.1 Reforestation and forest restoration

• Description, objectives and benefits of the measure

Forests contribute to hydrological balance, protection against landslide and mitigation of damage from flooding. Reforestation and forest restoration increase vegetation density, enhances water retention and mitigate discharge to upstream reservoirs. More vegetation stabilizes soil surface and reduces soil erosion while forest loss and degradation affect hydrological balance and ecosystems in long term. Forests also play the role in regulating hydrological cycle by inducing precipitation, controlling evapotranspiration and regulating overflow. Upper canopies are known to store and release water into the atmosphere and induce rainfall while lower canopies mitigate overflow and reduce impacts from flooding and landslide. Besides, forest also helps to mitigate drought in long-term due to it helps to balance water cycle. Several relevant agencies recognized the role of forest, hence, they initiated reforestation and forest restoration for drought mitigation.

Change in forestlands by deforestation and forest degradation has significant impacts on hydrological cycle and ecosystems, alter ecosystem services and unavoidably affects human lives that rely on such service.

Figure 4 *Reforestation and forest restoration*

Source: https://actionaidrecycling.org.uk/reforestation-examples-around-the-world/

"Reforestation" is a process that replaces the loss of forest from deforestation or logging concession. The process consists of planting on any areas where trees were previously lost or removed and includes community reforestation, agroforestry and planting of economic timber species.

“Forest restoration" is rehabilitation of forest ecosystems by accelerating recovery of forest structures, ecosystems services and biodiversity in order to return them to their previous states as far as possible. This action includes preventing further encroachment, protection against forest fire and planting to stimulate natural recovery. The forest restoration therefore focuses on supporting self-reestablishment of forest ecosystems and restoring structure and functions with planting of keystone species. Number of canopies, species richness, conservation status of species and water and soil quality can measure success of the restoration. The forest restoration is thus a divergence to reforestation. [15,16]

Reforestation and forest restoration aim to rehabilitate forest ecosystems altered by natural or human actions in order to return them to their natural state as far as possible as well as to restore their ecosystem services they previous provided as much as possible. The reforestation and forest restoration also contribute to maintaining hydrological balance, improvement of water quality and reduction of cost associated with water management for consumption.

Reforestation and forest restoration were carried out extensively by relevant state agencies, private sector and civil society. The actions were, however, restricted to planting selected few tree species which are not only inadequate in addressing biodiversity aspect of the endeavor but also proven to be inappropriate to local setting in some areas. However, recently responsible agencies, especially Royal Forest Department and the Department of Department of National Parks, Wildlife and Plant Conservation, paid attention to increasing biodiversity, ecosystem and community’s livelihoods when they initiate reforestation and forest restoration programs. [17,18]

[15] The Forest Restoration and Research Unit (FORRU), Chiang Mai University, 2006, Planting a forest: Concepts and Guidance for Tropical Forest Restoration

[16] Elliott, S., (2000). Defining forest restoration for wildlife conservation. In: Elliott, S., J. Kerby, D. Blakesley, K. Hardwick, K. Woods and V. Anusarnsunthorn (eds.) Forest Restoration for Wildlife Conservation. Chiang Mai University, pp 13-17.

[17] Watershed Conservation and Management Office, (2563) Handbook on naturally reforestation. Department of National Parks, Wildlife and Plant Conservation, Bangkok.

[18] Forest Conservation and Plant Research Office. (2564) Ecosystem reforestation for community livelihoods in protected areas. Department of National Parks, Wildlife and Plant Conservation, Bangkok.

Figure 5 *Community reforestation*

Source: Thailand Environment Institute (2022)

• Topographical (natural ecosystems, soil profiles, slope and vegetation cover) and hydrological conditions for adoption of the measure

Reforestation and forest restoration must take into account a number of critical issues as follow;

Types of original forestlands such as hill evergreen forests, mixed deciduous forests and deciduous dipterocarp forests, would determine selection of appropriate species for reforestation including those used as pioneer, dominant and secondary species. Pioneer species are generally fast growing when abundance supply of sunlight is available while dominant species are usually the most common in original forestlands (see Table 1).

Table 1 *Examples of pioneer and dominant species for reforestation and forest restoration in different types of forests.*

Type of forest	Pioneer species	Dominant Species
Montane forest	*Trema orientalis* (L.) Blume) *Schima wallichii* (DC.) Korth. *Duabanga grandiflora* (DC.) Walp. *Erythrina subumbrans* Merr. *Artocarpus lakoocha* Roxb.	*Castanopsis argyrophylla* King *Castanopsis acuminatissima* (Blume) A.DC.) *Diospyros glandulosa* Lace *Magnolia champaca* (L) *Dipterocarpus* sp.
Mix deciduous forest	*Gmelina arborea* Roxb. *Sterculia foetida* L. *Spondias pinnata* (L.f.) Kurz	*Xylia xylocarpa* (Roxb.) *Pterocarpus macrocarpus* Kurz. *Afzelia xylocarpa* (Kurz) Craib. *Tectona grandis* L.f.
Dry Diperocarp forest	*Croton oblongifolius* Roxb. *Haldina cordifolia* *Terminalia alata* *Canarium subulatum* *Morinda coreia*	*Shorea obtusa* Wall. ex Blume. *Shorea siamensis* Miq. *Dipterocarpus obtusifolius* Teijsm. ex Miq. *Dipterocarpus tuberculatus* Roxb. *(Dipterocarpus intricatus)* Dyer. *Cratoxylum* sp.

Note:

Pioneer species are the vegetation that temporarily grow in certain period of succession process before being replaced by dominant species. Pioneer species can be either herbaceous or woody plants.

Dominant species are vegetation that found more than other species in the certain area. It has influence on plants composition. Dominant species can be widely distributed in different ecosystems or specifically grown in certain ecosystem. [19]

[19] New Phytologist Foundation. (2019) https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.15789

Soil profiles (i.e. clay and sandy) and their impact on drainage must also be taken into account. Some species such as Tembusu (*Fagraea fragrans* Roxb.) and Indian Almond tree (*Terminalia catappa* L.), grow well in sandy soil. Depth of soil surface should also be taken into consideration. Areas with shallow soil surface could be riddled with stones and may only accommodate species that originally thrived in such condition.

Slope must be taken into account in light of difference in the depth of root systems between species. Areas with slope greater than 35 degree should be left as natural forestlands and serve as wildlife habitats and head watershed areas.

• Design and construction details, appropriate materials, material specification, construction considerations and size of working areas

In natural vegetation, spacing between trees are found to be greater in areas with lower precipitation. Reforestation and forest restoration on dry lands should therefore provide adequate spaces between trees in order to prevent them from competing for water. Dense vegetation, on the other hand, occurs in areas with high rainfall. Reforestation and forest restoration should thus take into consideration the amount rainfall as one of major factors.

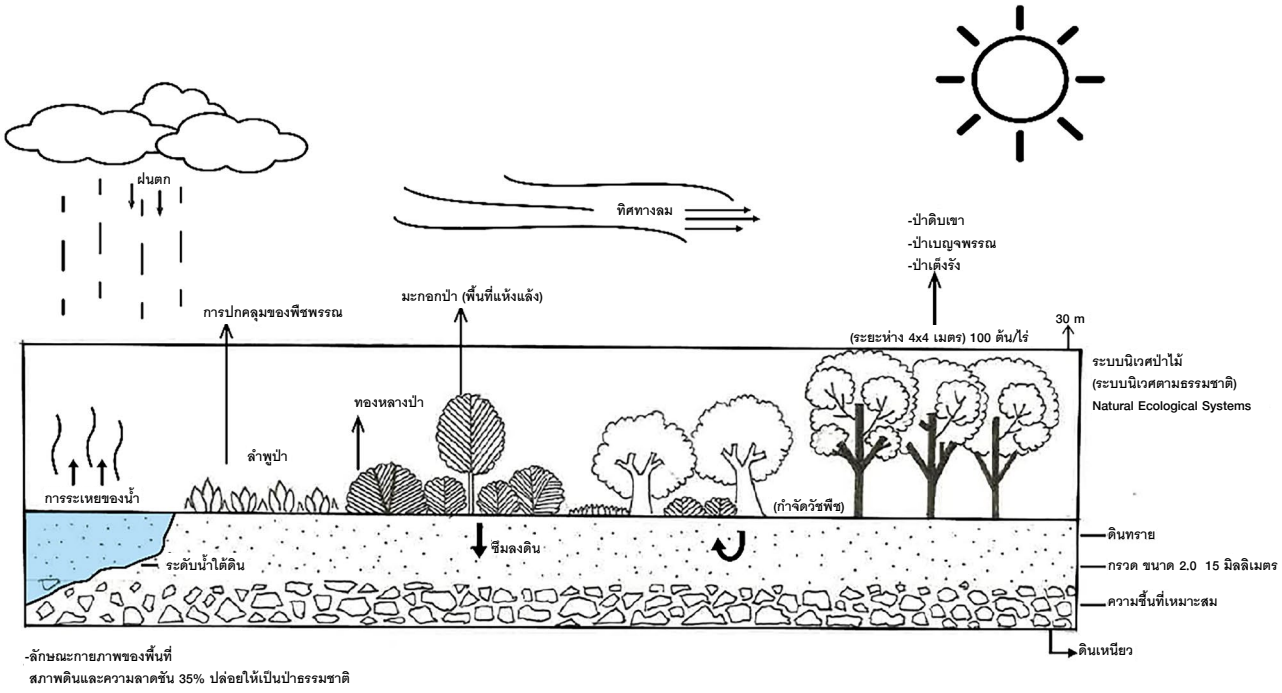

Figure 6 *Factors affecting reforestation and forest restoration*

Amount of water required for reforestation and forest restoration depends on density of the planting. As previously mentioned, spacing must be provided when planting on dry lands and weeds should be removed to prevent them to compete with seedlings. Soil cover could be provided to improve soil's water absorption and reduce water loss through evaporation. Planting in rows can accommodate watering systems. This is, however, unnecessary when planting is for patching cleared lands. In any circumstance, spacing should be consistent with vegetation density of original forestlands and characteristics of planted species (canopy profiles).

Common spacing used for planting trees is 4 x4 meters or around 100 trees per 0.16 hectares. Reforestation and forest restoration place an emphasis on the original forestlands when determining the spacing. Since any area officially qualified as a forestland must cover at least 0.5 hectares, the spacing for planting has to be no less than 30x30x30 centimeters. For actual planting, seedling can grow faster with compost and bamboo sticks can be used to secure seedlings to the ground. The stick should be painted red to make them stand out from unwanted vegetation (weeds) and survival and growth rate of seedlings must be regularly measured.

When a planting area exceeds 16 hectares, it should be separated into smaller plots and a 6 meters wide passage should be built to provide access to the plots in order to facilitate transport of seedlings and maintenance. The passage may also serve as a fire break and a route for fire patrol.

- **Estimated budget requirement**

The 2021 pricing reference published by Budget Standard Division 1 of Bureau of the Budget (Annex D) set the price for reforestation at 4,020 THB per 0.16 hectares and identified maintenance cost from the 2nd to 6th year at 1,060 THB per 0.16 hectares. While the maintenance cost from the 7th to 10th year was set at 510 THB per 0.16 hectares. The reference also set the seedling price at 2.96 THB per seedling. The reference can be used by local agencies and communities in estimating cost of the operation and for requesting financial aids from private sectors and other donors when sufficient funding is not available.

- **Maintenance**

Maintenance in the first few year should focus on eliminating weeds by covering ground around planted trees or by physical removal. For larger areas, chemicals might be used for removing weed providing that their instructions are strictly followed and labor force is not available for physical removal of weeds. The chemicals must be avoid in head-watershed areas or at size in close proximity to reservoirs.

Replanting, fertilizer use and forest fire prevention are generally required for any reforestation and forest restoration. Monitoring of forest recovery can be carried out with regular gathering of data on survival and growth rate of seedlings and trees.

• **Applications**

Synergy of reforestation and forest restoration with other measures can be observed from their contributions to hydrological balance and sediment retention. Rehabilitation of forestlands upstream general decelerates sedimentation in downstream catchments and reservoirs.

Caution is also required when adoption this measure since most forestlands in the country are protected by laws which prohibit and regulated certain actions. Selection of species must also avoid introduction of alien species and should taken into consideration native species diversity in order to return forests to their original conditions as far as possible.

A case study on reforestation and forest restoration is as summarized in the box below.

The Forest Restoration and Research Unit of Chiang Mai University (FORRU), Mae Sa Mai Community of Mae Rim District and Doi Suthep-Pui National Park conducted a research on forest rehabilitation with the framework species method and was able to restore an area back to its natural condition. The actions received a silver globe award from the Royal Forest Department in 2000 for their contribution to study of native forest, utilization of pioneer and native species for reforestation, placing emphasis on species diversity and enabling participation by relevant community and state agencies.

Source: https://www.forru.org/th/about/

3.2 Forest buffer strip installation

- **Description, objectives and benefits of the measure**

Establishing forest buffer strip has long been developed as a concept for protection of water sources such as creeks, canals and rivers as well as coastlines. To prove the benefits of this concept, data was gathered on environmental conditions of water sources including through inspection of their chemical characteristics such as acidic, alkalinity, oxygen concentration and heavy metal contamination as well as physical features such as turbidity.

Figure 7 *Forest buffer strips*

Source: https://cropwatch.unl.edu/2017/nda-offers-funding-buffer-strips

In the 1980's, ecosystem approach was more widely adopted as guidance for designing and designating forest buffer strips including in determining sizes that would maximize benefits for conservation and rehabilitation. As technological advancement, significantly improved assessment and data gathering process for conservation of water resources, positive impacts from forest buffer strips on ecosystems became more measurable.

Urban climate adaptation is widely adopted and give rise to the concept of urban forestry, which aims to create larger green areas to urban environments. Forest buffer strips nicely fit this concept and were established on several vacant riverfronts in towns and cities. The forest buffer strips are also a showcase for adoption of ecosystem approach and climate change adaptation.

Figure 8 *Urban forest buffer strips*

Source: https://cointwashingmachine.blogspot.com/2018/09/blog-post_17.html

Of all riverbank ecosystems from upstream to downstream areas, those found to be the most difficult for conservation and rehabilitation are located in areas with community settlements and with high level of human activities such as urban and rural communities.

In 2008, James H. Thorp and his colleges published a book entitled "The Riverine Ecosystem Synthesis". The document describes unique and diverse riverine ecosystems in Australia, including enormous river basins that viewed as regional ecosystems. Riverine ecosystems in Australia are of critical importance in sustaining unique plant and animal species found nowhere else on earth. Federal, state and local agencies are therefore involved in conservation and rehabilitation of the ecosystems. Ecosystem approach and climate change adaptation were adopted to address impacts from flooding, drought and severe forest fire. Establishment of forest buffer strips was one of several measures employed to tackle these impacts.

The concept of establishing forest buffer strips is more compatible to areas where natural environments are largely intact such as Na Kha Canal of Rayong Province, Tapee River Basin and Trung River Basin. The success of the forest buffer strips in these areas also explain the frequent failures of reforestation in Thailand. Unlike establishment of forest buffer strips, reforestation was often conducted without adequate understanding on ecological succession and discipline. By planting rows of a single selected species in both inland and mangrove forests, survival rate of seedlings is low and time and funding are often wasted away for series of replanting.

In addition to its compatibility to areas where nature remains largely intact, establishing forest buffer strips is proven to be beneficial to adjacent agricultural, rural and urban areas by enabling sediment retention, overflow mitigation, riverbank stabilization. Vegetation in the forest buffer strips also contributes to nutrient retention, adds green and recreational areas for urban residents and enhances carbon sequestration.

• Topographical (natural ecosystems, soil profiles, slope and vegetation cover) and hydrological conditions for adoption of the measure

Urban Water Series published by UNESCO in 2008 provide guidance on assessment, design and data gathering and analysis for ecosystem-based conservation of water sources. The document identifies two types of assessment as follow;

1. Bio-assessment implies a study made by gathering ecosystem information through applying ecosystem indicators for all species ranging from the smallest such as phytoplankton, zooplankton, macro invertebrates and macrophytes to larger fish species and by taking into account interconnection between aquatic and terrestrial habitats and roles and functions of vegetation around reservoirs.

2. Physical and geomorphological assessment implies a study carried out by gathering of information on landscape, topography, slope, riverbed characteristics, discharge rate, flow speed, water table, sedimentation rate, shoreline erosion, etc.

Outcomes of both assessment would provide a basis for designing and designating forest buffer strips as well as for determining their landscape and selecting appropriate plant species that best serve the function of the forest buffer strips.

• Design and construction details, appropriate materials, material specification, construction considerations and size of working areas

Theory of Hierarchy is one of several theories on large ecosystems. The theory explains horizontal and vertical interconnection between ecosystem components and can be used to elaborate on ecosystem diversity. Based on the theory, the width of forest buffer strips in several countries is around 10-30 meters starts from riverbank when banks are very steep while in floodplains, the width of forest buffer strips is 50 to 100 meters. The establishment of forest buffer strips is usually consistent with laws on land use regulation in several countries. [20]

Theory of Hierarchy is also consistent with a guidance on planning and design of forest buffer strips (riparian forest buffer) developed by University of Missouri Center of Agroforestry [21]. The guidance suggests splitting the forest buffer strips into three zones as follow;

[20] United Nations Environment Programme Publication. (2014) Green Infrastructure Guide for Water Management: Ecosystem-based management approaches for water-related infrastructure projects

[21] University of Missouri Center of Agroforestry. (2013) Training manual for applied agroforestry practices – 2013 Edition, Chapter 5: Upland & Riparian Forest Buffers. University of Missouri, USA.

Zone 1 along the riverbank should be planted with fast growing species such as shrubs in order to provide soil cover and stabilize the ground. The species should also be resilience to flooding. Zone 1 itself connects riverine systems with ecosystems on shore.

Zone 2 is located further inland and connected to Zone 1. Trees and shrub species with resilience to temporary inundation are recommended. Branching species such as Bush willows and Madan can trap garbage brought by overflow while fruit bearing species could attract birds and other small animal species and contribute to increase in biodiversity.

Zone 3 is connected to Zone 2 and to possibly farming or residential areas. Local shrubs or monocots species with extensive and deep root systems should be planted. Zone 3 contributes to sediment retention and mitigating overflow.

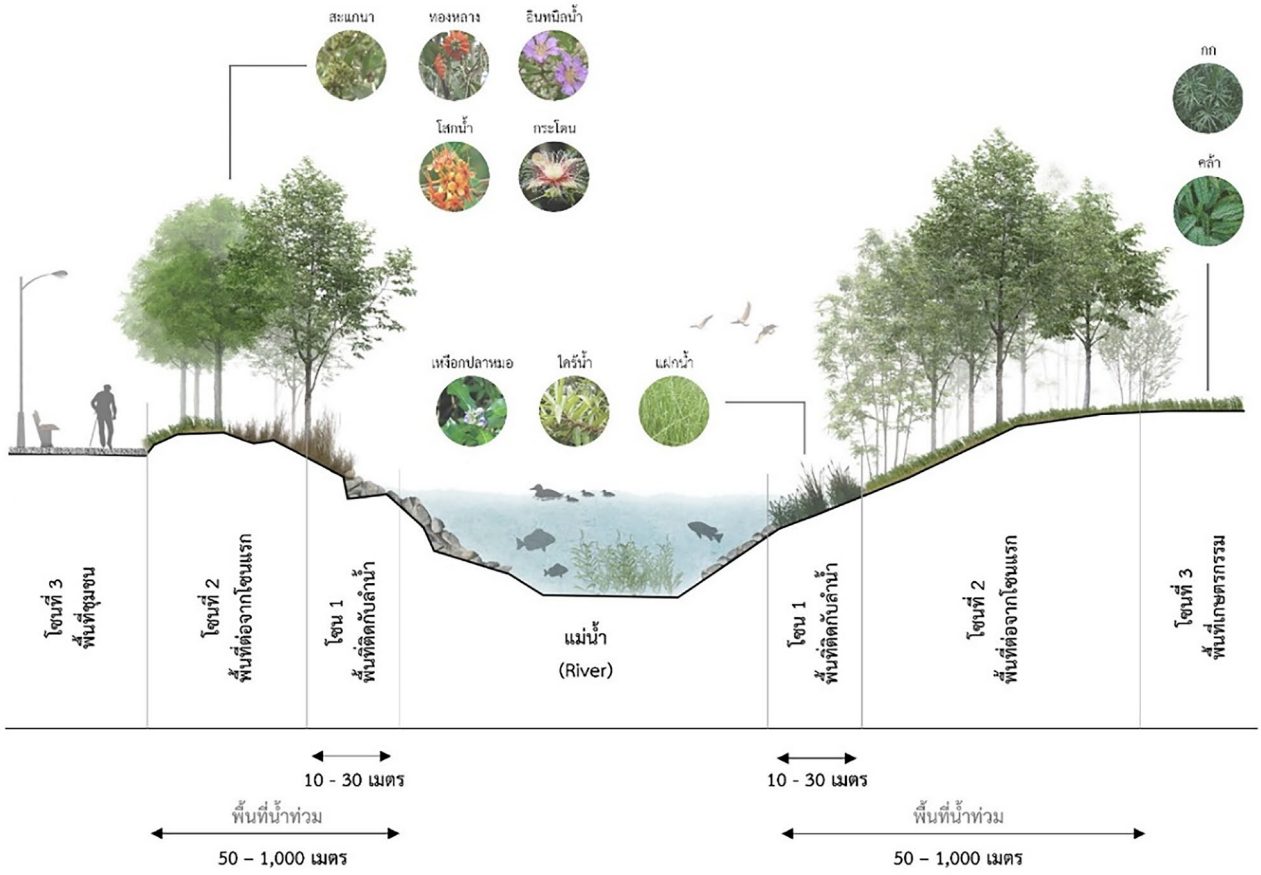

Figure 9 *Recommended forest buffer strips*

Native plant species that are compatible for each Zone are as shown in Table 2. The plants indicated in the table can be found in all regions of Thailand.

Table 2 *Example of plant species that are compatible for each zones of forest buffer strips.*

Zone 1	Zone 2	Zone 3
Homonoia riparia Lour. *Syzygium antisepticum* (Blume) *Salix tetrasperma* Roxb.) *Vetiveria zizanioides* (L.) *Nauclea orientalis* (L.) *Mitragyna diversifolia* (Wall. ex G. Don) *Crateva magna* (Lour.) DC. *Elaeocarpus hygrophilus* Kurz. *Garcinia schomburgkiana* Pierre. *Barringtonia acutangula* (L.) Gaertn. *Sonneratia caseolaris* (L.) Engl. *Acanthus ebracteatus* Vahl.	*Combretum quadrangulare* Kurz. *Erythrina variegata* L. *Lagerstroemia speciosa* (L.) Pers. *Saraca indica* L. *Bambusa blumeana* Schult.f. *Ficus racemosa* L. *Ficus* sp. *Careya sphaerica* Roxb. *Syzygium cumini* (L.) Skeels.	*Cyperus involucratus* Roxb. *Vetiveria zizanioides* (L.) *Pluchea indica* (L.) Less. *Schumannianthus dichotomus* (Roxb.) *Sesbania javanica* Miq. *Antidesma ghaesembilla* Gaertn. *Phyllanthus taxodiifolius* Beille)

The widths of the forest buffer strips are determined by objectives of their utilization and spatial constrains. They can be listed in accordance to each objective as follow.

1. Forest buffer strips established to stabilize shore must be at least 6 meters wide and can reach the width of 10 meters.

2. Forest buffer strips established to provide habitats for aquatic animals must be at least 8 meters wide and can reach the width of 14 meters.

3. Forest buffer strips established to enable sediment retention must be at least 12 meters wide and can reach the width of 25 meters.

4. Forest buffer strips established to enable nutrient retention must be at least 28 meters wide and can reach the width of 40 meters.

5. Forest buffer strips established to mitigate impacts from flooding must be at least 20 meters wide.

6. Forest buffer strips established to provide wildlife habitats must be at least 20 meters wide.

Selection of different planting methods (seed, seedling, etc.) is determined by budget available and their compatibility to chosen species. No less than 253 trees should be planted for each plot of 0.16 hectares [22]. By keeping spacing between tress at 2 x 3 meters, 266 trees can be planted for each plot of 0.16 hectares. However, the planting should eventually reflect of pre-existing vegetation.

- **Estimated budget requirement**

No specific pricing for establishing forest buffer strips has been official set. The 2021 reference costs published by Budget Standard Division 1 of Bureau of the Budget (Annex D) can be used as guidance on cost associate with such undertaking. The reference set the price for reforestation at 4,020 THB per 0.16 hectares and identified maintenance cost from the 2nd to 6th year at 1,060 THB per 0.16 hectares while the maintenance cost from the 7th to 10th year was set at 510 THB per 0.16 hectares.

- **Maintenance**

Maintenance on each zone in forest buffer strips is as shown in Table 3.

[22] Department of Environmental Protection. (2006). Pennsylvania stormwater best management practices manual. Chapter 6 Riparian buffer restoration. Department of Environmental Protection, Pennsylvania. USA.

Table 3 *Maintenance on each zone in forest buffer strips*

Zones	Benefits	Maintenance
Zone 1 (on the riverbanks with fast growing shrubs that are resilient to flooding)	• Providing shades and reducing water temperature. • Stabilizing bank. • Adding organic matters and expanding habitats. • Acting as the final filter of any discharge into reservoirs. • Reducing overflow speed.	• Prohibit logging and ban livestock from the area. • Regularly remove fallen trees and other woods when drainage is present. • Replace trees loss from strong wind or flooding. • Ban any use of chemicals.
Zone 2 (connected further inland from Zone 1 with mixture of fast and slow growing plants and shrubs which are resilient to temporary inundation)	• Facilitating water permeation in soil. • Enabling nutrient and chemical retention. • Providing foods. • Expanding habitats. • Reducing overflow speed. • Enabling retention of wastes that may damage farming or residential areas.	• Clear some areas when vegetation become too thick. • Allow harvest of fruits and other products to motivate locals to take care of the site. • Avoid activities that may harden soil. • Ban livestock from the area • Promote ecological learning such as bird watching and study of vegetation. • Ban any use of chemicals.
Zone 3 (connected to Zone 2 with shrubs and monocots)	• Mitigating overflow. • Enabling retention of sediments and other materials that may damage farming or residential areas. • Enabling nutrient and chemical retention.	• Trim overgrown trees. • Allow livestock in the area given that the animals can be kept away from Zone 2. • Regular remove dead plants along the border with farming or residential areas.

- **Applications**

Synergy of establishing forest buffer strips with other measures derives from their contribution to stabilization of riverbank, protection against riverbank encroachment, decelerating sedimentation with sediment retention, mitigating overflow and improvement of water quality through nutrient retention. Moreover, the setback from river body benefits timber farmers as it is in line with standard and criteria of sustainable forest management, either the Forest Stewardship Council [23] (FSC) standard or the Sustainable Economic Timber Standard 14061. The setback also benefit oil palm farmers as it is in line with sustainable palm oil standard for smallholder under the Roundtable on Sustainable Palm Oil (RSPO) [24] certification.

Caution is also required when adoption this measure since a number of riverbanks in the country are protected by laws which prohibit and regulated certain actions. Several others are privately owned and the measure can only be adopted with consents of their owners. Selection of species must also avoid introduction of alien species and should taken into consideration species diversity in order to make the area resemble natural conditions as far as possible. Besides, attention is required when planning trees in Zone 1, to make sure trees will not hinder natural flow.

[23] Forest Stewardship Council Canada. 2008. Certification Standards for Best Forestry Practices in the Maritimes Region. Forest Stewardship Council Canada, Ontario, Canada.

[24] https://rspo.org/smallholders

A case study on establishment of forest buffer strips is as summarized in the box below.

In 2021, millions trees were planted on both banks of rivers and tributaries in Scotland in order to protect natural salmons from rise in temperature derived from climate change. Fishery scientists had found water temperature in rivers and other reservoirs in Scottish Highland to be too high for spawning of salmons, putting survival of the species at risk. Member of communities on riverbanks therefore plants more trees by the riverside to reduce water temperature, making the riverine ecosystems more suitable for the spawning.

Photo from Murdo MacLeod/The Guardian

3.3 Construction of Retention Ponds and Restoration of Oxbow Lakes

- **Description, objectives and benefits of the measure**

Temporary retention ponds implies reserve catchments and reservoirs used for storing excess overflow for dry season. They are varies in size and shape in accordance to the topography. Oxbow lakes or horseshoe bends are divergence of waterways caused by sedimentation and are often found in lower plains. Both are credited for enabling water retention during any period with excessive flow.

Figure 10 *Temporary retention ponds*

Source: https://pantip.com/topic/35751409

Figure 11 *Restoration of an oxbow lake*

Source: http://nwrm.eu/measure/reconnection-oxbow-lakes-and-similar-features

Temporary retention ponds may referred to natural ponds or lowland areas that can be used for retarding water as defined King Rama IX's projects on flood prevention. In one of more well-known royal projects, Nong Yai, a temporary retention pond, was used as catchment for Tha Sae Canal in order to prevent flooding in the city of Chumphon Province. Nong Yai has a storage capacity of around 3 million cubic meter and discharge water into the sea via Hua Wang and Phanang Tak Canals. The project was taken note by Department of Public Works and Town & Country Planning (known at the time as Department of Town & Country Planning), Ministry of Interior, who is responsible for regulating land use and 3 million cubic meter storage capacity was officially set as a criteria in designating any areas as a temporary retention pond in town planning.

Oxbow lakes were often formed by meandering streams in downstream areas with low gradient and at elevation of the mean sea water level, making them susceptible to mostly horizontal erosion. The meandering streams are characterized by higher flow in outer bends and low flow in inner bends. The outer bends are, therefore subjected to more erosion causing what is known as cut bank while lower flow in inner bends induced sedimentation and created point bars. Continue erosion and sedimentation keep meander a stream until a part shaped like oxbow or horseshoe breaks off from the tributary. Oxbow lakes were often used as temporary retention ponds since many of them can be found in adjacent to major tributaries in lower plains [25]

Figure 12 *Temporary retention pond in a community*

Source: https://ldpwatersheds.org/stormwater-detention-basin-basics/

[25] www.mitrearth.org

Figure 13 *Oxbow lake in Mun River*

Source: www.GeoThai.net

• Topographical (natural ecosystems, soil profiles, slope and vegetation cover) and hydrological conditions for adoption of the measure

Retention ponds were previously selected from natural reservoirs used by communities for consumption and agriculture as well as for flood retention and drought alleviation. These ponds were maintained by communities or state agencies and some were developed into recreation and tourist sites. With worsening flood and drought, there was a demand for retention ponds where natural reservoirs were not available and construction of artificial retention ponds and other similar storage facilities occurred in several regions of the country. Adoption of ecosystem approach and climate change adaptation were often absence in construction of these ponds since primary focus of the construction is to provide adequate water storage capacity to meet the need of local economic expansion. However, recently the ecosystem and climate change adaptation concepts are considered and applied when establishing retention pond for water storage and mitigate impacts of flood.

A retention pond should be constructed in an area that are connected to other natural occurring and man-made reservoirs in order to induce water flow and mitigate flooding. The pond can serve as a retention and treatment pool for wastewater. According to His Majesty's Royal Encyclopedia [26] and Office of the Royal Development Projects Boards [27], retention ponds can be classified by their size as follow;

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[26] His Majesty's Royal Encyclopedia, the Royal Project on Retention Pond (www.www.hii.or.th/wiki84/index.php?title=ก-แก้มลิง)

[27] Office of the Royal Development Projects Boards, the Royal Project on Retention Pond. (http://km.rdpb.go.th/)

1. Retarding basins are big ponds or lakes that server as the main catchment for rainwater over large areas. Water is generally stored for a period of time before being discharged into riverine systems. Retarding basins include reservoirs of dams and dikes as well as cultivating fields and are also used for irrigation, fisheries and other purposes.

2. Medium retention ponds are natural creeks, canals and ponds found in river basins.

3. Regulating reservoirs are small pools found in parks, playgrounds, parking areas or backyards. The reservoirs usually drain into creeks or canals.

The focus of all three types of retention ponds is their connection to natural or man-made riverine systems which is crucial in increasing water flow and facilitating drainage and in meeting the primary objectives of water retention and flood mitigation. Retarding basins, medium retention ponds and regulating reservoirs can all be found In Bangkok. They were utilized not only to mitigate flooding but also to address water pollution. For example, Klong Mahachai-Sanam Chai, a retarding basin with storage capacity of 6,000,000 cubic meters is used to mitigate flooding and water pollution in Thonburi District and other outskirts of Bangkok, while Nongbon Lake with storage capacity of 5,000,000 cubic meters is used to alleviate flooding in Phra Khanong and Prawet Districts.

Medium retention ponds in Bangkok include Bung Kum (with storage capacity of 148,000 cubic meters) which is used to tackle flooding in Seri Nakhon Phatthana and Thawisuk Villages of Bung Kum District and a pond at the Railway Authority's Golf Club (with storage capacity of 107,000 cubic meters) which is used to mitigate flooding in Bang Sue District. Of regulating reservoirs found in Bangkok, the pond located in adjacent to Burachat Chaiyakon Hospital (with storage capacity of 12,800 cubic meters) is used in reduce flooding in Ratchathewi District, while Rama 9 Pond (with storage capacity of 10,875 cubic meters) is used to mitigate flooding on Rama 9 Road. The pond in Phet Kanchanarom Park located under an overpass at the intersection of Petchkasem and Kanchanaphisek Roads is another example of regulating reservoirs in Bangkok.

Figure 14 *Regulating reservoir of Phet Kanchanarom Park*

Source: www.earth.google.com

Restoration of oxbow lakes is another option for conservation and development of natural reservoirs in floodplains where sedimentation is the most common problem. State funded dredging of oxbow lakes was often carried out to increase water storage capacity for agriculture and consumption of local communities. Lower inflow was found in several oxbow lakes due to alteration of drainage passages in adjacent areas, and restoration of oxbow lakes should take into account this and other environmental change in surrounding areas. Despite the growing interest in oxbow lakes, adoption of ecosystem approach and climate change adaptation were largely absence in restoration of these sites.

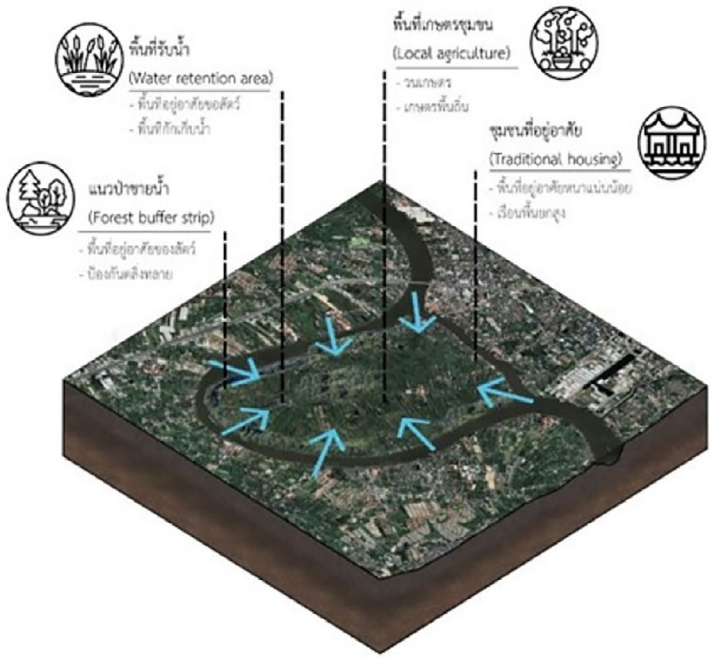

Figure 15 *Characteristic and guidance on utilization of oxbow lakes*

• Design and construction details, appropriate materials, material specification, construction considerations and size of working areas

To restore an oxbow lake, Sydro Consultant [28] conducted a study in Yom Long of Phrae Province and recommended that the design should take into account the topographical profile of the waterway. The consultant further pointed out that the bank should design to benefit agriculture by maintaining various gradients of land and maintaining minimum flow in the waterway as well as by enabling connection with major tributaries to accommodate movement of aquatic life and integrate the restoration into the development at the basin level.

The use of oxbow lakes as catchments and reservoirs should be further explored in Thailand, particularly in lower northern, central and northeastern regions where many of such oxbow lakes can be found in major tributaries.

[28] Sydro Consultant. 2022. Technical Guidance Development and Application of Ecosystem-based Adaptation measures in the Thai Water Sector: Technical Workshop on Oxbow Lake Design.

• **Estimated budget requirement**

Budget requirement for construction of temporary retention ponds and restoration of oxbow lakes often consists of meeting the cost for dredging and expanding the width of waterway. The 2021 reference cost published by the Budget Standard Division 1 of Bureau of the Budget (Annex D) set a price of dredging works of any reservoir with capacity over 1,260 cubic meters. Although the actual cost may vary with fluctuation of fuel price, the reference do provide guidance to local agencies and communities in estimating cost for the undertakings.

• **Maintenance**

Maintenance of temporary retention ponds consists of;

- Dredging when it is necessary by regular inspection, particularly after flooding season.
- Dredging drainages and inspecting damages on concrete drainage.
- Removing weeds such as water hyacinth, floating moss and Hydrilla as well as terrestrial species such as prickly wood weed, which is an invasive alien species.
- Repairing and improving pumping facilities.
- Conducting maintenance on water gates
- Repairing flood barriers.
- Inspecting water quality on regular basis in order to mitigate impacts from household, industrial and agricultural wastewater.

Maintenance of oxbow lakes is similar to that for temporary retention ponds and includes;

- Dredging when it is necessary by regular inspection, particularly after flooding season.
- Inspecting outlets to major tributaries.
- Removing water hyacinth, floating moss, Hydrilla, prickly wood weed and other invasive alien species.
- Conducting maintenance on water gates
- Strengthening bank that may be damaged by overflow or livestock.
- Inspecting water quality on regular basis in order to mitigate impacts from agricultural wastewater. Since an oxbow lake is a close system, water temperature and dissolve oxygen should be monitored.
- Maintaining minimal water table for preservation of aquatic ecosystems.

• **Applications**

Synergy of construction of retention ponds and restoration of oxbow lakes with other measures can be observed in mutual supportiveness with establishment of forest buffer strips in several areas. These include their contribution to sediment retention, mitigation of nutrient-loading, flood protection, expanding water storage capacity and maintenance of ecosystems. Retention ponds and oxbow lakes do attract various aquatic animals, which can contribute in improvement of local livelihoods.

Caution is also required when adoption this measure since construction of retention ponds for water retention may case economic damage to farmlands and other areas and compensation might have to be made to redress such damage. Restoration of oxbow lakes requires maintaining minimal water table for preservation of aquatic ecosystems and connecting the areas with major tributaries, including through water gates. Since an oxbow lake is a close system, use of fertilizer and pesticide should be avoided. Moreover, to dredge the retention pond or oxbow lake, the suitable depth for aquatic life and vegetation in the area is need to be considered.

3.4 Natural bank erosion control

- **Description, objectives and benefits of the measure**

Riverbank erosion on major tributaries in Thailand derives from both natural and man-made causes. Several reports clearly indicate that most of the erosion was induced by human activities as erosion rate was found to be higher in areas with greater human activities.

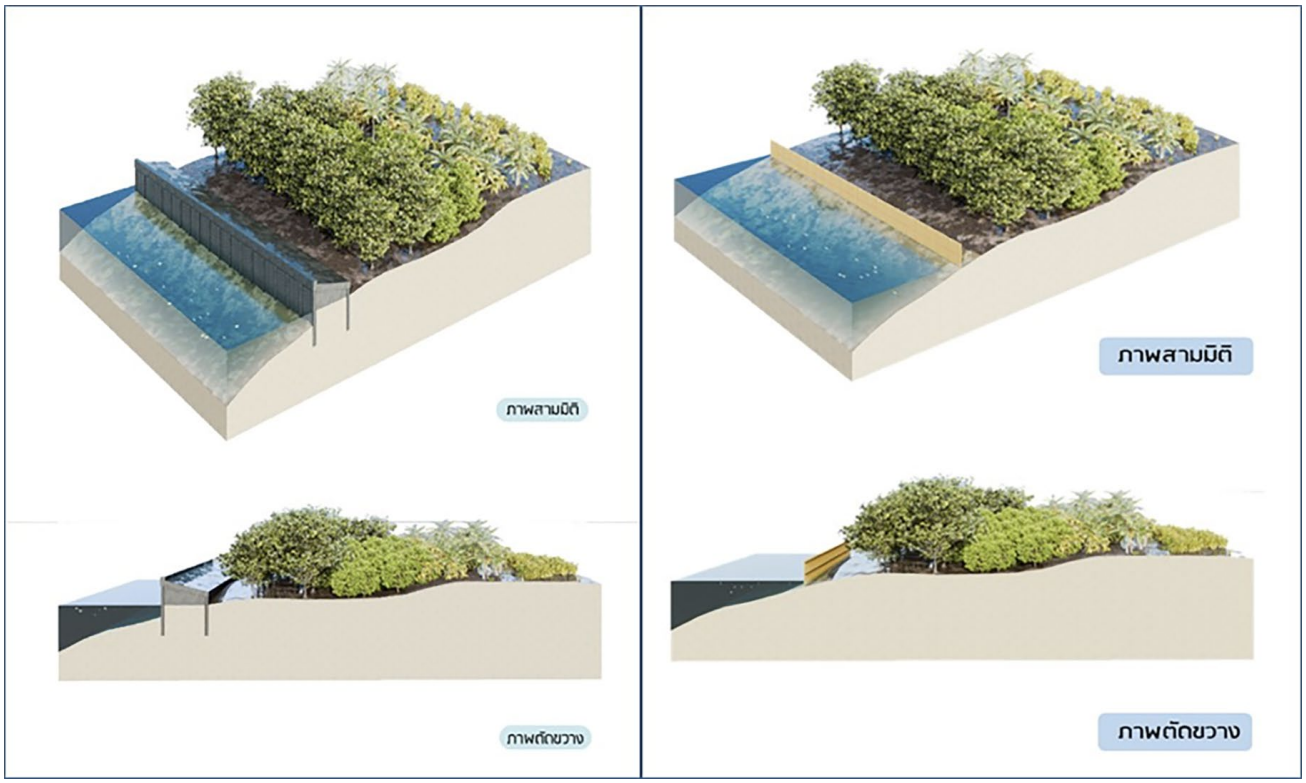

Figure 16 *Protection against riverbank erosion with hard measure and with natural materials*

Fundamental solutions for the erosion include;

1. Soft Measures/ Non-Structural Measures

Soft measures prioritize components of natural environments before structural construction. The measures place an emphasis on ecosystems and natural balance and avoid any mean that may have impacts on the environment. These include regulating land use though out the riverbank, limiting human activities on riverbank, and adopting stringent legal measures such as designation of buffer zones and building set back to reduce risks from human activities.

2. Hard Measures/ Structural Measures

Hard measures focus on building permanent structures (usually with reinforced concrete) to protect against erosion including by building concrete barriers on riverbeds along an entire riverbank. This is a preferred measure for addressing riverbank erosion in almost everywhere in Thailand (including for coastal erosion) as seen in Suphan River, Pran Buri Estuary and other several tributaries as well as in Mekong River. The structural measures are known to alter water flow and sedimentation and replace riverine habitats with concrete structures, generating impacts to terrestrial and aquatic ecosystems, causing biodiversity loss and inducing extinction.

3. Hybrid Measures/ Green-Grey Measures

Hybrid measures combine speed and other advantages of hard measures with application of vegetation as suggested by soft measures. This includes using building materials riddled with holes to grow plants or providing space for vegetation. A number of materials have been developed to this end as described in the box below.

Figure 17 *Nature-based protection against riverbank erosion*
Source: https://www.sepa.org.uk/media/150971/wat_sg_23.pdf

Figure 18 *The use of hard structure to protect riverbank (left) and pre-construction condition (right)*
Source: Thailand Environment Institute, 2022

• **Topographical (natural ecosystems, soil profiles, slope and vegetation cover) and hydrological conditions for adoption of the measure**

In 2008, Kinga Krauze and his colleagues published an article entitled "Aquatic Habitat Rehabilitation, Goals, Constraints and Techniques". A section of the document describes nature-based protection against shoreline erosion as follow.

"Nature-based" implies methods, processes and materials that are consistent to what occurs in natural as far as possible. The article also provides detail elaboration on nature-based protection against riverbank erosion and points out the primary need for comprehensive data collection and analysis in order to reveal accurately causes of the erosion and to determine protection methods that are most consistent to natural process of the ecosystem.

Giving diverse hydrological systems and dynamism of tributaries, riverbanks erosion may derive from several causes and can occurs in both dry and wet seasons. Studies on water suggest that the erosion in dry season derive from the loss of soil moisture in area where vegetation is largely absence. A common nature-based protection against such erosion is to plant species with deep root system and good climate resistance such as Vetiver and other relative species.

Kinga Krauze and his colleagues also introduced an ecosystem rehabilitation concept that can be adopted for protection against riverbank erosion. The concept suggests gathering and analysis of hydrological and other physical data in order to develop alternative solutions for consideration.

Serious erosion occur when large volume of water flow at great speed. The very basic of the solution is to reduce the flow to the level that it have as little impact to riverbank structure as possible. This may initially consist of widening waterway and adding retention ponds to provide more room for water in accompany with provision of water break such as placing rocks on riverbeds and planting aquatic plants, and rehabilitation of ecological systems.

Steep riverbanks, in particularly, are at risk from erosion. Reducing gradient of the ground may partially mitigate erosion. Further landscape modification to flatten riverbanks could, however, cover relatively large ground and may require buying back large area of lands.

• Design and construction details, appropriate materials, material specification, construction considerations and size of working areas

Kinga Krauze and his colleagues recommended several successful methods, including spacing rock placement to facilitate development of root systems of vegetation. The vegetation can then provide new habitats as well as feeding and spawning sites for various fish species including torrent catfishes.

Almost all methods for nature-based protection against riverbank erosion yield desirable outcomes over a relative long period. Attentive and diligent efforts are required before ecosystems can be self-sustained. Nevertheless, they are proven to be the most sustainable and should be adopted at greater extend in the future.

Thailand has been found to favor adopting hard measures for protection against riverbank erosion since they are viewed to be less time consuming in yielding results. Structures built for erosion protection are never durable in long term and recurring cost for repair and rebuilding is hardly economical.

Nature-based protection against riverbank erosion may employ plants with deep root systems including species commonly found on shores such as willow (*Salix tetrasperma* Roxb), Willow-Leaved Water Croton (*Homonoia riparia* Lour), Ficus (*Ficus* sp.) Vetiver (*Chrysopogon zizanioides*), Nipa palm (*Nypa fruticans*) and mangrove apple (*Sonneratia caseolaris*).

• Estimated budget requirement

No specific pricing for nature-based protection against shoreline erosion has been official set. The 2021 cost reference published by Budget Standard Division 1 of Bureau of the Budget (Annex D) can be used as guidance on cost associate with such task. The reference set the price for reforestation at 4,020 THB per 0.16 hectares and identified maintenance cost from the 2nd to 6th year at 1,060 THB per 0.16 hectares while the maintenance cost from the 7th to 10th year was set at 510 THB per 0.16 hectares. The reference further set the seedling price at 2.96 THB per seedling. When placement of hard structures are required in accompany of nature-based protection, the cost can be referred to Section of irrigation, concrete and foundation works of the reference cost. Actual cost may differ between regions due to difference in price of materials.

• Maintenance

Guidance on maintenance of forest buffer strips can be adopted for maintenance of areas used for nature-based protection against bank erosion. Additional maintenance is required for hard structures, including by ensuring minimal water table and making annual repair.

• **Applications**

Synergy of nature-based protection against bank erosion with other measures can be seen in mutual supportiveness with establishment of forest buffer strips in several areas. These include sediment retention, mitigation of nutrient-loading, flood protection, expanding water storage capacity and maintenance of ecosystems. Areas used for nature-based protection against bank erosion do attract various aquatic animals, which can contribute in improvement of local livelihoods.

Caution is also required when adoption this measure from the initial stage. Physical characteristics of sites chosen for the undertaking, including gradient of shore, water flow, torrent and depth of water column, should be thoroughly explored due to their implications to selection of methodology. Steep shore with strong torrent may need hybrid measures since soft measures alone might not be able to address problems that are more pressing. Relevant laws and regulation concerning buffer zones and local rules may also need to be taken into account. Local agencies may carry out nature-based protection against bank erosion with consent and participation of communities when the works are located in and around their residents, providing that the tasks are consistent with relevant laws and regulation and the need to preserve pre-existing ecosystems.

Several communities in Khlong Noi Sub District of Mueang Surat Thani District in Surat Thani Province are located along both banks of Tapee River. Concrete barriers had been built to prevent erosion of the riverbanks but they were broken down after less than 10 year. Instead of requesting repair, member of the communities discussed alternatives for protection against shoreline erosion and used local plants such as, Nipa palms and cork trees, to stabilize riverbanks. The plants did not only yield products that were used locally but also enabled creation of habitats for aquatic animals, including river prawns which generate extra income for the communities.

Photo: Thailand Environment Institute, 2022

Hybrid measure against bank erosion was adopted for a tributary of Tamsui River in Taipei, Taiwan. The measure aimed to address impacts of bank erosion on housing of local residents while ensuring protection of natural ecosystems. ACEBags™ are filled with local soil and placed in Gabion Steel boxes, which are used to form barriers on riverbanks. The bags are riddled with holes in order to facilitate plant growth. The structure remains sturdy this day and are now covered with vegetation, making them more presentable in urban landscape while accommodating local ecosystems and enabling protection of riverbank.

Photo: www.geoace.com, 2009

3.5 Mangrove Reforestation and Restoration

- **Description, objectives and benefits of the measure**

Mangrove forests are ecosystems of global importance. Rapid loss and degradation of mangrove forests have, however, reduced their ecosystem services and crippled their capacity for coastal protection, maintenance of fishery resources and retention of pollutants. In recognition of these problems, several sectors initiated mangrove reforestation on multiple sites and its quickly became one of the most popular conservation activity. Similar to inland reforestation, mangrove reforestation often failed to actually bring back mangrove forests [29] due to the lack of attention on selection of species and planting sites, disconnection with adjacent communities and absence of good maintenance.

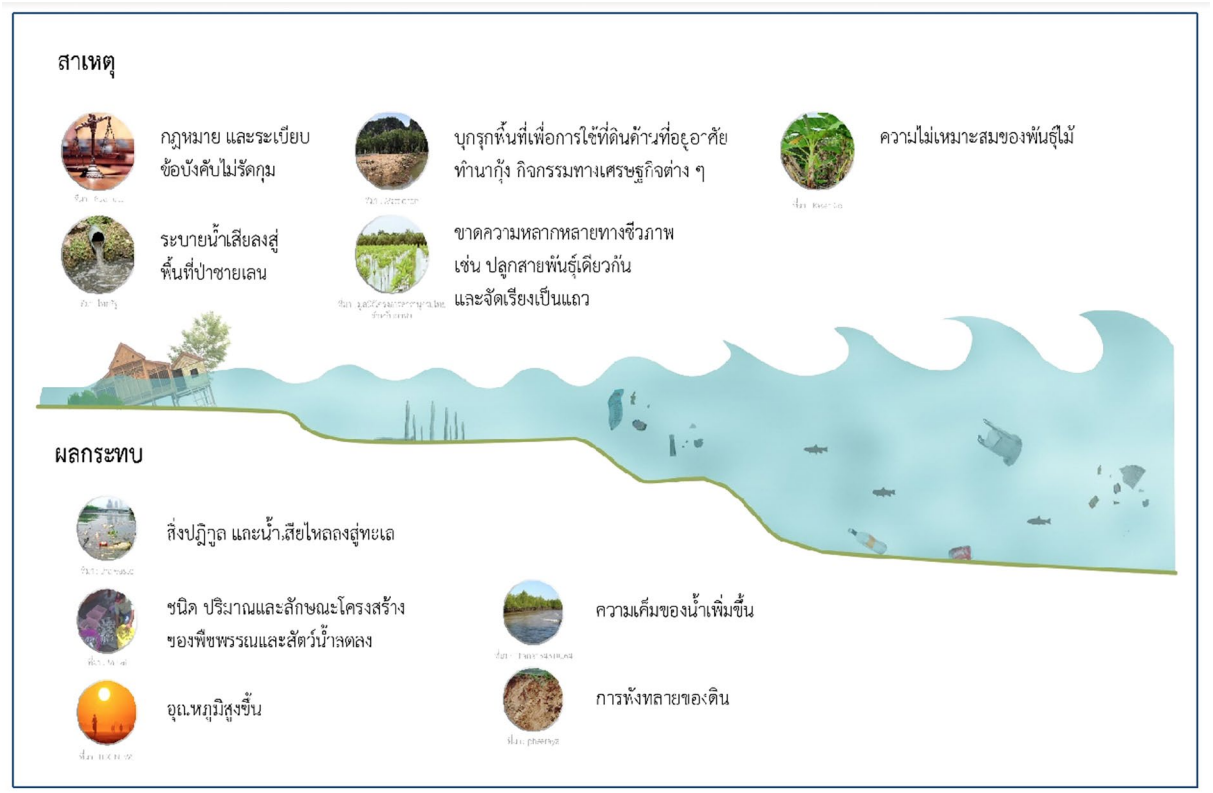

Figure 19 *Causes and impacts of mangrove degradation*

Photo: Thailand Environment Institute

[29] Mangrove for the Future, 2017. Mangrove restoration : To plant or not to plant

Mangrove forests are comprised with multiple plant communities and are an integral part of costal ecosystems in addition to mudflats and sea grass beds. Critical functions of mangrove forests in the ecosystems include provision of nursery sites for aquatic animals, protection against erosion and strong wind, and retention of sediments, nutrients and pollutants. According to Mangrove Conservation Division of Department of Marine and Coastal Resources, approximately 278,400 hectares [30] of mangrove forests remained intact in 2020. Most mangrove forests were loss to encroachment for settlement and shrimp farming.

Mangrove reforestation has long been carried out by state agencies, private sectors and communities. In the past, the activity often used a few selected species such as Red Mangrove (*Rhizophora mucronata* Poir.) and *Rhizophora apiculata*, and planting areas are usually low in biodiversity. However, recently the responsible agency, the Department of Marine and Coastal Resources (DMCR) pays attention to increase diversity of tree species for mangrove reforestation and restoration. It is resulted in more biodiversity in mangrove reforested areas conducted by the DMCR and relevant stakeholders.

Figure 20 *Mangrove reforestation with communities*

Photo: Thailand Environment Institute, 2007

[30] Department of Marine and Coastal Resources. (2022) Guidebook on mangrove forest. Division of Mangrove Forest Resource Conservation. Department of Marine and Coastal Resources, Bangkok

• **Topographical (natural ecosystems, soil profiles, slope and vegetation cover) and hydrological conditions for adoption of the measure**

Natural mangrove forests have distinct distributions of species due to their tolerance and adaptability to different levels of salinity and other environmental conditions. The forests established themselves with pioneer species and thrived on successions of species that followed. Planting anything but pioneer species would not only prevent the species succession and may also disrupt natural reproduction process.

Mangrove reforestation should employ diverse arrays of species and carefully identify suitable planting sites for each species. Doing so would ensure more diversity in vegetation and enhancing ecosystem services of the forests.

Planning for mangrove reforestation requires identification of plant community structures. This include species richness and composition, size of plants and their canopies, plant density, plant succession and spatial distribution of vegetation.

Structure of mangrove forests is characterized by zoning of species where a single or a few dominant species can be found in a particular zone, usually in parallel with shoreline. Lugo and Snedaker (1974) [31] used the structure as the basis in classifying mangrove forests into (1) fringe forests, (2) riverine forests, (3) overwash forests, (4) basin forests and (5) dwarf forests. Lower canopies should also be taken into account when elaborating on mangrove structures.

[31] Lugo, A.E. and S.C. Snedaker (1974). The ecology of mangroves. Annual Reviews of Ecology and Systematics 5: 39-64.

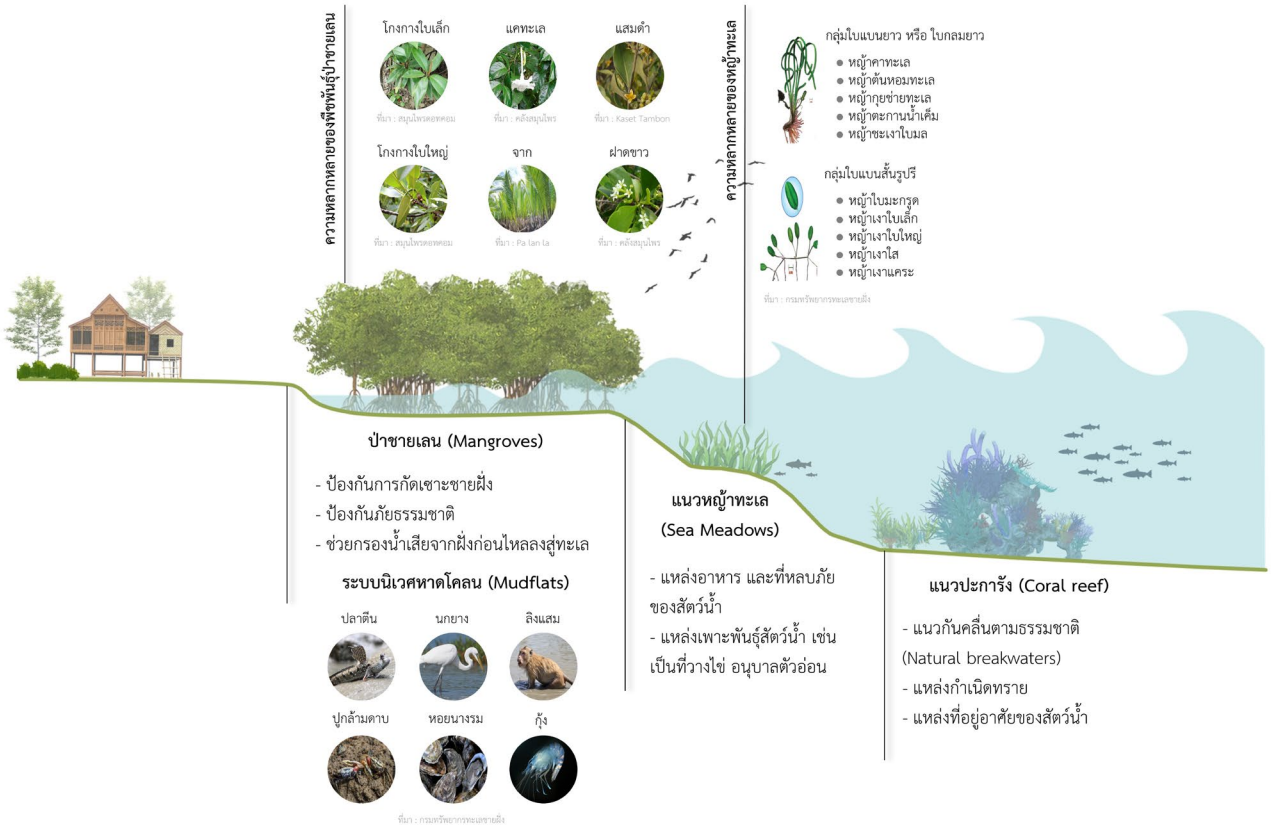

Figure 21 *Mangrove reforestation and restoration*

• Design and construction details, appropriate materials, material specification, construction considerations and size of working areas

Mangrove forests are comprised with terrestrial and aquatic plant species. Terrestrial species such as trees, shrubs, herbs, palms, epiphytes and parasite plants are the main component of mangrove forests while aquatic species, such also seaweeds, occupies water body. This handbook pays attention only to terrestrial plants used for mangrove reforestation and restoration. Selection of the species is based on their tolerance to salinity and their compatibility to clay soil as shown in Table 4

Table 4 *Certain ecological characteristic of mangrove species in Thailand (saline tolerance is range from high (+++++) to low (+) and ? makes where data is unavailable)*

Species	Shade tolerance	Not shade tolerance	Saline tolerance	Mud level
Rhizophora apiculata		+	+++	Low, Medium
Rhizophora mucronata		+	++	Low, Medium
Dolichandrone spathacea	+		+?	High
Nypa fruticans	+		+	Low, Medium
Heritiera sp.	+		?	Medium, High
Aglaia cucullata	+		+?	Medium, High
Xylocarpus granatum	+		+++	Medium, High
Xylocarpus moluccensis	+		+++	Medium, High
Excoecaria agallocha	+		+++	Medium, High
Cynometra iripa	+		++	High
Bruguiera cylindrica	+		++	Medium, High
Bruguiera parviflora		+	++	Medium, High
Pemphis acidula		+	?	High

Table 4 *Certain ecological characteristic of mangrove species in Thailand (saline tolerance is range from high (+++++) to low (+) and ? makes where data is unavailable)*

พันธุ์ไม้	ทนร่ม	ไม่ทนร่ม	ทนทานต่อความเค็ม	ระดับพื้นที่เลน
Aegialitis rotundifolia		+	++++?	Medium, High
Ceriops decandra	+		++	Medium, High
Ceriops tagal		+	+++	Medium, High
Lumnitzera racemosa		+	++++	High
Lumnitzera littorea		+	++++	High
Bruguiera sexangula	+		+	Medium, High
Bruguiera hainesii	?		++?	Medium, High
Bruguiera gymnorrhiza	+		+++	Medium, High
Cynometra ramiflora	+		++?	High
Kandelia candel		+	+++?	Medium, High
Sonneratia caseolaris		+	+	Low, Medium
Sonneratia ovata		+	+++?	Medium, High
Sonneratia alba		+	+++	Low, Medium

Table 4 *Certain ecological characteristic of mangrove species in Thailand (saline tolerance is range from high (+++++) to low (+) and ? makes where data is unavailable)*

พันธุ์ไม้	ทนร่ม	ไม่ทนร่ม	ทนทานต่อความเค็ม	ระดับพื้นที่เลน
Sonneratia griffithii		?	+++?	Medium, High
Aegiceras corniculatum		+	+++	Low, Medium
Avicennia lanata		+	+++?	Medium, High
Avicennia alba		+	+++?	Low, Medium, High
Avicennia officinalis		+	+++?	Low, Medium, High
Avicennia marina		+	+++++	Low, Medium, High
Heritiera littoralis	+		++	Medium, High
Acanthus sp.	+		++	Low, Medium, High
Scyphiphora hydrophyllacea	?		?	Medium, High

Source:: Sarayuth and Roongsuriya (2011) [32]

[32] Sarayuth Boonyavejchewin and Roongsuriya Buasalee (2011) Mangrove Ecosystems and Vegetation, Department of National Parks, Wildlife and Plant Conservation, Bangkok.

Mangroves can directly grow from their seeds or pots or be planted with seedlings. Species with long pods such as Red Mangrove, *Rhizophora apiculata*, Narrow-Leaved Kandelia and Tagal Mangrove, can be readily planted in the ground. Although this method is more convenient and more cost-effective (lower cost of transport), extra care must be taken to ensure that only ripen pods of good conditions (i.e. undamaged by insects) are used in planting.

Mangrove seedlings often grow faster and have better survival rate than plants grown from seeds or pods. Particularly attention is, however, required to prevent any damage to seedling roots during germination while seedlings are comparatively heavier to transport and might not be suitable for some areas.

Some mangrove species can be planted with their seeds. These include Cannonball Mangrove (*Xylocarpus granatum*), Cedar Mangrove (*Xylocarpus moluccensis*), Api-api putih (*Avicennia alba*), Grey Mangrove (*Avicennia marina*), White-flowered Black Mangrove (*Lumnitzera racemosa*), Red-flowered Black Mangrove (*Lumnitzera littorea*), Looking-Glass Tree (*Heritiera Littoralis*) and Borneo Teak (*Intsia bijuga*). Since mangrove seeds can be easily flooded away in nature, seedling has proven to be a better option.

Spacing in planting mangroves are usually around 1 x1 or 1.5 x 1.5 meters [33]. Mangrove can be planted closer for timber harvest. Planting mangroves to protect against strong wind and wave or to provide nursery sites for aquatic animal could have spacing of 0.75 x 0.75 meters. Sticks should be used to hold seedlings in place.

- **Estimated budget requirement**

The 2021 pricing reference published by Budget Standard Division 1 of Bureau of the Budget (Annex D) set the price for Mangrove reforestation at 6,580 THB per 0.16 hectares and identified maintenance cost at 1,190 THB per 0.16 hectares. The reference also set a price for maintaining mangrove seed production at 820 THB per 0.16 hectares. The reference can be used by local agencies and communities in estimating cost of the operation and for requesting financial aids from private sectors and other donors when sufficient funding is not available.

[33] Mangrove Conservation Office (2011), Handbook on Mangrove Seedlings and Planting, Department of Marine and Coastal Resources, Bangkok.

• **Maintenance**

To ensure better survival and growth rate, the following actions must be taken.

1. Removing weeds when seedlings receive sufficient supply of rainfall in order to avoid competition for water. Weeds should also be removed before they outgrow seedlings. Their removal must be carried out with physical labor only and use of chemicals must be avoid in order to prevent endangering aquatic animals and ecosystems.

2. Inspecting survival rate after removing weeds in order to determine the need for replanting. Random survey can be use providing that the sample size is no less than 5% of the total area. Survival percentage is calculated by comparing number of survived plants to the total numbers of planted seedlings. The survey can also be used to measure plant growth.

3. Replanting is carried out when the survival rate is found to be less than 80%. Replanting should be carried as soon as possible and be completed within the same season of the initial planting. Seedlings of the same generation should be used in replanting since they are more likely to have relatively similar growth rate to that of the initial seedlings.

• **Applications**

Synergy of mangrove reforestation and restoration with other measures can be observed from the benefits from mangrove ecosystems in attracting aquatic life, supplying timbers, honey, fishes and other natural products and providing ecosystem services such as protection against erosion, retention of pollutants, enabling carbon sequestration and maintaining fishery resources. The measure also establishes linkage between mangrove forests and other ecosystems such as sea grass beds and coral reefs and is consistent with the technical objective of nature-based mangrove restoration in regaining richness of the mangrove forests [34].

Caution is also required when adoption this measure since most mangrove forests in the country are under supervision of Department of Marine and Coastal Resources. When community-based mangrove reforestation and restoration are allowed to be carried out by relevant laws and regulations, selection of species must compatible to planting sites and species diversity should taken into consideration in order to ensure that planted mangroves resemble their natural conditions as far as possible. Besides, to conduct mangrove reforestation in new area, force of wave and current are need to be considered. To ensure that the new planted seedlings will not damaged by current and strong wave, bamboo stake is need to be attached with seedling. The stake will support the seedling to tolerate to the force of wave and current. Mangrove reforestation and restoration can be conducted along with bamboo fence installation to prevent coastal erosion as it is widely practiced in the Thai Gulf.

[34] Mangrove for the Future, 2017. Mangrove restoration : To plant or not to plant

Community of Prednai village, Huangnamkhao sub-district, Muang district, Trat province conducted mangrove reforestation and restoration in the area of former shrimp farms. Community members defined restoration, conservation and utilization zones. The mangrove reforestation was conducted by taken salinity level of the area into account. Ecosystem restoration through participatory approach is the key success factor. The community started their activity from 1998 and the mangrove forest under the community management is rich in biodiversity and is their main source for collecting foods.

Source: Thailand Environment Institute, 2022

3.6 Coastal Wetland Restoration and Management

• Description, objectives and benefits of the measure

In 2008, Richard T. T. Forman wrote a book entitled "Urban Regions; Ecology and Planning; Beyond the City" for publishing by Cambridge University Press. The publication emphasizes urban development with knowledge and understanding of ecosystems. The book also classifies aquatic ecosystems into freshwater ecosystems and marine and coastal ecosystems.

Freshwater ecosystems consist of rivers, creeks, lakes, wetlands and other freshwater reservoirs of every shape and size. The ecosystems are subjected to different hydrological cycle to that of marine and coastal ecosystems, which are comprised of coastal wetlands, estuaries, open seas and several others.

Brackish water ecosystem can be found at the edge of fresh water and salt water, it usually occurs around the estuarine, which thick layers of mud and is a habitat of low salt tolerance mangrove species. In some areas, brackish water ecosystem is the large waterbody with the regularly flow of fresh and salt waters, such as the middle part of Songkla lake. Brackish water ecosystem is an ecotone that connects fresh water ecosystem with that of salt water.

Saltwater Ecology or marine ecosystem comprised of several ecosystem that largely depend on saltwater to survive, such as seagrass ecosystem of coral reef ecosystem.

Figure 22 *Coastal wetland restoration and management*
Source: https://cdnsciencepub.com/doi/10.1139/anc-2017-0001

Estuaries and other coastal areas are mostly occupied by human settlements, particularly ever-growing and densely populated cities and metropolitans. These urban settlements have extensive impacts on natural ecosystems nearby and even those located further away. Restoration and management of coastal wetlands area therefore different from those for inland wetlands.

Richard T. T. Forman classified coastal wetlands into four categories as follow;

1. Rocky coastlines comprises mostly of rocks and often feature unique landscapes shaped by long period of erosion.

2. Sandy coastlines are mostly covered with sand of 0.063-2 millimeters in size and include beaches. Their topography signifies how wind, wave as other natural processes in coastal areas enable accumulation of sand on coastline.

3. Coastal wetlands such as Don Hoi Lot Mudflat in Samut Songkhram Province, Songkhla lake, lagoons in Prachuap Khiri Khan and Rayong Provinces were enlisted in Thailand 's national wetland inventory by Ministry of Natural Resources and Environment.

4. Bays and harbours are a combination of natural and man-made environments and are thus most affected by human activities.

Asides from Richard T. T. Forman's classification, there is an interesting ecosystem, that is mudflat. Mudflat mostly is a gentle slope area, which suitable for silt to deposit more than other types of seabed. Besides, mudflat consists of mangrove species, which their roots enhance sedimentation with high nutrient. It is resulted in abundant of aquatic life in mudflat areas. [35]

Estuary bays are another ecosystem of critical importance. The ecosystems retain nutrient discharged from inland, foster high level of biodiversity, provide food for human and several aquatic animals and accommodate spawning of benthos the like of mollusc species. Notable estuary bays in Thailand include Bandon Bay in Surat Thani Province, Pattani Bay and estuaries along the shoreline of the Andaman Sea.

Figure 23 *Coastal wetland, Ranong estuarine*

Source: Thailand Environment Institute, 2022

[35] กรมทรัพยากรทางทะเลและชายฝั่ง https://www.dmcr.go.th/detailAll/3742/nws/22

• **Topographical (natural ecosystems, soil profiles, slope and vegetation cover) and hydrological conditions for adoption of the measure**

Coastal ecosystems are highly dynamic and under influence of more fluctuate climate and other environmental conditions than those of inland ecosystems. These rapid changes including daily tides, change in sea currents, monsoons, cyclones and tsunami are capable of altering the ecosystems within a brief period of time.

The immediate targets for coastal wetland restoration are areas affected by urbanization, particularly those that are of economic importance such as port, industrial and tourist towns. Impacts of these towns on the ecosystems often depend on their size and their environmental management.

Richard T. T. Forman proposed setting up green spaces for restoration of water resources and ecosystems in coastal wetlands. The green spaces serve as a buffer zone to protect natural ecosystems from human activities. He was convinced that natural ecosystems are capable to making recovery without human intervention and humans are only required to vacate vulnerable habitats of the ecosystems.

Setting up green spaces in towns with high level of economic activity is often difficult due to high price of real estates. It usually a challenge for states agencies to make adequate compensation to land owners when attempt to converts their lands into green spaces. Nevertheless, establishing green space remains one of the most sustainable solution available.

Rehabilitation of the physical structure of river habitats recommended by Kinza Krauze and his colleagues can be adopted to address coastal wetland ecosystems that suffer from slow or difficult recovery. The recommendations consists of çmaintaining hydraulic connection and establishing stream meanders.

Example of the recommended physical alteration is the re-meandering of waterway in Europe. Such action has increased water body, expanded habitats and conserved biodiversity.

Figure 24 *Morava River in Central Europe before (left) and after (right) re-meandering*
Source: http://riverwatch.eu/en/the-morava-anniversary-project-2014

Natural meanders can be found in several of Thailand's river basins. Some of these wetlands such as lagoons on the coasts of the Gulf of Thailand and the Andaman Sea are at risk from economic activities, including tourist.

• Design and construction details, appropriate materials, material specification, construction considerations and size of working areas

The primary objectives of measures for coastal wetland restoration and management are to mitigate climate change impacts such as the rise in sea level rise, intense wave and flooding as well as to reduce habitat loss by erosion. Notable areas-based measures includes;

1. Building and strengthening sand dunes to mitigate impacts from storm surge in accompany with other measures such as building strips of grassland and nature based barriers (with available wood materials) to protect against strong wave.

2. Restoring and managing drainage systems in coastal wetlands in order to direct discharge to new flood protection lines.

3. Landscaping beaches and other areas with sandy surface in order to mitigate erosion.

The extend of ecologically and environmentally sound utilization of wetlands must be taken into consideration in management of coastal wetlands. In 2021, Wetland Management Planning Section of Land Use Policy Planning Division in Land Development Department (Ministry of Agriculture and Cooperatives) developed a plan for the management of a Ramsar Site "Kaper Estuary - Laem Son National Park -Kraburi Estuary (see Annex D). The plan can be used as guidance in planning for management of other coastal wetlands.

As the coastal wetland restoration and management is a measure to be applied at landscape level and is comprised of several measures integrated together according to the context of each area. Practitioners aim to apply this measure need to find more information and details of sub-measures to be implemented according to the area's context. The planned measure is need to be in line with relevant laws and regulations. More information and details can be found in the website of the Department of Marine and Coastal Resource, which is overseeing coastal areas. https://www.dmcr.go.th/home

• Estimated budget requirement

Since wetland restoration largely employs natural recovery, most interventions would concern controlling or regulating human activities such as urban encroachment, discharge of wastewater and excessive tourist activities. Funding may be need for dredging and other restoration of natural waterway around coastal wetlands. The cost for this works can be referred to the 2021 pricing reference published by Budget Standard Division 1 of Bureau of the Budget (Annex D) under the heading on irrigation construction and coastline dredging. The costs may vary with fuel price at any given time.

• Maintenance

As mentioned above, coastal wetland restoration generally consists of controlling or regulating human activities that may have impacts on the ecosystems. Adoption and enforcement of town planning and other relevant laws are thus the focus of the intervention in order to prevent damages from wastewater discharge, encroachment, etc.

- **Applications**

Synergy of coastal wetland restoration and management with other measures can be seen from their contribution to pollutant retention, protection against coastal erosion and storm surge, enhancing carbon sequestration, supporting freshwater and marine fishery, enabling connection with other ecosystems and providing habitats for coastal species.

Caution is also required when adoption this measure since coordination with relevant agencies including Department of Marine and Coastal Resources, the Harbor Department and local administrations might be required when determining wetland use. This is to ensure sustainability of coastal wetland restoration and management in longer term.

Louisiana wetland restoration and management were carried by National Oceanic and Atmospheric Administration (NOAA) with adoption of Coastal Wetlands Planning, Protection and Restoration Act. The program consisted of 40 smaller projects and was successful in rehabilitating over 5,056 hectares of coastal areas. These smaller projects were comprised of beach protection, water flow restoration, sediment retention and coastline stabilization.

Source: National Oceanic and Atmospheric Administration (NOAA)
https://www.fisheries.noaa.gov

Table 5 Contributions of selected EbA measures on ecosystem services and their synergy with other measures (Adapted from GIZ et al, 2020 and NWRM, 2014) [36, 37]

Measure	Description	Ecosystem services and synergy with other measures											
		Provisioning services		Regulating services					Cultural services		Supporting services		
		Water storage/ reducing impacts from drought	Increase fish stock	Conservation of biodiversity	Groundwater control	Mitigation of risk from flooding	Reduce erosion/ sedimentation	Decrease water pollution	Recreation area	Aesthetic and cultural value	Spawning and nursing areas for aquatic life	Enhance food security	Synergy with other measures
Reforestation and forest restoration	Reforestation and forest restoration contribute to quality and quantity of water. Through water cycle, forest discharge water to midstream and downstream areas, which mitigate drought. Reforestation and forest restoration in steep slope areas decrease risk of landslide.												

[36] GIZ, UNEP-WCMC and FEBA (2020) Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bonn, Germany

[37] NWRM. Natural Water Retention Measures. European Commission. 2014. http://nwrm.eu/

Table 5 Contributions of selected EbA measures on ecosystem services and their synergy with other measures (Adapted from GIZ et al, 2020 and NWRM, 2014)

Measure	Description	Ecosystem services and synergy with other measures											
		Provisioning services		Regulating services							Supporting services		
		Water storage/ reducing impacts from drought	Increase fish stock	Conservation of biodiversity	Groundwater control	Mitigation of risk from flooding	Reduce erosion/ sedimentation	Decrease water pollution	Recreation area	Aesthetic and cultural value	Spawning and nursing areas for aquatic life	Enhance food security	Synergy with other measures
Installing forest buffer strip	Installing forest buffer strip helps to control water flow and water quality. It traps exceed nutrients from settlement areas and farmlands. Vegetation along waterbody reduce force of water flow and trap sediments flow to other water sources.												
Construction of retention pond/ Oxbow lake restoration	Construction of retention pond helps to retard water and trap sediment during flooding season as well as increase biodiversity of vegetation and aquatic life. Oxbow lake restoration helps to connect oxbow with main river, enhance water flow, store water during dry season and help to retard water during flood.												

Colour code High Medium Low Irrelevant

Table 5 Contributions of selected EbA measures on ecosystem services and their synergy with other measures (Adapted from GIZ et al, 2020 and NWRM, 2014)

Measure	Description	Ecosystem services and synergy with other measures											
		Provisioning services		Regulating services							Supporting services		
		Water storage/ reducing impacts from drought	Increase fish stock	Conservation of biodiversity	Groundwater control	Mitigation of risk from flooding	Reduce erosion/ sedimentation	Decrease water pollution	Recreation area	Aesthetic and cultural value	Spawning and nursing areas for aquatic life	Enhance food security	Synergy with other measures
Natural bank erosion control	Natural bank erosion control focuses on application of vegetation to stabilize riverbank and restoring ecosystem along the bank to enhance natural flow of river.												
Mangrove reforestation and restoration	Mangrove forest reduces waves' height and force, protects coastal areas, reduce coastal erosion, traps sediments from upstream rivers, habitat of aquatic life, and increases biodiversity. Mangrove restoration can be done by letting the mangrove forest restore and regenerate naturally, while mangrove reforestation should be applied by using various species and consider original forest structure in reforestation activity.												

Table 5 Contributions of selected EbA measures on ecosystem services and their synergy with other measures (Adapted from GIZ et al, 2020 and NWRM, 2014)

Measure	Description	Ecosystem services and synergy with other measures											
		Provisioning services		Regulating services							Supporting services		
		Water storage/ reducing impacts from drought	Increase fish stock	Conservation of biodiversity	Groundwater control	Mitigation of risk from flooding	Reduce erosion/ sedimentation	Decrease water pollution	Recreation area	Aesthetic and cultural value	Spawning and nursing areas for aquatic life	Enhance food security	Synergy with other measures
Coastal Wetland Restoration and Management	Coastal wetland comprised of various ecosystems, such as mangrove forests, beach forests, seagrass beds, coral reefs and mud beach. Those areas help to reduce impacts from storms. Coastal wetland restoration and management can be done by protect those areas and let them restore naturally as well as remove all dikes and hard infrastructures and consider the importance of ecosystem.												

Colour code High Medium Low Irrelevant

Table 6 *Guideline of practical and applicable monitoring and evaluation methods by community after applying EbA measures (Adapted from GIZ et al, 2020)* [38]

Measure	Description	Aspects of changes and samples of criteria for monitoring and evaluation				
		Biodiversity	**Physical**	**Water quantity and quality**	**Food security**	**Others**
Reforestation and forest restoration	Reforestation and forest restoration contribute to quality and quantity of water. Through water cycle, forest discharge water to midstream and downstream areas, which mitigate drought. Reforestation and forest restoration in steep slope areas decrease risk of landslide.	Number of plant and animal species in the area that applied EbA measure increased.	Number of landslide in the area that applied EbA measure decreased.	Water source maintain water all year round compared to before applying reforestation and forest restoration measure.	Community surround the reforested or forest restoration area can harvest more foods.	Community gains more recreation areas.
Installing forest buffer strip	Installing forest buffer strip helps to control water flow and water quality. It traps exceed nutrients from settlement areas and farmlands. Vegetation along waterbody reduce force of water flow and trap sediments flow to other water sources.	Number of plant and aquatic species in the area that applied EbA measure increased.	Area damaged by flash flood decreased	• Amount of sediment flows to other water sources decreased. • Amount of exceed nutrients from settlement areas and farmlands flow into water sources decreased.	Community surround the forest buffer strip installed area can harvest more foods.	Community gains more recreation areas.

[38] GIZ, UNEP-WCMC and FEBA (2020) Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bonn, Germany

Table 6 *Guideline of practical and applicable monitoring and evaluation methods by community after applying EbA measures (Adapted from GIZ et al, 2020)*

Measure	Description	Aspects of changes and samples of criteria for monitoring and evaluation				
		Biodiversity	Physical	Water quantity and quality	Food security	Others
Construction of retention pond/ Oxbow lake restoration	Construction of retention pond helps to retard water and trap sediment during flooding season as well as increase biodiversity of vegetation and aquatic life. Oxbow lake restoration helps to connect oxbow with main river, enhance water flow, store water during dry season and help to retard water during flood.	Number of plant and aquatic species in the area that applied EbA measure increased.	Areas damaged by flood and drought are decreased.	• Amount of water stored for dry season is increased. • Quality of water in oxbow lake is improved after reconnected with main river.	• Surrounding communities use water from retention pond for farming in longer period and be able to produce more foods. • More sources for fishing.	Community gains more recreation areas.
Natural bank erosion control	Natural bank erosion control focuses on application of vegetation to stabilize riverbank and restoring ecosystem along the bank to enhance natural flow of river.	Number of plant and aquatic species in the area that applied EbA measure increased.	Riverbank damaged by erosion are decreased.	Quality of water along riverbank is improved	• Surrounding communities can harvest more vegetation for foods. • Vegetation planted to stabilize riverbank attract more aquatic life resulting in more foods for community.	Natural riverbank gives aesthetic scenery, which is attracting more tourists.

Table 6 *Guideline of practical and applicable monitoring and evaluation methods by community after applying EbA measures (Adapted from GIZ et al, 2020)*

Measure	Description	Aspects of changes and samples of criteria for monitoring and evaluation				
		Biodiversity	Physical	Water quantity and quality	Food security	Others
Mangrove reforestation and restoration	Mangrove forest reduces waves' height and force, protects coastal areas, reduce coastal erosion, traps sediments from upstream rivers, habitat of aquatic life, and increases biodiversity. Mangrove restoration can be done by letting the mangrove forest restore and regenerate naturally, while mangrove reforestation should be applied by using various species and consider original forest structure in reforestation activity.	•Number of plant and aquatic species in the area that applied EbA measure increased. • Migratory birds in the areas of mangrove reforestation and restoration are increased.	Coastal areas damaged by erosion are decreased.	Amount of sediment flows to the sea is decreased.	• Spawning and nursery areas for aquatic life are increased. • Sources of foods for community are increased.	Natural recreation areas are increased.
Coastal Wetland Restoration and Management	Coastal wetland comprised of various ecosystems, such as mangrove forests, beach forests, seagrass beds, coral reefs and mud beach. Those areas help to reduce impacts from storms. Coastal wetland restoration and management can be done by protect those areas and let them restore naturally as well as remove all dikes and hard infrastructures and consider the importance of ecosystem.	• Number of plant and aquatic species in the area that applied EbA measure increased. • Migratory birds in the areas of the restored coastal wetland are increased.	• Areas damaged by storm surge are decreased. • Coastal areas damaged by erosion are decreased.	• Amount of polluted water to discharge to the sea is decreased. • Amount of water preserve to maintain ecosystem is increased.	• Spawning and nursery areas for aquatic life are increased. • Sources of foods for community are increased.	Natural recreation areas are increased.

Table 5 presented benefits of each EbA measure for ecosystem services, besides, the synergy between each measure also presented. Based on the studies of GIZ, UNEP-WCMC and FEBA (2020) and Natural Water Retention Measures (2014), level of contribution of each EbA measure toward ecosystem services was determined to High, Medium, Low, and irrelevant.

Practical and applicable monitoring and evaluation methods for changes after EbA measures application that can be applied by community are presented in Table 5. In case community members wanted to know more of some parameters such as changes in ground water level, amount of sediment, exceed nutrients from settlement areas or farmlands or migrant birds identification and counting method, relevant agencies such as Department of Groundwater Resources, Pollutions Control Department, Department of Environmental Quality Promotion, Department of Agriculture, Office Of Natural Resources and Environmental Policy and Planning or Department of Marine and Coastal Resources are ready to support.

3.7 Application of Ecosystem-based Adaptation

Applying ecosystem-based adaptation does not only require knowledge and understanding on ecosystems but also need inputs from other disciplines and adoption of interrelated measures. This would consist of carrying out local works while coordinating with higher authorities who decide on overall scope and nature of climate change adaptation.

Given that natural ecosystems have a carrying capacity to accommodate human activities, ecosystem approach and climate change adaptation need to be adopted to regulate such activities.

Richard T. T. Forman wrote about critical measures for regulating human activities in his book entitles "Urban Regions; Ecology and Planning beyond the City". These measures generally focus on controlling land use at urban, regional and basin levels in accompany with other supporting measures such as designation of shoreline greenbelts, allocation of open space and setting building conditions that may include regulating building material. Overall development pattern of entire waterway may also have impacts to ecosystems and environments in certain areas.

Synergy can be forged with other measures such as those related to awareness building. Stakeholders must be made aware of benefits from adoption of ecosystem-based adaptation and locals should be motivated to participate in maintaining their reservoirs. Policy-makers and administrators at all levels should also be convinced to commit efforts for climate change mitigation so that cooperation can be achieved and maintained in longer run.

Technical caution in applying measures in this handbook mostly concerns poor data gathering, insufficient information and imprecise analysis of ecosystems. These may distort findings and lead to ineffective or even detrimental management of soil and water resources. Extra care must be taken when address problems that are not easily rectifiable such population decline, biodiversity loss and extinction risk.

Further caution should be taken when using the measures to adopt policies and practices. Prioritization of ecosystems based on economic and other human interests may exclude ecosystem values that cannot be measured in economic terms and result in loss of species and ecosystems.

There are case studies of Ecosystem-based Adaptation in other country. Notable works in pioneering period include restoration of Kinneret Lake in Israel during 1970's. The most frequently mentioned ecosystem-based adaptation is the flood prevention in Munich, Germany. To mitigate flooding, concrete flood barriers were removed, waterways were widened and ecosystems on both banks were rehabilitated. The measures did not only protect the city from flooding but also improved environmental conditions along entire waterways and increase diversity and population of fish species. Factors behind this successful project include the determination of governmental agencies to apply EbA measure and the support from all sectors in the society. Measures from this case study were later adopted and build on by other countries include Taiwan and South Korea.

Figure 25 *Isar River, Munic, Germany after extend riverbed and ecosystem restoration*
Source: https://panorama.solutions, 2017

Chapter 4

Conclusion

Richard T.T. Forman wrote in the final chapter and conclusion of his book "Urban Regions; Ecology and Planning beyond the City" on the big picture of ecological approach where holistic assessment and analysis are required for inseparable components of ecosystems. He noted that all are interconnected as flora cannot persist in absolute absence of fauna and vice versa while creeks and other tributaries cannot be viewed as autonomous entities to basins they are located. Some are more intimately relied on each other and a collapse of one component may trigger loss of others.

Given that almost all environmental problems derived from human activities, increase in human population and urbanization continue to worsen the problems and depleted soil, water and other natural resources. Recognizing the problems, the global community agreed to the need for regulating human activities as defined by the term "sustainable development". The term signifies commitment of countries and others in international community as later elaborated in 17 Sustainable Development Goals (SDGs) where biodiversity and ecosystems are included in at least one goal.

Adopting ecosystem approach and climate change adaptation is a major contribution to meeting the SDGs. Ecosystem restoration mitigates climate change impacts by increasing carbon sequestration, reducing global temperature and mitigating severity of natural disasters while strengthen food security for ever increasing global population.

Applying Ecosystem-based Approaches (EbA) for water resource management contributes to several Sustainable Development Goals [39]. Fore instance, Goal 2, Zero Hunger as several measures help to increase biodiversity of plant and aquatic life, which are foods for local communities, and some measures help to store water in dry season which helps communities to produce more foods to increase food security and decrease famine. Some EbA measures such as installation of forest buffer strips helps to trap sediments and exceed nutrients from communities and farmlands, resulted in helping clean water that safe for health, which is the Goal 6, Clean Water and Sanitation. Reforestation and forest restoration both land forest or mangrove forest help to mitigate impacts of climate change due to it increases carbon sequestration and decrease global temperature, which is the Goal 13, Climate Action. Furthermore, all EbA measures compiled in the CoP support Goal 14, Life below Water by enhance water cycle and good water quality, which is important for all aquatic life. For the Goal 15, Life on Land, reforestation and forest restoration increase biodiversity and natural habitats. Most importantly, collaboration among relevant stakeholders in water sector to apply EbA in water resource management contribute to Goal 17, Partnerships for the Goals. [40]

4.1 Promoting the Application of Ecosystem-based Adaptation (EbA)

As previously mentioned, ecosystem-based adaptation is a novel concept in Thailand. Most in Thai society are indifferent and disinterest to or without adequate knowledge on ecology and only a few select groups of the populace are enthusiastic about the sake of ecosystems. More importantly, very few local experts have knowledge and skill to effective adopt ecosystem-based adaptation in the country. Cooperation from and coordination between all concerned sector are required in enabling adoption of measures for the ecosystem-based adaptation.

Mainstreaming ecosystem-based adaptation should take into consideration the following guidance;

1. Target groups should be divided into (1) private sector and state agencies, including local administrations, (2) private operators that use water resources and (3) local populations (including the youth) who should gain better knowledge on their water resources and ecosystems.

2. Simplifying messages on ecosystems and tailoring them to target groups and their setting while avoiding use of technical terms.

3. Tailoring adaptation measures to each target group and delivering them in video or publications.

4. Organizing seminars and field trainings on adoption of the adaptation measures and conducting pilot projects to demonstrate the adoption. At least one pilot project should be implemented in a river basins and the project period should be no less than 5 years.

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[39] FEBA (Friends of Ecosystem-based Adaptation). (2022). Ecosystembased Adaptation and the successful implementation and achievement of the Sustainable Development Goals. IUCN, Gland, Switzerland. 40 pp. https://doi.org/10.5281/zenodo.6789086

[40] https://thailand.un.org/th/sdgs

5. Agencies relevant to water resource management at local level should integrate their works and focus on participatory approach as well as engage local stakeholders to plan and solve problems related to water resources.

6. Monitoring and evaluating adoption of the adaptation measures in order to improve the Code of Practices and meet the target for adoption of ecosystem approach.

4.2 Effective Water Resources Management

Most technical publications agree that water is a scarce resource. It scarcity was caused by the rise in global population and economic development and further worsened by global warming and climate change. Several countries in Africa reportedly experienced severe drought when rainfall was absence for 4 years. UNICEF expected that a half of global population or around 4 billion will suffer from water shortage by the year 2025 and the problem may lead to famine.

Effective water resources management was frequented mentioned and recommended in seminars and technical papers. Although the actual management varies in accordance to different requirements and environmental settings, water resources management generally consists of flexible allocation of water on annual basis including by saving sufficient water in a year of low precipitation.

The general practices of water resources management in Thailand is to allocate water for urban consumption, industrial production and agricultural use while securing adequate supply for maintenance of natural ecosystems. The priority for the allocation is to meet the consumption demand, followed by the need of the industry. Agriculture sector, on the other hand, was often called for lessening their water requirement to meet the annual supply, including by switching crops.

Climate change mitigation is a universal commitment to reduce carbon dioxide emission in order to decrease impacts from global warming. This concept is reinforced by climate change adaptation and both were adopted by several countries in an effort to keep the rise of global temperature within 1.5 Celsius. To this end, ecosystem-based adaptation was developed and has been gradually and consistently improved in both technical and practical aspects, such as integration of a finding on significant carbon sequestration by sea grass. Effective water resources management and ecosystems restoration which are measures for ecosystem-based adaptation, are critical contribution to climate change mitigation.

Several measures for effective water resources management were recommended. Of these, waterworks repair is found to be particular crucial in reducing water loss in urban environments since pipes were often found damage by poor maintenance and increase in water pressure (in expanding towns and cities).

Water-saving sanitary ware is an innovation for reducing urban water demand. this allow reusing toilet water for cleaning and watering plants. Other related innovations include producing freshwater from seas and estuaries for urban consumption.

Industrial machinery and processes were improved to increase their water efficiency. Chicken processing plants now use only 5 liters of water in butchering one chicken while several other factories installed treatment facilities into to reuse wastewater.

State agencies have long recommended switching crops and farming practices to accommodate changing climatic conditions. Such recommendations are often ignored when some crops fetch better price for farmers. For example, high price of rice often drives framers to cultivate the crop even in drought season when groundwater is the only reservoir available. Tourist industry also has great demand for water in dry season and often resort to exploiting any available aquifers. This excessive use of groundwater has found to deplete its supply and digging for aquifers in tourist site such as Samui and Phuket Islands are now exceed the depth of 100 meters.

Adopting ecosystem-based adaptation for effective water resources management is more complex than the traditional approach for the management. Widening and deepening knowledge and understanding of water resources are thus required in accompany with more technical research and study.

At the 15th meeting of the Conference of the Parties to the UNCCD (Cop 15) in May 2022, the Intergovernmental Panel on Climate Chang (IPCC) called for adoption of ecosystem approach in addressing water resources challenges including flooding and drought. The meeting itself took note of importance of biodiversity in tackling multiple aspects of environmental crisis and was of an opinion that water resources conservation should be implemented in conjunction with other measures namely soil resource conservation, soil improvement, energy conservation and phasing out fossil fuel as well as measures to reduce global temperature rise.

Unlike the dry Middle East and stormy island countries, annual rainfalls are drastically different between regions of Thailand. The southern provinces of Ranong and Trat were found to have the average annual rainfall of 4,000 millimeters while the average annual precipitation found in several provinces in Northeastern Thailand is only around 1,100-1,400 millimeters. Water resources management must therefore takes into account variability of climate and other environmental conditions.

Northeastern Thailand is the most challenging area for effective water resources management due to extreme environmental conditions. Chaiyaphum Province and Chok Chai District of Nakhon Ratchasima Province were found to have the lowest average annual rainfall of 1,100 millimeters while in the area with the highest precipitation, Nakhon Panom Province, the average annual precipitation was recorded to be around 2,400 millimeters. Only 8 % of Chi and Mun River Basins, the major river basin of the region, were found to be forestlands. Despite being drier and more arid than other regions, the Northeastern Region contains tens of thousands of smaller wetlands throughout river basins, including swamps, and ponds as well as ancient irrigation systems known as Baray.

Most technical reports conclude that water resources management in Northeastern Thailand face multiple problems and challenges including flooding, drought, water shortage, shoreline erosion, lack of conservation awareness, poor water quality and absence of technically sound management. Adopting ecosystem approach and climate change adaptation would likely to be the most difficult and challenging also.

Annual rainfall in Northeastern Thailand was found to be generally sufficient to accommodate rain harvesting (i.e. on rooftops) in both urban and rural communities. This measure can prove to be effective providing that it is accompanied by legal instruments such as local laws adopted by Australian states of New South Wales and Australian Capital Territory where its mandatory for each household to provide sufficient facilities for storing rain water.

Northern Thailand is geographically characterized by its head watershed forests, which are of critically importance in maintaining hydrological balance. Effective water resources management should thus include reforestation and forest restoration measures for forestlands that were converted into maize, orange and coffee farms where large amount of pesticide and other chemicals are used. These chemicals do not only have adverse effects on immediate natural ecosystems but also seriously affect water quality for consumption in midstream and downstream areas.

Besides, the northern region is facing water scarcity during dry season. The rivers those are usually flooded during rainy season are lacked of water. To solve the issue, reforestation and forest restoration in upstream and mountainous areas are indispensable. In addition, network of small size reservoir for drying season should be considered, for example, restoration of oxbow lakes those are scattered along the major rivers in the region.

Most of Central Thailand are midstream floodplains that are comprised of swamps, ponds, creeks, canals, irrigation systems and other major reservoirs for agriculture. Effective water resources management for the region should focus on drainage and its implications on flood mitigation during monsoon season and high tide, particularly in urban areas.

In addition to being a catchment for several major tributaries, Central Thailand have a number of coastal areas that suffer severely from erosion due to the loss of mangrove forests (i.e. around an estuary of Chaopraya River). Loss of habitats for otter, waterfowls, and other animal and plant species were also reported in estuaries of Mae Klong and Tachin Rivers. Effective water resources management for the region should thus place immediate attention on mangrove reforestation and restoration and on coastal wetland restoration and management in order to protect biodiversity.

Effective water resources management is more challenging in Southern Thailand. In addition to worsening shoreline erosion, heavy storms were found to cause multiple flood events where coastal cities and towns were flooded by direct downpour as well as by overflow from adjacent mountainous areas that receive heavy rainfall. Multiple inundations of Nakhon Si Thammarat, Surat Thani and Ranong Provinces as well as Takua Pa District of Phang Nga Province were the result of such events.

Despite having the high average rainfall in the country (over 4,000 millimeters per year in Ranong Province), some parts of Southern Thailand were to suffer from drought. The region is characterized by high mountain ranges, narrow strip of lower plains and several short rivers. The mountain ranges mostly consist of tropical forests which serve as the head watershed areas of the region. Of these forests, Klong Nakha Forest acts as an ecological corridor for the Andaman Coastline and is connected with head watershed forests of Tapee River Basin. These forests are rich with animal and plant species, including some rare birds. Other notable ecosystems of Southern Thailand include Ban Don Bay (a mudflat with high level of macro invertebrate species diversity), Songkhla Lake, Pattani Bay and sea grass conservation sites for dugong in Trang Province.

Effective water resources management for Southern Thailand should thus adopt different approaches to those for other regions. Focus must be placed on balancing the needs of urban, industrial, and agricultural sectors as well as of tourism which have become more vital to local and national economic development. It should be noted that water demand from these sectors has increased yearly.

The fact that natural systems have a carrying capacity to support human activities should underline the importance of effective water resources management for Southern Thailand. To this end, review should be conducted on development of policies that influence balance of water resources and ecosystems with high biodiversity, particularly coastal ecosystems that support habitats and spawning sites of rare species. These include conversion of beaches used by sea turtles to lay eggs into hotel and other facilities for tourism and entertainment.

Adopting ecosystem-based adaptation can meet multiple objectives and yield several benefits including climate change mitigation, effective water resources management and environmental conservation at ecosystem level. Holistic approaches for biodiversity conservation and restoration requires not only comprehensive knowledge but also understanding of divergence of circumstances in meeting the objectives.

These complex processes, in particular those concerning ecosystems, may take longer to yield results and cannot always satisfy human demand for quick solution. They should be left to their own device while closely monitoring their progress in manner that truly consistent with the ecosystem approach.

Annex A
Elaboration on Ecosystem-based Adaptation Code of Practice Compendium for the Thai Water Sector in Selecting Measures for their inclusion in EbACoP

Measures	Objectives	Climate vulnerabilities	Description	Examples and images
Upstream measures				
1. Forestation and Reforestation	Head-Watershed management	• Landslide • Flooding	Reforestation increases vegetation density, enhances water retention and mitigates discharge to upstream reservoirs. More vegetation also stabilizes soil surface and reduces soil erosion.	The measure was adopted for the head-watershed areas in Mae Sot District of Tak Province, Pua District of Nan Province and Mae Saluai District of Chiang Rai Province.  *Source: https://actionaidrecycling.org.uk/reforestation-examples-around-the-world/*
2. Construction of check dam	Reservoir management	• Flooding/ drought	Mitigating overflow on slopes and in valleys by constructing dikes with natural materials such as bamboo, logs and stones.	The measure was widely adopted in mountainous areas such as in community forests of Samakkhi Tham Village in Sai Yok District of Kanchanaburi Province and a creek known as Huai Hongkhrai in Doi Saket District of Chiang Mai Province.  *Source: https://panorama.solutions/fr/node/1106*

Measures	Objectives	Climate vulnerabilities	Description	Examples and images
3. Forest buffer strip installation	Reservoir management	• Flooding/ drought • Strong wind • Water quality	Rows of trees planted along shorelines serve as windbreak, reduce loss of soil surface, induce nutrient and sediment retention and mitigate sedimentation.	The measure was used in Europe and was also adopted in several areas of Thailand including Pro Prong Canal in Watthana Nakhon District of Sa Kaeo Province.  *Source: https://cropwatch.unl.edu/2017/nda-offers-funding-buffer-strips*
4. Construction of sediment pools	Reservoir management	• Flooding/ drought	Pools constructed for sediment retention can decelerate sedimentation.	The measure was adopted in several countries and was recommended by Land Development Department for reservoir management.  *Source: https://restorerivers.eu/wiki/index.php?title=File%3ASediment_pond_in_the_middle_part_after_measure.jpg*
Midstream measures				
1. Buffer strip installation	Reservoir management	• Euthrophication and water shortage	Covering soil with vegetation on shorelines that are adjacent to cultivated lands. Legumes and grass species were commonly chosen for this task.	The measure was adopted in Europe, the United States and Japan.  *Source: https://www.startribune.com/buffer-strip-bill-has-support-from-sports-groups-opposition-from-farmers/295838741/*

Measures	Objectives	Climate vulnerabilities	Description	Examples and images
2. Oxbow lake restoration/ reconnection	Reservoir management	• Flooding/ drought problems	Reconnecting natural waterways to increase catchment during rainy season and building up natural storage capacity for drought season.	The measure was adopted in several countries and used in Thailand for oxbow lakes of Yom River Basin.  *Source: http://nwrm.eu/measure/reconnection-oxbow-lakes-and-similar-features*
3. Waste water treatment by vegetation	Water quality management	• Water quality problems • Ecological impacts from water pollution	Use aquatic plants such as reeds, canna lilies, vetivers and water hyacinths for waste water treatment. The plants are grown on buoys to prevent them to spread in reservoirs.	The measure was adopted in several countries and used in a number of places in Thailand including Makkasan Swamp.  *Source: https://www.asla.org/2011studentawards/376.html*
4. Natural bank erosion control	Direct water management	• Flooding/ drought problems • Shoreline erosion problems	Using natural materials to build structures to enhance capacity of trees and other soil cover species in mitigation and prevention shoreline erosion.	The measure was adopted in several European countries and used in a many areas in Thailand such as Suphan Buri River and a creek known as Huai Thapthan.  *Source:https://www.sepa.org.uk/media/150971/wat_sg_23.pdf*

Measures	Objectives	Climate vulnerabilities	Description	Examples and images
5. Constructed wetland	Water and water quality management	• Flooding problems • waste water problems	Wetlands are constructed to provide catchment for rainy season or to enable wastewater treatment. Attempts would be made to ensure that the wetlands resemble the natural occurring ecosystems of their kinds as far as possible.	The measure was adopted in several countries including China, Taiwan, the United States and in Europe.  *Source: https://www.dragonflypond-works.com/blog/constructed-wetland-stormwater*
6. River bed enhancement/ re-naturalization	Direct water management	• Drought problems • Shoreline erosion problems	Balancing amounts of coarse and fine sediments on river beds since any imbalance could induce erosion and accelerate sedimentation.	The measure was adopted in several European countries.   *Source: http://nwrm.eu/measure/riverbed-material-renaturalization*
7. Retention basin and retention pond establishment	Direct water management	• Flooding problems	Expanding temporary catchment for rainy season by using pre-existing natural reservoirs such as creeks and swamps or by building new reservoirs in catchment areas.	The measure was adopted in several countries as well as for Lower Tachin River in Thailand.  *Source: https://www.eurekalert.org/multimedia/724922*

Measures	Objectives	Climate vulnerabilities	Description	Examples and images
8. Water-spreading weirs construction	Direct water management	• Drought problems	Building short barriers with rock and concrete on river beds that dried out during drought season could enable water retention, maintain moisture, reduce water flow and mitigate soil erosion.	 *Source: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. 2012. Water-spreading weirs for the development of degraded dry river valleys Experience from the Sahel. Bonn and Eschborn, Germany*
Downstream/coastal measures				
1. Mangrove reforestation/ restoration	Coastal erosion Protection and sediment retention	• Coastal erosion derived from mangrove loss	Planting mangrove by taking into account species diversity and vegetation density as well as the need to address deterioration in species richness of mangrove forests.	Mangrove planting was carried out to prevent coastal erosion worldwide including in the Philippines, Malaysia, Indonesia and Thailand.  *Source: https://www.onespecialty.com.ng/services/mangrove-restoration/*
2. Mangrove aquaculture promotion	Coastal erosion mitigation	• Soil and water deterioration from intensive shrimp farming • Coastal erosion derived from mangrove loss	Integrating farming of shrimps, mud crabs, and fishes with mangrove conservation by planting the tree species in farming areas.	The measure was adopted in Vietnam and Thailand.  *Source: https://vovworld.vn/th*

Measures	Objectives	Climate vulnerabilities	Description	Examples and images
3. Restoration and management of coastal wetlands	Flood management	• Strong wave • Strom surge	Preventing water loss and maintaining water table in the wetlands by can mitigate impacts from strong wave and storm surge.	The measure was adopted in the United States, India and other countries.  *ที่มาของภาพ https://cdnsciencepub.com/doi/10.1139/anc-2017-0001*
4. Dune construction and strengthening	Flood management	• Strong wave • Strom surge	Ensuring that sand dunes are covered with vegetation or materials and fences are constructed in order to reduce impacts from wind erosion.	The measure was adopted on beaches in Japan and other countries.  *Source: https://thefloodhub.co.uk/wp-content/uploads/2020/11/Coastal-Management-Hard-and-Soft-Engineering.pdf*
5. Beach nourishment or replenishment	Coastal erosion mitigation	• Strong wave • Strom surge	Sand, gravels and rocks can be used to filled eroded spots.	The measures was adopted on the coastline of the Gulf of Thailand including Cha Am District of Phetchaburi Province and Thepha District of Songkhla Province.  *Source: https://www.gov.uk/government/news/7m-beach-nourishment-scheme-to-protect-thousands-of-homes-in-lincolnshire*

Annex B
The Criteria for Selecting Measures for Ecosystem-based Adaptation Code of Practice Compendium for the Thai Water Sector (EbA Code of Practice)

The criteria for selecting measures for the Code of Practice consists of the following eight components (modified from GIZ, 2021 [41]);

1. Using locally available materials, employing simple methods and ensuring easy maintenance

The measure replicates natural process, provides options to use locally available materials, enables adoption of local knowledge, allows for local operation by communities and ensures easy maintenance.

2. Enhancing community capacity on climate change adaption

The measure builds capacity to store water for dry season, mitigate impacts from flooding and accommodates the needs of vulnerable groups.

3. Restoring and maintaining ecosystems.

The measure maintains soil moisture, reduces pollution, improves water quality, while avoids causing adverse impacts on feeding and spawning of aquatic fauna, on plant and animal diversity and other environmental qualities in and around area of its implementation.

4. Cost effective in investment and maintenance

The measure is cost effective in acquiring materials and labor and in maintenance.

5. Being supportive to equitable management and capacity building

The measure facilitates participation in planning and decision-making and systematic delegation of roles and authorities through formulation of local rules or agreements.

6. Having multi level policy supports

The measure is supported by national policies, agencies directives and other plans at basin, provincial or local levels.

7. Making available information or case study for adoption in other parts of the country.

Implementation of the measure generates information, produce documents (i.e. handbooks) or develop curriculums on its adoption as well as makes available case studies on its satisfactory adoption in various areas, on actions that built on the measure and on further applications of its implementation.

8. Yielding other benefits

he measure enhances benefits of other measures and builds cooperation between sectors including the state, private sector, civil society, communities, and other local water users.

[41] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. (2021). Integrating EbA and IWRM for climate-resilient water management. Bonn, Germany.

Annex C
EbA Measures selected by Stakeholders through Participatory Approach

พื้นที่	มาตรการ	คะแนนเฉลี่ย	เกณฑ์ 1 ใช้วัสดุท้องถิ่น	เกณฑ์ 2 การปรับตัวต่อ climate change	เกณฑ์ 3 ฟื้นฟูระบบนิเวศ	เกณฑ์ 4 ประหยัดงบประมาณ	เกณฑ์ 5 บริหารจัดการอย่างเท่าเทียม	เกณฑ์ 6 มีนโยบายสนับสนุน	เกณฑ์ 7 มีข้อมูลหรือกรณีตัวอย่าง	เกณฑ์ 8 มีประโยชน์ด้านอื่น ๆ
ต้นน้ำ	การปลูกฟื้นฟูป่า	4.263	4.52	4.45	4.47	4.32	4.12	4.19	4.00	4.03
	การปลูกแนวป่ากันชนตามริมน้ำ	3.888	4.40	3.82	4.25	3.97	3.94	3.46	3.43	3.84
	การทำฝายชะลอน้ำ	3.786	4.06	4.09	3.73	3.53	3.79	3.48	3.76	3.85
	การสร้างบ่อดักตะกอน	3.374	3.71	3.69	3.53	3.21	3.26	3.13	2.96	3.50
กลางน้ำ	การสร้างแก้มลิงหรือบ่อชะลอน้ำ	3.727	3.75	4.09	3.91	3.30	3.52	3.67	3.87	3.72
	การป้องกันการกัดเซาะตลิ่งแบบธรรมชาติ	3.613	3.82	3.76	3.61	3.81	3.61	3.13	3.52	3.66
	การปลูกแถบพืชดักตะกอน	3.509	3.87	3.52	3.81	3.80	3.53	2.95	3.13	3.46
	การสร้างพื้นที่ชุ่มน้ำเทียม	3.494	3.70	3.76	3.72	3.55	3.45	3.00	3.15	3.63
	การสร้างฝายน้ำล้น	3.486	3.39	3.76	3.77	3.30	3.48	3.37	3.37	3.45
	การปรับปรุงท้องน้ำ	3.481	3.31	3.65	3.67	3.33	3.37	3.58	3.38	3.55
	การจัดการน้ำเสียโดยใช้พืช	3.453	3.63	3.34	3.79	3.74	3.45	3.00	3.32	3.36
	การฟื้นฟูทางน้ำรูปแอก/เชื่อมกับแหล่งน้ำสายหลัก	3.431	3.63	3.58	3.56	3.50	3.53	3.09	3.08	3.48
ปลายน้ำ	การปลูก/ฟื้นฟูป่าชายเลน	4.287	4.48	4.39	4.53	4.32	4.16	4.03	4.13	4.25
	การฟื้นฟูและจัดการพื้นที่ชุ่มน้ำชายฝั่ง	3.992	4.31	4.10	4.21	3.97	4.03	3.73	3.59	4.00
	การส่งเสริมการเลี้ยงสัตว์น้ำชายฝั่งอย่างยั่งยืน	3.903	4.18	3.90	3.97	4.10	3.94	3.64	3.55	3.94
	การก่อสร้างและเสริมความแข็งแรงของเนินทราย	3.328	3.37	3.74	3.55	3.28	3.14	3.17	3.07	3.30
	การเสริมทรายชายหาด	3.252	3.33	3.55	3.37	3.14	3.14	3.35	3.04	3.10

หมายเหตุ: = สอดคล้องกับเกณฑ์มากที่สุด (คะแนนเฉลี่ย 4.21-5.00) = สอดคล้องกับเกณฑ์มาก (คะแนนเฉลี่ย 3.41-4.20) = สอดคล้องกับเกณฑ์ปานกลาง (คะแนนเฉลี่ย 2.61-3.40)

Annex D
Relevant laws, Regulations and Documents

No	Laws, Regulations and Documents	QR Code
1	Map of watershed quality	
2	Pricing reference published by Budget Standard Division 1 of Bureau of the Budget, 2021	
3	Set back from public water source	
4	Plan for the management of a Ramsar Site "Kaper Estuary -Laem Son National Park -Kraburi Estuary	
5	Act on the promotion of Marine and Coastal Resources Management, B.E. 2558 (2015)	
6	Mangrove restoration; Grow or not to grow	

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